Ambient water quality of Boston and Proper Bays, Port Lincoln 1997–2008

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Cover picture: Boston Bay wharf, Port Lincoln by Sam Gaylard

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This publication is a guide only and does not necessarily provide adequate information in relation to every situation. This publication seeks to explain your possible obligations in a helpful and accessible way. In doing so, however, some detail may not be captured. It is important, therefore, that you seek information from the EPA itself regarding your possible obligations and, where appropriate, that you seek your own legal advice.

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Summary

This report summarises 11 years of ambient water quality sampling by the Environment Protection Authority. This monitoring is intended to assess the current condition of water quality in Boston & Proper Bays and will set a baseline of data that can be used for future monitoring in the marine environment. This report is intended to be used by scientists, researchers, industry and some sectors of the general public.

Boston and Proper Bays are a group of coastal embayments on the Eyre Peninsula with Boston Bay being the largest. It is a large, shallow natural harbour created by Boston Island and is in the southwestern corner of Spencer Gulf. Boston bay is currently used as a deepwater port for the Eyre Peninsula's large grain industry and the exponentially growing aquaculture industry. There are riverine flows from the Tod River north of Boston Bay, discharges from the Port Lincoln wastewater treatment plant, urban stormwater and various industrial and shipping facilities and aquaculture operations.

Environmental impacts have been reported in Boston Bay in the last 20 years. At least three quarters of the Southern Bluefin Tuna stock died from commercial and research tuna farms in Boston Bay during April and May 1996. Temporarily poor water quality was seen as a major cause of the death of these fish. Also in 1996 an EPA study used aerial photography to show a net reduction of 168 hectares of seagrass in Boston and Proper Bays [Hart 1999]. There have also been concerns raised about the nutrient loads from the expanding aquaculture industry. In response to these issues the EPA commenced an ambient water quality monitoring program in Boston and Proper Bays in 1997.

This report summarises water quality based on three default environmental values from the Australian & New Zealand *Guidelines for Fresh and Marine Water Quality 2000* (ANZECC):

1   protection of the aquatic ecosystem

2   protection of aquaculture

3   protection of recreational users.

Water quality has been classified as good, moderate or poor based on criteria in the ANZECC Guidelines and used by the EPA in previous water quality reports. Comparisons are also made over time and between the different sites.

Using these guidelines water quality was broadly classified as good at all sites with only chlorophyll *a* (a measure of algae) classified as moderate across all sites (Figure 1). Elevated chlorophyll *a* can be indicative of nutrient pollution. The nutrient parameters were classified as good, however field observations of seagrass epiphytes suggest there is evidence of nutrient enrichment.

Comparatively, Proper Bay was considered to be the most impacted site (Figure 1). While most classifications were still considered good (see later) it showed higher total nitrogen and chlorophyll *a* than other sites studied. Town Jetty and Billy Lights Point also had some elevated parameters including total nitrogen. In the north of Boston Bay, North Shields was the site least impacted with the lowest concentrations for most parameters.

The elevated nutrient results seen at Proper Bay suggest that nutrient discharges are potentially impacting water quality in the Bay. Nutrient sources are the tuna processors that discharge wastes into this bay, and the Billy Lights Point wastewater treatment plant effluent is also likely to enter Proper Bay under certain wind and tide scenarios. This nutrient condition is exacerbated by poor water exchange between the bay and surrounding waters. Town Jetty and Billy Lights Point may be impacted from urban stormwater, the Billy Lights Point wastewater treatment plant, poor practices at the town wharves, and the high density of commercial boats potentially discharging wastes into Boston Bay.

A detailed survey of biological indicators of nutrient pollution such as seagrass condition would complement this water quality assessment and provide a better understanding of ecological condition and therefore water quality in Boston and Proper Bays, and better inform managers as to whether current management practices are effective.
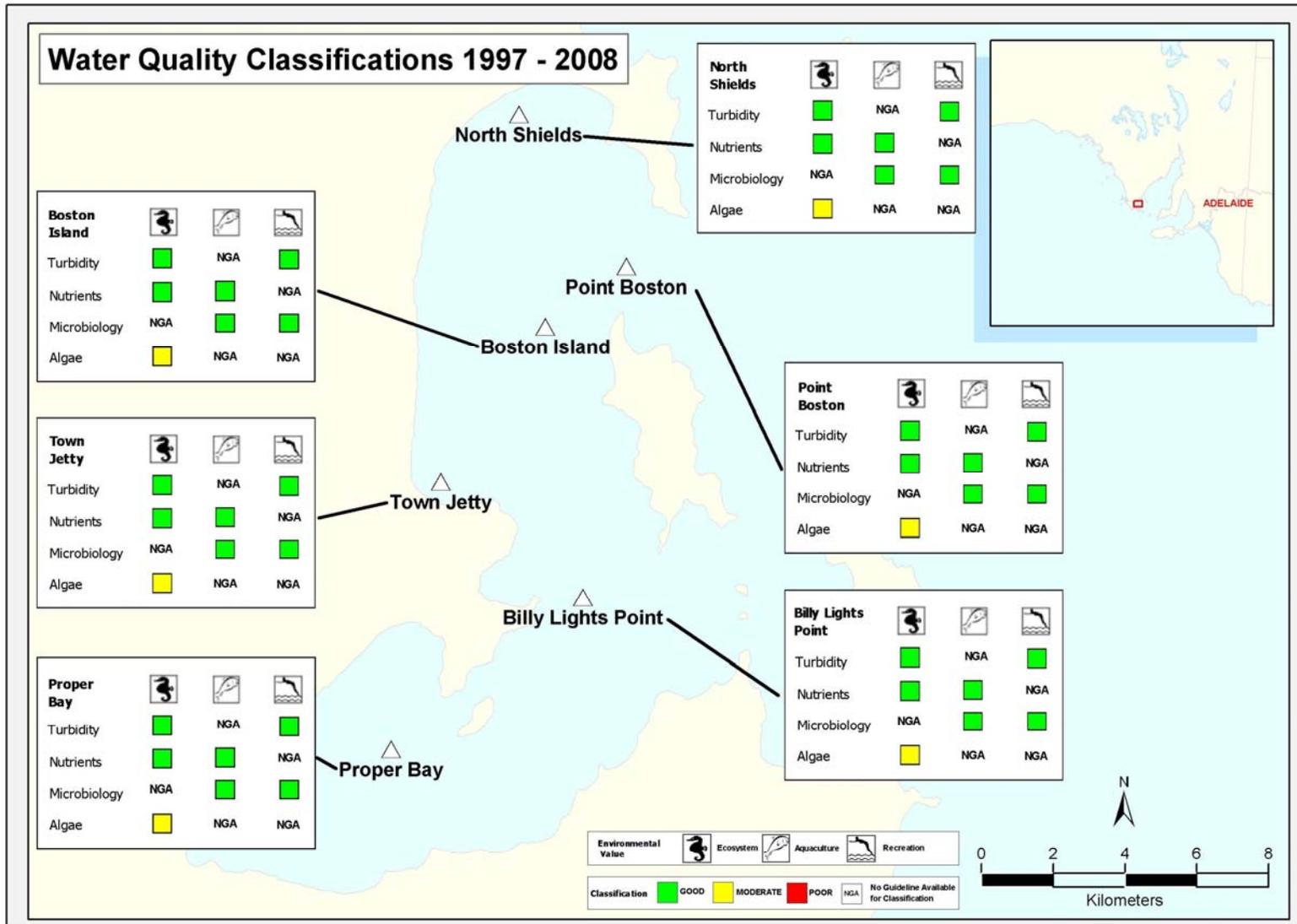
Figure 1   Water quality classifications for Boston and Proper Bays 1997–2008

1   Introduction

Boston and Proper Bays are a group of coastal embayments on the Eyre Peninsula with Boston Bay being the largest. It is a large, shallow natural harbour created by Boston Island and is in the southwestern corner of Spencer Gulf (Figure 2). It is approximately 15 km long and 5 km wide and has a maximum depth of 16–17 m [Petrusevics 1993]. Generally Boston and Proper Bays are considered a part of the same embayment region and are commonly referred to as Boston Bay.

The Eyre Peninsula is predominantly an agricultural region, producing more than 45% of South Australia's wheat and 20% of its barley. Port Lincoln, a city of 13,000 people, lies on the western shores of Boston Bay. Agricultural produce is mostly shipped out through the large deepwater port. The port facilitates the import and export of large amounts of cargo, particularly grain and barley. In 2002–03, 1.76 million tonnes of cargo were moved through Port Lincoln [Flinders Ports 2005].

The marine environment to the west of Port Lincoln is dominated by exposed waters, cliffs and rocky coastlines with sheltered waters coming in the lee of islands. Seagrasses and diverse fish and faunal communities proliferate in these sheltered waters [Glover & Olsen 1985]. The eastern side of Boston Bay is sheltered from the predominant southwesterly wind and swell and as a result this region has developed sandy beaches, fewer cliffs and mangrove habitats between headlands. This region supports extensive seagrass beds and biologically diverse communities of fish and invertebrates [Glover & Olsen 1985].

In 1996 the EPA commissioned a study on seagrass in Boston and Proper Bays using aerial photography. Photos taken in 1996 were compared to historical photos from the mid-1970s. These photographs showed extensive seagrass in areas less than 20 m deep throughout the bays. The study showed a net reduction of 168 hectares of seagrass since the mid 1970s [Hart 1999]. This report showed the main areas of seagrass decline were located around the northern tip of the bay near North Shields and some smaller regions of decline around Town Jetty, Boston Bay, Porter Bay and Proper Bay, particularly on the deeper edges (Figure 3). Seagrass meadows are dynamic systems, therefore it is hard to judge whether the decline seen in photographs is due to a natural occurrence (eg natural growth and retreat), or human-induced change (eg pollution). Similarly aerial photographs of seagrass are often variable in quality due to image quality, depth penetration and classification methodologies. In order to be more certain that the observed loss is real, additional information on water chemistry and seagrass condition indicators is needed.

There are a large number of potential sources of pollution that may impact on water quality in Boston and Proper Bays. Some of these sources may be a constant stream of pollution, such as the wastewater treatment plant at Billy Lights Point, while others may contribute pulses of pollutants which temporarily impact on water quality such as stormwater.

Stormwater runoff from paved surfaces in Port Lincoln flows into Boston and Proper Bays through a number of large drains. These discharges are likely to have elevated levels of nutrients (from fertilisers, animal faeces), bacteria (animal faeces, sewage overflows) and heavy metals (primarily copper, lead and zinc from vehicle traffic) and have the potential to impact on water quality.

Sewage from Port Lincoln is treated by the SA Water WWTP at Billy Lights Point. This is a secondary treatment system which discharges nutrient-rich water into the marine waters around Billy Lights Point. This discharge is high in ammonia, oxidised nitrogen and phosphorus and is discharged at a rate of 2.5 ML per day. This load of nutrients is likely to be contributing to nutrient enrichment in both Boston and Proper Bays.

Aquaculture

Aquaculture in South Australia, and the Port Lincoln region in particular, has developed very rapidly over the last decade and is increasing in economic importance for Port Lincoln and South Australia. In 2002–03 the farm gate value of the aquaculture industry was $256 million, making up over half of the value of the seafood production in South Australia [ASBTIA 2009].

Southern Bluefin Tuna (*Thunnus maccoyii*) or SBT have been caught using lines in the waters of the Great Australian Bight for many years. Since 1991 the vast majority of tuna are now corralled into seine nets and slowly towed to Port Lincoln where they are transferred into holding nets. Here they are fattened up for a period of 3–5 months for the lucrative overseas markets, particularly Japan [PIRSA 2005]. Before 1996 most farms were located inside Boston Island where the sheltered waters made for calmer weather and better access, however after the 1996 mortality event (see below) the majority of farms moved to the outside (seaward side) of Boston Island into deeper water.

Sea-cage aquaculture is a source of nutrients into the marine environment. The feed conversion ratio for SBT varies between 10–17:1 [Fernandes et al 2007], which relates to 10–17kg of feed for every 1 kg of fish growth. Fish respiration and excretion, uneaten feed and faecal material from large numbers of farmed fish creates significant amounts of nutrients directly into the marine environment, the vast majority of this in a dissolved form [Fernandes et al 2007a].

In recent years sea-cage aquaculture has expanded to include Yellowtail Kingfish (*Seriola lalandi*), Snapper (*Pagrus auratus*) and Mulloway (*Argyrosomus japonicus*), which all contribute to the nitrogen, phosphorus and carbon loads into the marine waters. Land-based aquaculture such as abalone farms also discharge nutrients into both Boston and Louth Bays. Figure 2 shows the aquaculture zones, leases, licences and application licenses [Aquaculture Public Register 2009]. There are other significant seafood industries in the Port Lincoln region, with considerable oyster and abalone farming output contributing to the local economy..

Once the SBT is harvested many are transported to the fish-processing factories in Port Lincoln. These facilities discharge nutrient-rich wastewater into the nearshore environment of Proper Bay. These discharges have been on-going since before to the aquaculture boom in the region and have been implicated for the loss of over 40 ha of seagrass from the nearshore environment of Proper Bay [Caldwell & Connell 1976]. While the load of nutrients has decreased over the years there is still evidence of nutrient enrichment [this report] and seagrass loss [Hart 1999]. Significant works have been undertaken by some operators over the last 10 years to reduce or halt the discharge into the marine environment. However not all discharges have ceased with nutrient-rich water is still discharged into Proper Bay during processing.

 A key aspect of both the viability and marketing of the seafood industries in Port Lincoln is the good water quality. This provides both a sustainable fishery and a 'green advantage' for marketing clean seafood, which in turn may generate higher prices in the market place.
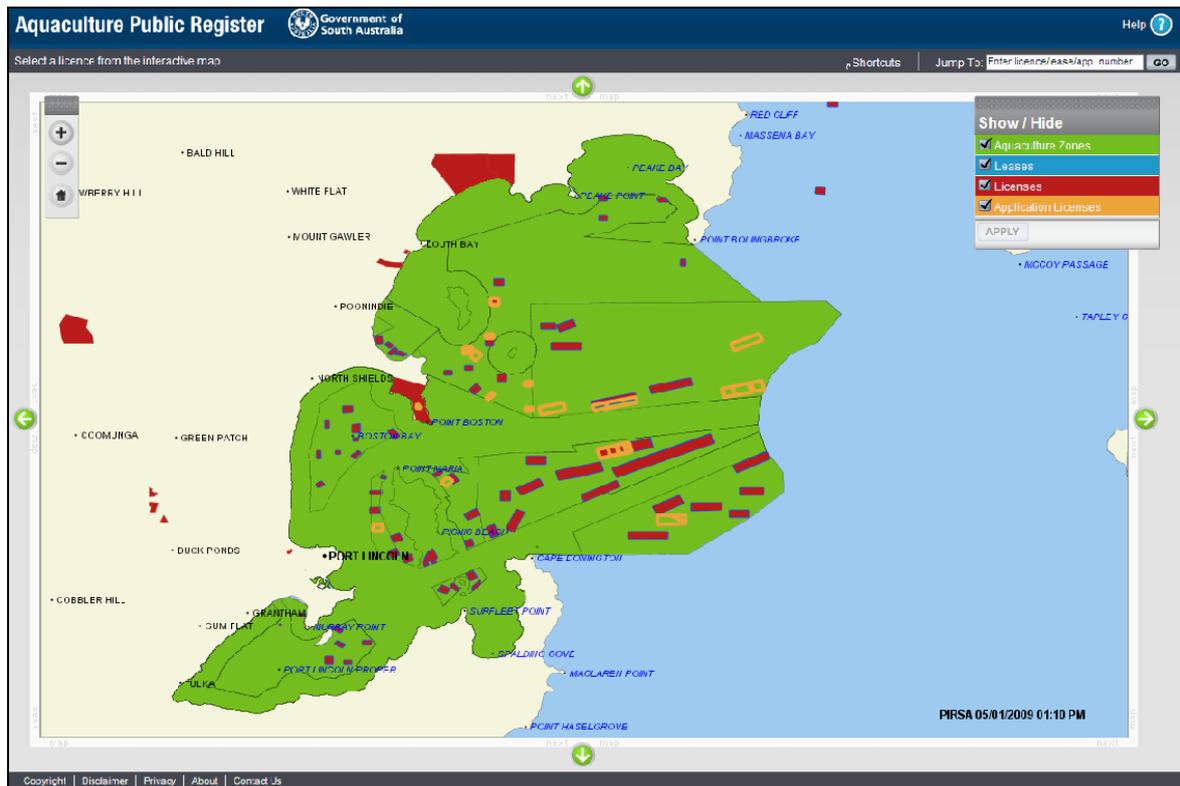
Figure 2   Map of aquaculture in Port Lincoln region, 5 January 2009

The 1996 tuna mortalities

On 11–12 April 1996 the remnants of tropical cyclone 'Olivia' travelled southeast over the Great Australian Bight and passed over Port Lincoln producing strong northeasterly winds for approximately 12 hours. This wind produced waves with sufficient energy to lift fine organic sediment from the sea floor into suspension [Petrusevics 1996; Grzechnik 2000]. In combination with a dodge tide, these sediments are thought to have coated the gills of the fish [Clarke 1996] and were likely to have decreased the dissolved oxygen in the water. The result was the death of over 1,700 tonnes of tuna comprising approximately 75% of the stock in the farms at the time.

Since this event the majority of the SBT cages have been moved outside of Boston Island into deeper water where the current speeds are higher to dissipate wastes generated.

The Tod River

The Tod River is the only creek on the Eyre Peninsula and discharges into Louth Bay north of Boston Bay (Figure 2). The catchment is approximately 412 km^2 and originates in the Koppio Hills. Annual rainfall on the Eyre Peninsula varies between 200 and 500 mm year. In the Koppio Hills rainfall is generally about 500 mm/yr, falling mainly during winter [Rixon et al 2002]. The main land uses in the Tod River catchment are broadscale cropping and grazing. Rixon et al (2002) describes the condition of the catchment as heavily modified since European settlement and the resultant increase in salinity is impacting on vegetation along the river.

Agricultural impacts are commonly derived from the application of fertilisers that introduce excess nutrients into waters, which ultimately flow into the marine environment. Other impacts can be from the addition of pesticides and herbicides used to control insects, weeds, and bacteria from grazing animals. An additional impact often overlooked is an increase in sediments from erosion of the land due to a lack of vegetation-retaining soil and stock access in the creek. The extensive cropping in the Tod River catchment (and other catchments) results in a more intensive control over weed species and higher use of herbicides [Rixon et al 2002]. Elevated levels of nutrients, sediments and pesticides/herbicides may be entering Louth Bay via the Tod River during periods of heavy rainfall impacting on water quality. The flow into the marine environment from the Tod River is only monitored at a gauging station five km

northwest of Poonindie which is approximately 5 km from the mouth into Louth Bay. Since records started in 1972 the average discharge from this station is 244 ML, 75% of which is discharged in July–September. In more recent times (>2,000) the discharge from this station has reduced 27% to 176 ML a year. Currently there is no monitoring as to whether this water reaches Louth Bay.

Shipping

As stated above Port Lincoln has a significant shipping industry with large volumes being imported and exported each year. This volume is expected to drastically increase with the predicted mining boom over the next decade and beyond. This expected increase has highlighted the need for a second deepwater port in the southern Spencer Gulf. The large volume of commercial shipping is also a potential source of nutrients entering the marine environment through the potential for discharge of sewage and fish wastes into the waters around Boston and Proper Bays. During tuna harvesting, some gutting and gilling of fish is undertaken on purpose-built Japanese 'harvesting' ships and there has been some anecdotal evidence of poor practices from these boats, which is possibly contributing nutrients in the region.

The Port Lincoln wharves have undergone an environmental audit and have found to have a number of poor practices which are likely to be contributing nutrients into the marine environment via spillage of grain, fertilisers, and fish wastes during transfer on and off boats.
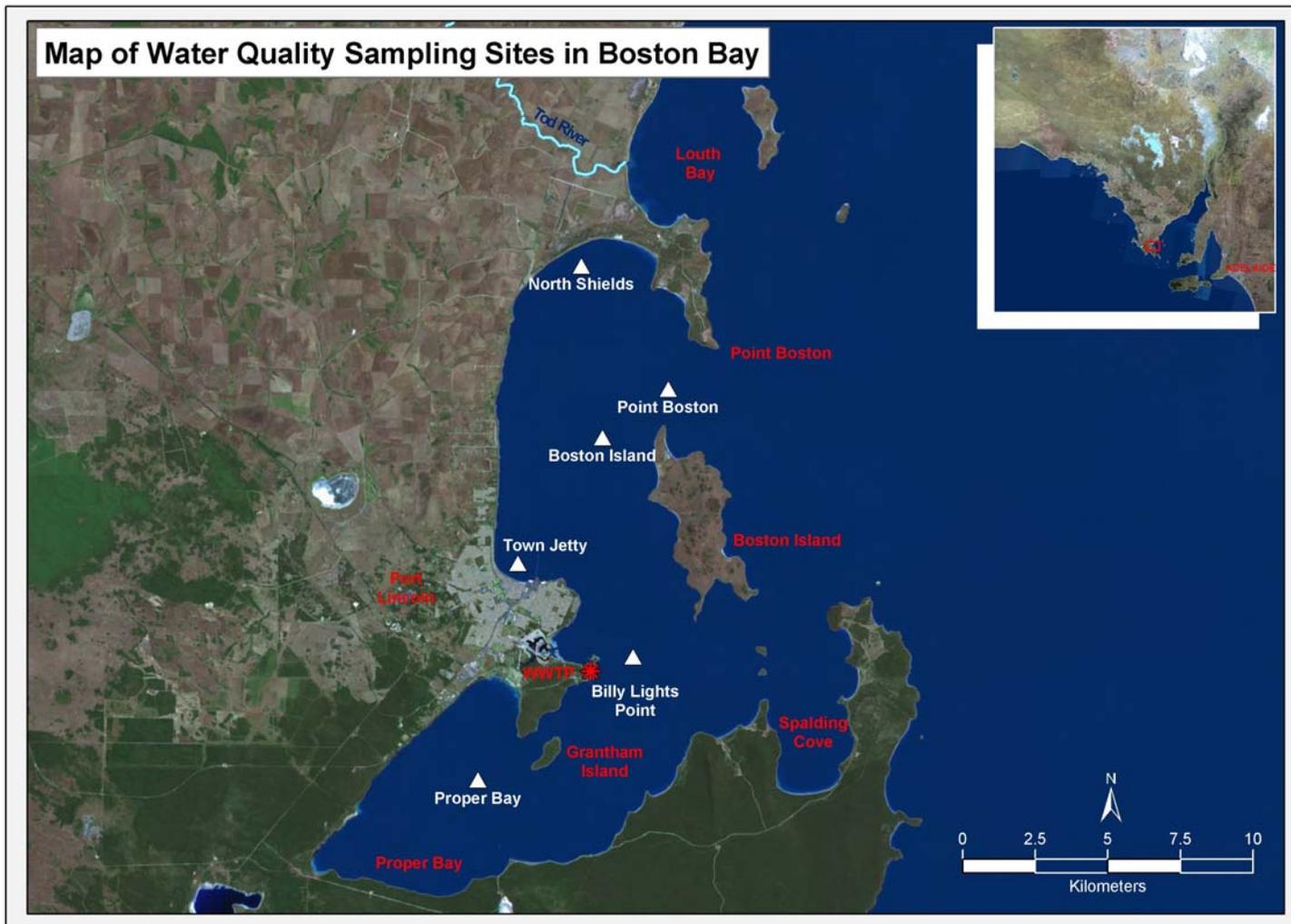
Figure 3   Map of water quality sampling locations in Boston and Proper Bays
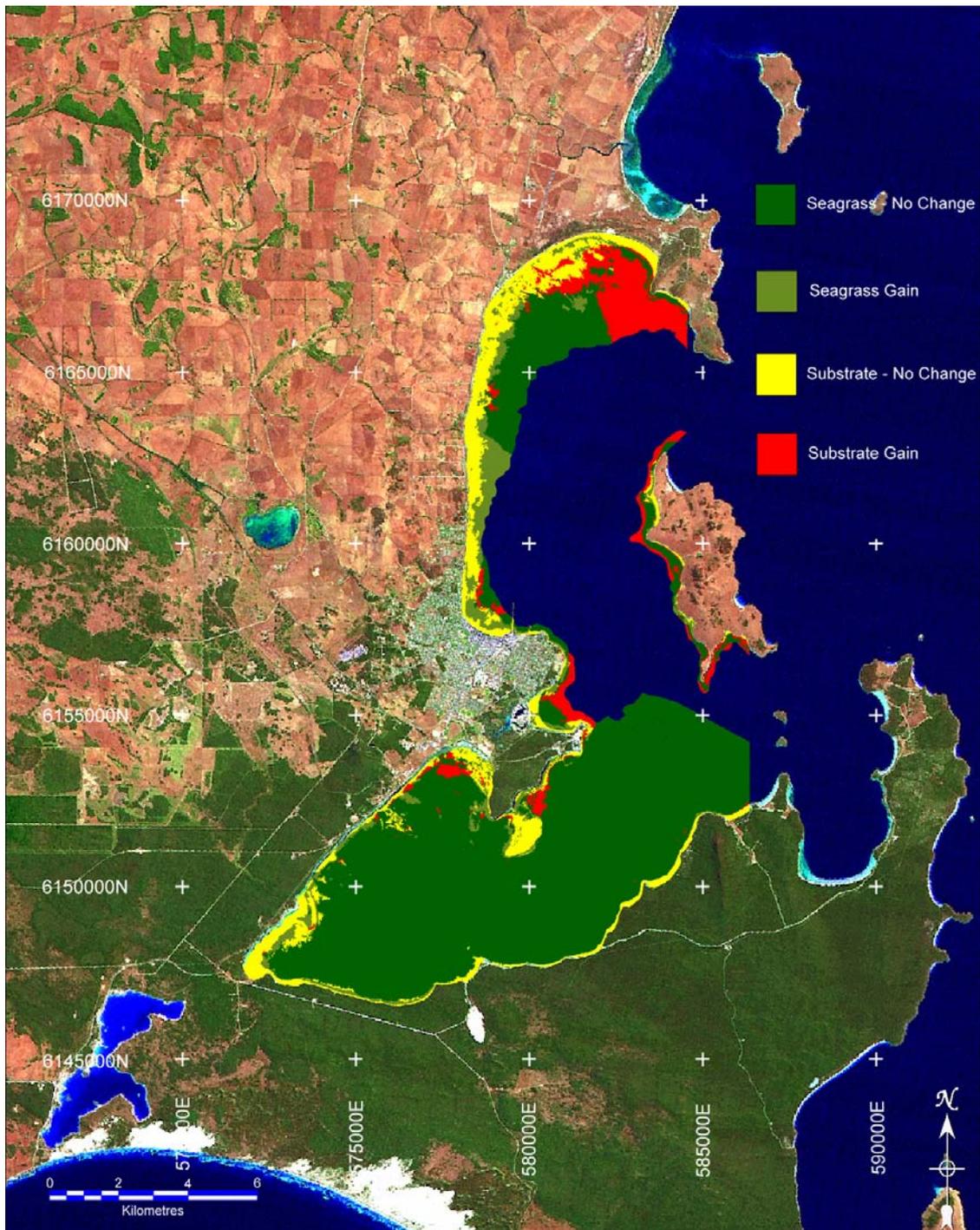
Figure 4   Map of seagrass loss classifications in Boston and Proper Bays 1970s–1996. Reproduced with permission from Hart (1999)

Aim of the monitoring program

Ambient water quality is a representative measure of the overall water quality of a waterbody over a given period. It indicates the condition of water when all the impacts that may influence the waterbody are considered as a whole rather than focusing on the effects of individual discharges. Obviously this has limitations in small-scale variation in time and space, and within a given budget. However it is aimed to give a reliable and accurate description of water quality for the region and inform of large-scale changes between sites and over time.

The EPA considers that the highest risk to ecosystem values in the marine environment of Boston and Proper Bays is from an increase in nutrients. Secondly microbial pathogens are a potential contaminant for recreational users and also in

aquaculture and as such, the Environment Protection Authority (EPA) established an ambient water quality monitoring program in Boston and Proper Bays. This program started in August 1997.

This report summarises the first 11 years of sampling and aims to:

- Determine the ambient water quality of Boston and Proper Bays from August 1997 to June 2008.

- Categorise water quality as good, moderate or poor using a classification system based on the Australian and New Zealand *Guidelines for Fresh and Marine Water Quality* (ANZECC 2000) for the designated environmental values of the waters.

- Classify microbial data based on the National Health & Medical Research Council *Guidelines for Managing Risks in Recreational Water* (NHMRC 2008).

- Examine spatial differences in water quality within the region and discuss factors that may be affecting variability between sites.

- Assess long-term trends in water quality to ensure that development and the use of the waters are ecologically sustainable for both the aquatic ecosystem condition and for aquaculture protection in the long term.

- Investigate any relationship between water quality and regions of seagrass loss in Boston and Proper Bays.

2 Survey methods and data analysis

Environmental values

Environmental values are particular values or uses of water that are conducive to a healthy ecosystem and also contribute to public benefit, welfare, safety and health. These environmental values require protection from the real and potential effects of pollution if they are to be maintained (EPA 2003b).

All sites within Boston and Proper Bays have been assigned the default environmental values under the *Environment Protection (Water Quality) Policy 2003*. These values are the 'Protection of Ecosystem', 'Protection of Aquaculture' and 'Protection of recreational users of water'.

The National Water Quality Management Strategy (NWQMS 2000) outlines the process for designating site-specific environmental values based on significant community input and developing site-specific water quality objectives to maintain and protect these agreed values. It is anticipated that the Eyre Peninsula Natural Resource Management Board will coordinate this process in the near future with significant stakeholder and community consultation.

Comparison against guidelines values

The EPA uses both the median and the 90th percentile to classify each water quality parameter. The median reflects typical water quality and the 90th percentile includes most results (more details are provided in the discussion of each parameter). These values are compared to designated environmental values within the Australia and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).

Microbiological data for recreational values are compared to the Guidelines for Managing Risks in Recreational Water (NHMRC 2008). This document recommends classifying the data using the 95th percentile and uses a risk-based approach to classify the recreational water bodies based on an inspection of potential sources of pathogens in the water (sanitary inspection).

A desktop sanitary survey was carried out and potential sources of faecal pathogens were identified and their risk to recreational water quality and shellfish aquaculture assessed. The research showed that:

- The Port Lincoln WWTP discharges secondarily treated wastewater offshore from Billy Lights Point. This discharge is not disinfected but the effluent is rapidly diluted by tidal water movement. This source is considered to be a low risk to Boston and Proper Bays.

- The Tod River is considered a low risk to Boston and Proper Bays for several reasons: it is primarily an agricultural catchment and does not receive sewage inputs. Microbial pollution from this source is likely to be non-human in origin. The human population within the Tod River catchment is considered low and water flow rates are also considered relatively low. Based on these factors and the dilution rate and distance from recognised recreational areas the Tod River is considered to be a low risk to Boston and Proper Bays.

- Bather shedding of microbes has been recognised as a potential source of microbial pollution in areas of high bather density and low dilution. The recognised recreational areas within Boston Bay are considered to have low bather density and high dilution, and are therefore classified as having a very low risk.

- The discharge of sewage from boats is a potential source for human-derived microbial pollution. There is a high density of commercial and recreational boats within Boston and Proper Bays and limited areas for discharge of wastes onto land. These areas can be reasonably close to the recreational and aquaculture areas around Boston and Proper Bays, and this is considered to be a moderate risk.

- There is evidence that seabirds around Boston and Proper Bays are thriving and this may be introducing additional faecal material into the marine environment in close proximity to aquaculture lease regions.

Overall the sanitary survey would indicate that the risk of ingesting microbially contaminated water by people engaging in primary contact activities[1] in recognised recreation areas would be low. Therefore the Enterococci guideline values being used in this report are 200 colonies per 100 mL and 500 per 100 mL for good and poor water quality respectively.

Survey design

Representative water samples from six sites in Boston and Proper Bays (Figure 2, Table 1) were taken monthly up until July 2007 when the program moved to quarterly. The sites are strategically located not to be influenced excessively by one single discharge but rather to provide an overall picture of water quality across the bays. While sites have been selected based on being representative of a region in the bays it is anticipated that if water quality is impacted in one region the sampling should be able to detect a difference between sites. If this occurs, inferences can be reached about discharges in the region and other risk factors in the region. This report is a summary of the data collected between August 1997 and June 2008.

Samples are collected and delivered to a NATA[2] accredited laboratory in Adelaide. All sampling is carried out according to the EPA sampling protocols to maintain quality and reduce the chance of introducing errors due to contamination or instability in parameters.

The parameters monitored in this program are broadly classified as physical, chemical or biological. Only one physical parameter is measured in Boston and Proper Bays—water clarity (measured as turbidity). Chemical parameters measured are ammonia (since May 2003), total nitrogen (sum of total Kjeldahl nitrogen and oxidised nitrogen), total phosphorus and oxidised nitrogen. Biological parameters measured are algal biomass (determined by chlorophyll *a*) and the microbial indicators faecal coliforms and enterococci.

Analytical services were undertaken by the Australian Water Quality Centre (AWQC) and all tests were undertaken according to NATA accredited protocols for that laboratory. Outlining specific analytical techniques is outside of the scope of the intended audience for this report. For detailed methodologies for analytical techniques please contact AWQC directly <www.awqc.com.au>.

Table 1   Boston & Proper Bay Site locations

Site	Longitude	Latitude
North Shields	135.886E	–34.623S
Point Boston	135.917E	–34.660S
Boston Island	135.892E	–34.676S
Town Jetty	135.862E	–34.715S
Billy Lights Point	135.905E	–34.739S
Proper Bay	135.849E	–34.782S

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[1] Primary contact activities are considered to be activities where there is whole-body contact, and some water will be swallowed, eg swimming, surfing, diving, snorkeling, windsurfing (NHMRC 2008).

[2] National Association of Testing Authorities

Statistical analysis

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 but can be found in previous EPA reports and statistical texts such as *Biometry* by Sokal & Rohlf (1995) and *Statistical Methods in Water Resources* (Helsel & Hirsch 1992).

In summary the median and 90th percentiles were used to classify the data. Microbial data was classified for the protection of aquaculture (shell-fishing waters) by using the median of the data which is in line with the ANZECC Guidelines for Fresh and Marine Water Quality (2000) and previous EPA reports and Enterococci has been classified using the 95th percentile which is consistent with the NHMRC Guidelines for Managing Risks in Recreational Waters (2008).

Comparing differences between sites

Inference testing in this report has been carried out using non-parametric methods as the data could not be consistently transformed to fit the assumptions of a normal distribution. Non-parametric tests use the ranks of the data to calculate differences between populations. In cases where there is censored data (results below the analytical detection limit) the ranks are tied at the lowest rank, which introduces little bias into the test. However in data sets where there is a significant amount of censored data (>50%) no statistical comparison of sites has been done. In this report results below detection limit have been treated as being at the detection limit, which is consistent with other EPA reports and is in line with the precautionary principle.

Significant differences between site medians were assessed using the Kruskal Wallis test plus a Dunn's multiple comparisons test to determine which groups were different using a family error rate of 0.05 [Sokal & Rohlf 1995; Helsel 2006]. This test allows us to determine if there are statistically significant differences between sites at the p=0.05 level. The p value is a confidence level that one data set is different to another data set by enough to say with confidence that they are different for some other 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. This level has been adopted to provide consistency with other EPA reports; however it does not in any way relate to environmental significance.

Detection of trends

Trend analysis, generally speaking is looking at the results of sampling to see if a variable is increasing or decreasing over time. Trend analysis is complex and depends largely on the number of samples taken over time and the variation in the data. Some statistical tests account for variation in the data that may be attributed to seasons (ie summer/winter; high flow/low flow, etc). Trend analysis was carried out using methods outline by Helsel & Hirsch (1992) by testing for a number of underlying patterns in the data such as seasonality and autocorrelation. If seasonality was detected a Seasonal Kendall test was applied; if there was no seasonality present then a Mann Kendall test was performed using the Kendall.exe program developed by the US Geological Survey [Helsel et al 2006]. On a number of occasions autocorrelation was detected and trend analysis was undertaken using a Mann Kendall test with reduced sampling frequency [Helsel et al 2006]. Again a significance level of p=0.05 was used for trend analysis, but as outlined above this is purely a statistical cut-off point rather than a statement that any trend is environmentally significant.

Statistical testing was undertaken using Minitab 14 and WQStatPlus (NIC Products & Services Solutions Group) and Kendall.exe <http://pubs.usgs.gov/sir/2005/5275/downloads/>.

3   Results

Physical parameters

Turbidity

Turbidity is a measure of the scattering of light through water. It is effected by particulate and dissolved material in the water column. Turbidity can also result from elevated nutrient levels in the water due to an increased amount of microalgae scattering light.

Turbidity can lower the amount of light penetrating through the water column, which can have significant impacts particularly in deeper waters where many benthic plants are at their maximum light limit. Turbid water can also affect recreational water quality by reducing the visibility in water, which can obscure hazardous objects in the water. Sources of turbidity in the marine environment often include natural wind and wave action on sediments, stormwater and river discharges, dredging, industrial discharges and boat traffic.

There are common instances when wind and wave action stir up sediment and cause high turbidity in relatively pristine areas. This can still affect seagrass photosynthesis, however it may not be due to human induced pollution. Table 2 shows the system for classifying turbidity in Boston and Proper Bays, which is based on the ANZECC Guidelines for Fresh and Marine Water Quality protection of ecosystem minimum value of 5 NTU. For the protection of Recreational users a range of values has been used with 5 NTU being the lower and 25 NTU being the higher. These values are based on the clarity of the water in relation to be able to see obstructions in the water.

Table 2   Water quality guidelines for turbidity in Boston & Proper Bays

	Ecosystem (NTU)	Aquaculture	Recreation (NTU)
GOOD	90th percentile <5	na	90th percentile<5
MODERATE	90th percentile>5>Median	na	90th percentile between 5 & 25
POOR	Median>5	na	Median>25

na = no guideline under this environmental value for this parameter

Table 3 indicates Town Jetty had the highest 90th percentile for turbidity with 0.861 NTU and a high median value of 0.400 NTU. These values are still well under the good classification water quality guideline of 5 NTU (Figure 1). North Shields had a median value of 0.295 NTU while Proper Bay had a 90th percentile of 0.568 NTU which were the lowest across all the study sites (Table 3). At no time during the water quality sampling did turbidity exceed the water quality guideline of 5 NTU (Figure 8). Boston Island had the highest maximum turbidity value of 2.870 NTU, which when compared to guidelines is still considered to be low.

Table 3   Statistical summary of turbidity (all values are NTU)

Site	Median	Standard deviation	90th Percentile	Max	N	Classification			Trend
						Ecosystem	Aquaculture	Recreation	
North Shields	0.295	0.237	0.622	1.410	68	GOOD	na	GOOD	↔
Point Boston	0.370	0.226	0.672	1.160	68	GOOD	na	GOOD	↔
Boston Island	0.387	0.364	0.780	2.870	68	GOOD	na	GOOD	↔
Town Jetty	0.400	0.295	0.861	1.520	69	GOOD	na	GOOD	↔
Billy Lights Point	0.401	0.232	0.752	1.150	69	GOOD	na	GOOD	↓ P=0.00313
Proper Bay	0.300	0.421	0.568	2.830	68	GOOD	na	GOOD	↔

na = trigger value not applicable

Turbidity was classified as good for the protection of the ecosystem and for the protection of recreational users across all sites in Boston and Proper Bays.

While the turbidity levels were all generally very low, Town Jetty and Billy Lights Point were both significantly higher than Proper Bay and North Shields.

There was a statistically significant decreasing trend in turbidity at Billy Lights Point.

Nutrients

Total nitrogen

Total nitrogen (TN) is a measure of all the different forms of nitrogen available to aquatic plants and animals and takes into account the various forms of nitrogen in the system. In this report TN is the sum of oxidised nitrogen (nitrate and nitrite) plus total Kjeldahl nitrogen (TKN) but does not include the very small amount of nitrogen present as elemental nitrogen (N_2). The effects of total nitrogen are similar to the impacts from ammonia and oxidised nitrogen. However a proportion of TKN consists of particulate and dissolved organic nitrogen, which is less readily available to plants and algae until it is biologically transformed into ammonia. The effects of elevated TN include promotion of algal blooms, reduced light penetration and potential toxicity from ammonia (see later sections for more detail). Table 8 shows the classification scheme for total nitrogen in the marine environment for the protection of marine ecosystems.

The water quality guideline for the protection of aquaculture species is not based on total nitrogen (TN) = TKN + NOx as shown above. The protection of aquaculture relies on total available nitrogen (TAN) = total ammonia (NH_3 & NH_4^+) + NOx.

Table 4   **Water quality guidelines for total nitrogen in Boston and Proper Bays**

	Marine ecosystem (mg/L)	Aquaculture (as TAN in mg/L)	Recreation
GOOD	90th percentile<1.00	90th percentile<1.00	na
MODERATE	90th percentile>1.00>Median	90th percentile>1.00>Median	na
POOR	Median>1.00	Median>1.00	na

na = no guideline under this environmental value for this parameter

All sites were classified as good throughout the region (Figure 1). Table 5 shows that Proper Bay had the highest median total nitrogen of the six sites at 0.163 mg/L while North Shields had the lowest at 0.110 mg/L. Town Jetty had the highest 90th percentile at 0.363 mg/L. Proper Bay had the highest single value of 1.225 mg/L, and this value exceeded the ecosystem water quality guideline (Figure 9). There were no occasions where water quality exceeded the TAN guideline for the protection of aquaculture.

Table 5   **Statistical summary of total nitrogen (all values are mg/L)**

						Classification			
Site	**Median**	**Standard deviation**	**90th Percentile**	**Max**	**N**	**Ecosystem**	**Aquaculture**	**Recreation**	**Trend**
North Shields	0.110	0.171	0.321	1.115	64	GOOD	GOOD	na	↓ P=0.0007
Point Boston	0.115	0.164	0.316	1.055	64	GOOD	GOOD	na	↓ P=0.011
Boston Island	0.115	0.166	0.342	1.055	65	GOOD	GOOD	na	↔
Town Jetty	0.116	0.171	0.363	1.125	66	GOOD	GOOD	na	↔
Billy Lights Point	0.115	0.179	0.343	1.175	65	GOOD	GOOD	na	↔
Proper Bay	0.163	0.168	0.335	1.225	64	GOOD	GOOD	na	↔

na = trigger value not applicable

[1] Aquaculture water quality guideline is based on total available nitrogen (TAN).

Total nitrogen was classified as good for the protection of the ecosystem across all sites in the study region.

There were no significant differences in total nitrogen concentrations between sites throughout Boston and Proper Bays.

There were statistically significant decreasing trends in total nitrogen at North Shields and at Point Boston.

Total ammonia

Total ammonia is a nutrient and can also be a toxicant. It provides a source of nitrogen to plants and algae, and can be directly toxic to invertebrates and fish. Ammonia is readily taken up by plants and algae, and be converted by bacteria to oxidised forms of nitrogen such as nitrate and nitrite. All of these forms of nitrogen are bio-available and can result in excessive algal and/or plant growth (eutrophication), which can lead to seagrass and habitat loss, and a reduction in biodiversity. Sources of ammonia in the marine environment are generally wastewater treatment plants, animal faeces and riverine discharges in agricultural areas (ammonia is commonly used as a fertiliser). Recent studies have shown that SBT respiration and excretion contributes significant amount of ammonia into the water column, which can be a major source in areas of high sea-cage aquaculture [Fernandes et al 2007a].

The EPA measures total ammonia, which includes both the un-ionised form of ammonia (NH_3) and the ammonium ion (NH_4^+). Both forms are available as nutrients, however it's the NH_3 form that is generally considered a toxicant. The toxicity of ammonia is heavily dependant on pH, salinity and temperature.

Total ammonia was included in the Boston and Proper Bays sampling program in May 2003 after an initial review of the EPA marine monitoring. Ammonia was considered important to be monitored because of its toxic nature and its availability to plants and algae.

The ANZECC trigger value for total ammonia is based on the ionised fraction of ammonia (NH_4^+), which is usually 92–98% of total ammonia in typical marine pH and southern Australian temperatures. The water quality guideline is 0.050 mg/L for the protection of aquatic ecosystems. The ANZECC guidelines also outline a water quality guideline for the protection of aquaculture species based on the un-ionised fraction of ammonia (NH_3). This is set at 0.100 mg/L and is based on toxicity rather than its impact as a nutrient.

Table 6   Water quality guidelines for ammonia in Boston and Proper Bays

	Ecosystem (mg/L)	Aquaculture (mg/L)	Recreation
GOOD	90th percentile<0.05	90th percentile<0.1	na
MODERATE	90th percentile>0.05>Median	90th percentile>0.1>Median	na
POOR	Median>0.05	Median>0.1	na

na = no guideline under this environmental value for this parameter

All sites in the study area were classified as good (Figure 1). Proper Bay, Point Boston and Town Jetty all had the highest medians of 0.011 mg/L while Proper Bay had the highest 90th percentile for ammonia throughout the study region at 0.032 mg/L. North Shields had the lowest median values in the study region. There were five occasions where the ammonia exceeded the water quality guideline of 0.050 mg/L, two of these occurred at Point Boston. There were no exceedences for the aquaculture guideline over the study period, however Billy Lights Point did register a value of 0.137 mg/L but this is measured as total ammonia and the un-ionised proportion (for which the aquaculture guideline relates to) is likely to be about 0.008 mg/L.

Table 7   Statistical summary of total ammonia (all values are mg/L)

Site	Median	Standard deviation	90th Percentile	Max	N	Classification			Trend
						Ecosystem	Aquaculture	Recreation	
North Shields	0.009	0.005	0.018	0.022	40	GOOD	GOOD	na	↓ P=0.0015
Point Boston	0.011	0.016	0.020	0.094	40	GOOD	GOOD	na	↓ P=0.0067
Boston Island	0.010	0.014	0.021	0.084	40	GOOD	GOOD	na	↓ P=0.0009
Town Jetty	0.011	0.007	0.016	0.043	40	GOOD	GOOD	na	↓ P=0.0089
Billy Lights Point	0.010	0.021	0.021	0.137	40	GOOD	GOOD	na	↓ P=0.0002
Proper Bay	0.011	0.012	0.032	0.061	40	GOOD	GOOD	na	↓ P=0.0044

na = trigger value not applicable

Ammonia was classified as good at all sites in Boston and Proper Bays for the protection of the ecosystem and aquaculture.

There were no sites that were significantly different to each other.

There were statistically significant decreasing trends across all sites in the study program.

Oxidised nitrogen

Oxidised nitrogen is the sum of the concentrations of dissolved nitrate (NO_3^-) and nitrite (NO_2^-). Nitrate is the more prevalent form in marine waters, with nitrite being oxidised rapidly to nitrate under normal aerobic conditions. Plants readily utilise both forms of nitrogen. Excesses of oxidised nitrogen result in blooms of micro and macroalgae and can potentially lead to seagrass and habitat loss. Oxidised nitrogen can enter the marine environment from agricultural runoff, aquaculture facilities, sewage effluent, contaminated groundwater, urban stormwater, atmospheric deposition and industrial discharges.

Table 8 shows the criteria used for classifying the 90th percentile and median values of oxidised nitrogen for the protection of ecosystem values. The criteria are based on a trigger value for oxidised nitrogen of 0.05 mg/L.

Similarly table 8 shows the classification scheme used for the median and 90th percentile values for nitrate and nitrite for the protection of aquaculture. The criteria are based on nitrite and nitrate as toxicants, with trigger values of 100 mg/L for nitrate and 0.100 mg/L for nitrite.

Due to low nutrient levels inherent in southern Australian waters and interferences common in the chemical analysis of seawater, there are often difficulties with analytical detection limits. Approximately 80% of the oxidised nitrogen samples

for Boston and Proper Bays were below the analytical detection limit (0.005 mg/L). In cases such as this, inferential statistics have not been performed on the data.

Table 8   Water quality guidelines for oxidised nitrogen in Boston and Proper Bays

	Ecosystem (mg/L) $(NO_3^- + NO_2)$	Aquaculture (mg/L) Nitrate (NO_3^-)	Aquaculture (mg/L) Nitrite (NO_2)
GOOD	90th percentile<0.05	90th percentile<100	90th percentile<0.1
MODERATE	90th percentile>0.05>Median	90th percentile>100>Median	90th percentile>0.1>Median
POOR	Median>0.05	Median>100	Median > 0.1

The median value calculated for all sites was 0.005 mg/L, which is the analytical detection limit. This median value is almost certainly overestimated because results below the detection limit were used as at 0.005 mg/L where in reality there is likely to be a spread of values below this. The area between Town Jetty and Proper Bay had the highest 90th percentile at 0.008 mg/L.

Table 9   Statistical summary of oxidised nitrogen (Nitrate & Nitrite) (all values are mg/L)

Site	Median	Standard deviation	90th Percentile	Max	N	Classification			
						Ecosystem	Aquaculture	Recreation	Trend
North Shields	0.005	0.007	0.007	0.011	65	GOOD	GOOD	na	*
Point Boston	0.005	0.007	0.007	0.015	65	GOOD	GOOD	na	*
Boston Island	0.005	0.005	0.005	0.010	65	GOOD	GOOD	na	*
Town Jetty	0.005	0.008	0.008	0.028	66	GOOD	GOOD	na	*
Billy Lights Point	0.005	0.008	0.008	0.037	66	GOOD	GOOD	na	*
Proper Bay	0.005	0.008	0.008	0.037	65	GOOD	GOOD	na	*

na = trigger value not applicable

Table 7 shows that oxidised nitrogen was classified as good across all sites for the protection of the ecosystem and aquaculture. Note that separate nitrite and nitrate concentrations were not available to classify against the aquaculture trigger value. However, the oxidised nitrogen values were used as a surrogate measure for both nitrate and nitrite.

Sites were not compared to each other due to the high number of data that was below the analytical detection limit. There were no obvious trends in oxidised nitrogen data since 1997 due to the high percentage of data below the detection limit.

Total phosphorus

Phosphorus is an essential element in both plants and animals. When in the soluble phosphate form it is readily available to plants and algae. However, the phosphate ion readily adsorbs to particulate matter making it generally unavailable. As a result phosphorus is often bound in sediments. Like nitrogen, elevated phosphorus can cause excessive algal growth (eutrophication). Nitrogen can often be the limiting nutrient in marine waters of southern Australia but when large amounts of nitrogen are discharged into an ecosystem, algal growth is often limited by phosphorus [Hecky & Kilham 1988]. Typically the most common sources of phosphorus in the marine environment are wastewater treatment plants and river discharges from agricultural areas (phosphorus is used as a fertiliser) and urban stormwater. However studies have shown that sea-cage aquaculture is also major source of phosphorus into the waters offshore of Port Lincoln [Fernandes et al 2007b].

Total phosphorus is classified using the position of the 90th percentile and the median for each site in relation to the water quality trigger value (Table 10) for the protection of ecosystems. The default trigger value for total phosphorus is 0.100 mg/L.

Table 10   Water quality guidelines for total phosphorus in Boston and Proper Bays

	Marine ecosystem (mg/L)	**Aquaculture**	**Recreation**
GOOD	90th percentile<0.1	na	na
MODERATE	90th percentile> 0.1> Median	na	na
POOR	Median>0.1	na	na

na = no guideline under this environmental value for this parameter

All sites were classified as good in Boston and Proper Bays (Table 11). North Shields was the site that had the lowest median total phosphorus concentration with 0.018 mg/L, however it also had the highest 90th percentile at 0.033 mg/L indicating high variability in the data. The Town Jetty had the highest total phosphorus recording over the eight years with 0.724 mg/L on the 29 June 2004. This is over seven times the water quality guideline. All sites other than Billy Lights Point and Proper Bay had one occasion where total phosphorus exceeded the water quality guidelines although none of these exceedences occurred at the same time.

Table 11   Statistical summary of total phosphorus (all values are mg/L)

						Classification			
Site	**Median**	**Standard deviation**	**90th Percentile**	**Max**	**N**	**Ecosystem**	**Aquaculture**	**Recreation**	**Trend**
North Shields	0.018	0.019	0.033	0.150	68	GOOD	GOOD	na	↓ P=0.0212
Point Boston	0.019	0.020	0.030	0.168	67	GOOD	GOOD	na	↓ P=0.0001
Boston Island	0.020	0.033	0.030	0.285	68	GOOD	GOOD	na	↓ P=0.0001
Town Jetty	0.020	0.085	0.028	0.724	69	GOOD	GOOD	na	↓ P=0.0073

Site	Median	Standard deviation	90th Percentile	Max	N	Ecosystem	Aquaculture	Recreation	Trend
						Classification			
Billy Lights Point	0.019	0.009	0.027	0.070	68	GOOD	GOOD	na	↔
Proper Bay	0.019	0.009	0.029	0.055	67	GOOD	GOOD	na	↓ P=0.0268

na = trigger value not applicable

Total phosphorus was classified as good across all sites in Boston and Proper Bays for the protection of ecosystems.

There were no significant differences between any sites in the study region.

There were statistically significant decreasing trends at all sites with the exception of Billy Lights Point.

Biological

Microalgae (measured via chlorophyll a)

Microalgae are a fundamental part of aquatic systems; they form the base of the food chain that marine ecosystems need to function. Despite this importance, they can be a problem if they occur in high numbers and form algal blooms, which can lead to oxygen depletion and increase turbidity of the water column.

Chlorophyll *a* is used as a measure of microalgal biomass in the water column. Using chlorophyll *a* compliments nutrient chemical monitoring as algal growth may be more representative of the nutrient status of the environment than periodic sampling of ambient nutrient concentrations due to it integrating all conditions over time. Unfortunately measuring phytoplanktonic chlorophyll *a* does not take into account macroalgae, which can be a significant part of the ecosystem, especially when considering the impacts of eutrophication.

Algal growth can be promoted by human impacts such as increases in nutrient loads from wastewater treatment plants, stormwater and rivers and also thermal pollution from industry.

Water quality is classified using the median and 90th percentile of the data and compared to the trigger value for the protection of ecosystems. Table 12 shows the water quality guidelines for chlorophyll *a* in Boston & Proper Bays.

Table 12   Water quality guidelines for chlorophyll *a* in Boston and Proper Bays

	Marine ecosystem (μg/L)	Aquaculture	Recreation
GOOD	90th percentile<1.00	na	na
MODERATE	90th percentile>1.00>Median	na	na
POOR	Median>1.00	na	na

na = no guideline under this environmental value for this parameter

All sites were classified as moderate throughout Boston and Proper Bays (Table 13). Proper Bay had the highest median chlorophyll *a* concentration of 0.800 μg/L, while North Shields had the lowest median concentration of 0.520 μg/L. Point Boston had the highest 90th percentile of 1.706 μg/L but the Town Jetty had the highest maximum concentration of 2.840 μg/L. While the data set did not statistically demonstrate a seasonal pattern the majority of exceedances occurred over

May and June (28 & 25% of all exceedances respectively).The town jetty was the site with the most exceedences of the water quality guidelines with 23 samples recording over 1µg/L of chlorophyll *a* or 22%, while Proper Bay recorded 20 (19%). North Shields had the lowest number of exceedences with 8 over the 11 years of sampling (8%).

Table 13   Statistical summary of Chlorophyll *a* (all values are µg/L)

Site	Median	Standard deviation	90th Percentile	Max	N	Classification			Trend
						Ecosystem	Aquaculture	Recreation	
North Shields	0.520	0.346	1.023	2.540	68	MODERATE	na	na	↔
Point Boston	0.600	0.583	1.706	2.780	69	MODERATE	na	na	↔
Boston Island	0.590	0.449	1.502	1.930	69	MODERATE	na	na	↔
Town Jetty	0.690	0.551	1.500	2.840	71	MODERATE	na	na	↔
Billy Lights Point	0.690	0.448	1.407	2.330	70	MODERATE	na	na	↔
Proper Bay	0.800	0.436	1.410	2.680	69	MODERATE	na	na	↔

na = Trigger value not applicable

All sites in Boston and Proper Bays were classified as moderate across the study region.

The Chlorophyll *a* concentrations in Proper Bay were significantly higher than North Shields and Point Boston. The Town jetty was also significantly higher than North Shields.

There were no significant trends in chlorophyll *a* concentrations throughout the study region.

Pathogens

Faecal matter contains a range of pathogens including viruses (polioviruses and enteroviruses), parasitic protozoa (Cryptosporidium and Giardia) and pathogenic bacteria such as Campylobactor and Salmonella. Instead of testing for all viruses, protozoans and bacteria, a subset of bacteria, such as faecal coliforms including Escherichia coli and enterococci are monitored. These are known as indicator bacteria [Corbin & Gaylard 2005].

While both E coli and enterococci are commonly used as indicator bacteria, the World health organisation (WHO) & the National Health and Medical Research Council (NHMRC) guidelines use just enterococci concentrations. This is due to E. coli being inactivated rapidly in high salinity water (such as in seawater) and are therefore not as persistent in marine and estuarine waters as enterococci. As an indicator of the presence of pathogenic organisms, which are also persistent in the marine waters, the guidelines consider enterococci to be a more suitable indicator organism than E coli [NHMRC 2008].

In this report the faecal coliforms are used to indicate the risk of contamination in shell fishing waters using the environmental value: protection of aquaculture. Enterococci have been used as indicators of the risk of contamination for recreational users of waters for primary contact (swimming, surfing, etc).

Faecal coliforms

Faecal coliforms are a group of bacteria that are passed through the gut of humans, livestock and wildlife and enter the environment through faeces. *Escherichia coli* (E Coli) is a subset of faecal coliforms.

In this report the classifications compared against the protection of aquaculture are only used as a guide as the ANZECC Guidelines recommend that the shellfish harvesting areas be assessed by using a risk based approach. This involves a sanitary inspection to determine potential sources of faecal bacterial contamination. Some harvesting areas are within close proximity to the Tod River mouth and to shipping lanes, potential sources of bacterial contamination. Risk based testing is currently being undertaken by the PIRSA Shellfish Quality Assurance Program (SASQAP).

Table 14 shows the classification scheme for faecal coliforms in Boston & Proper Bays. When comparing against the protection of aquaculture, ANZECC recommend using a trigger value incorporating the most probable number (MPN) technique. The EPA ambient monitoring use a membrane filtration technique which is expressed as Colony Forming Units (CFU) per 100 mL. While there are some subtle differences in the units it is accepted that for the purpose of this report they can be considered interchangeable. The trigger value for the protection of aquaculture is 14 MPN and is used by comparing the median value to this trigger value.

Table 14   Water quality guidelines for faecal coliforms in Boston and Proper Bays

	Marine ecosystem	**Aquaculture (CFUs per 100 mL)**	**Recreation**
GOOD	na	Median>14	na
MODERATE	na	No moderate classification	na
POOR	na	Median<14	na

na = no guideline under this environmental value for this parameter

Faecal coliforms were classified as good across all sites in Boston and Proper Bays*.* SASQAP have been monitoring bacterial water quality for the shellfish industry in Port Lincoln since 1998. This ongoing monitoring concludes that water quality in most areas of Boston and Proper Bays have very low numbers of faecal coliforms, with medians less than 1.0 faecal coliforms per 100 mL. There are five nationally classified shellfish harvesting areas in the region and all are classified as 'Approved' on the basis of these results.

The median at all sites was 0 faecal coliforms per 100 mL (Table 15). However the Town Jetty had a 95th percentile of 1.0 faecal coliform per 100 mL. These are obviously well below the aquaculture guideline value of 14.

Table 15   Statistical summary of faecal coliforms (all values are CFUs/100 mL)

						Classification			
Site	**Median**	**Standard deviation**	**90th Percentile**	**Max**	**N**	**Ecosystem**	**Aquaculture**	**Recreation**	**Trend**
North Shields	0	1.031	0	14	64	na	GOOD	na	↔
Point Boston	0	0.000	0	2	27	na	GOOD	na	↔
Boston Island	0	0.000	0	0	27	na	GOOD	na	↔

Site	Median	Standard deviation	90th Percentile	Max	N	Classification			Trend
						Ecosystem	Aquaculture	Recreation	
Town Jetty	0	0.347	1.0	21	64	na	GOOD	na	↔
Billy Lights Point	0	0.000	0	0	27	na	GOOD	na	↔
Proper Bay	0	0.000	0	0	27	na	GOOD	na	↔

na = guideline value not applicable

All sites in Boston & Proper Bays were classified as good for the protection of aquaculture across the study region.

There were no significant differences or significant trends in faecal coliforms numbers across all sites in Boston and Proper Bays, largely due to the fact that there were very few non zero values.

Enterococci

Enterococci is measured to assess water quality based on the protection of recreational users of water. Results are compared to the Guidelines for Managing Risks in Recreational Water (NHMRC 2008). Like faecal coliforms, enterococci is measured as an indicator of pathogenic bacteria and viruses that can enter the marine environment from industrial, vessels, stormwater and river discharges. Enterococci are considered a better indicator of the risk to recreational bathers due to their longer survival in marine waters compared to faecal coliforms including E coli. The NHMRC Guidelines recommend that water quality information be assessed with an accompanying sanitary inspection of the catchment to use a risk based approach to assess potential sources of bacterial contamination and whether their origins are likely to be human or animal based (see Introduction).

The EPA started the program measuring enterococci at two sites, the Town Jetty, being the location most likely to be used for swimming and a reference site at North Shields that is used as a point of comparison. Since 2003 enterococci has been measured from all six sites in order to look at spatial trends in more detail. There have been a limited number of sampling occasions at several sites and this means that 95th percentile cannot be reliably calculated for these sites.

Water quality was classified using the 95th percentile [NHMRC 2008] (ie almost all results) compared to the NHMRC Guidelines for low risk water environments. Table 16 shows the guideline values for low risk environments are 200–500 enterocooci cells per 100 mL. If the 95th percentile is above 500 the water quality is poor, between 200–500 moderate and below 200 the water quality is considered good.

Table 16   Water quality guidelines for Enterococci in Boston and Proper Bays

	Marine ecosystem	Aquaculture	Recreation (cells/100 mL)
GOOD	na	na	95th percentile<200
MODERATE	na	na	95th percentile between 200 & 500
POOR	na	na	95th percentile >500

na = no guideline under this environmental value for this parameter

All sites were classified as good for the protection of recreational users of water. The Town jetty had the highest geometric mean of all sites although several sites had only limited data. The Town Jetty also had the highest 95th percentile with 16.50 cells per 100 mL. This site also had the highest single recording of 590 cells per 100ml.

Table 17   Statistical summary of Enterococci (all values are cells/100mL)

Site	Geometric mean	Standard deviation	90th Percentile	Max	N	Classification			Trend
						Ecosystem	**Aquaculture**	**Recreation**	
North Shields	0.353	0.467	2.00	220	65	na	na	GOOD	↔
Point Boston	0.219	0.295	2.40	25	27	na	na	GOOD	↔
Boston Island	0.125	0.153	1.70	3	27	na	na	GOOD	↔
Town Jetty	0.956	0.504	16.50	590	66	na	na	GOOD	↔
Billy Lights Point	0.191	0.188	1.00	6	27	na	na	GOOD	↔
Proper Bay	0.164	0.215	1.70	9	27	na	na	GOOD	↔

* The geometric mean is commonly used when a data set differs by several orders of magnitude and is highly skewed such as is common with microbiological data. In these cases it is generally considered a good indicator of central tendency.

na = trigger value not applicable

Enterococci results were classified as good at all sites.

There were no significant differences between sites throughout the study region over the eight years of sampling.

There were no obvious trends in enterococci concentrations throughout Boston and Proper Bays.

4   Discussion

Background to monitoring

Monitoring the chemical constituents of water at regular intervals gives an indication of the quality of water for those discrete periods sampled. Biological monitoring can show the integrated effects of all impacts on water quality at each site [Friedrich et al 1996]. Biological indicators often utilised in the marine environment are chlorophyll *a* (an indication of algal biomass) [ANZECC 2000; Gaylard 2004], seagrass [Neverauskas 1987; Dennison et al 1993; Udy & Dennison 1997; EPA 1998; Westphalen et al 004] and sometimes macroalgal reef condition [Cheshire et al 1998; Turner et al 2006]. Aerial photography of seagrass has been used in Australia and around the world as a broad-scale indicator of seagrass coverage and hence an indicator of ecosystem health in aquatic environments since the mid-1980s [Cambridge & McComb 1984; Hart 1997; Kendrick et al 2002].

In this report chemical parameters have been used to classify water quality as good, moderate or poor based on guideline values published in ANZECC (2000) and methods used in previous EPA reports. Broad assessments of condition have been made using information on chemical and biological indicators measured (eg chlorophyll *a*), seagrass coverage indicated through aerial photography [Hart 1999] and qualitative field observations using underwater video [EPA unpublished field data].

Boston and Proper Bays in detail

Many aquatic ecosystems rely on light penetrating through the water to reach plants to facilitate photosynthesis. A reduction in photosynthesis over a sustained period will often result in decreases in plant biomass and survival [Walker et al 1999]. Turbidity concentrations across Boston and Proper Bays were very low and are classified as good for both the ecosystem protection and recreation values. Proper Bay was particularly low with significantly lower turbidity results than most sites within Boston Bay. The limited exchange of water, slower current speeds and less fetch to generate waves that resuspend sediment in shallow waters within Proper Bay may be likely contributors to the lower turbidity compared to the sites within Boston Bay.

Town Jetty had the highest turbidity, including the highest 90th percentile and standard deviation, indicating high variability in the results. Town Jetty also showed some disproportionally skewed results over winter and occasional detection of faecal bacteria. This may indicate pulse runoff after rainfall from urban areas, which enters the marine environment close to Town Jetty, decreasing the water quality. Petrusevics (1993) has observed a region of very slow water movement in the southern region of Boston Bay, due to converging tidal water movement directions from each side of Boston Island. This is similar to a region known as the 'Partings' in the Port River near Adelaide. This may possibly restrict flushing of water away from the Port Lincoln region. A second possibility is that the region is a natural sink for fine sediment that can easily be resuspended by wind and wave action. Poor materials handling practices on the Port Lincoln wharf and possibly the large amounts of commercial vessels operating the region may also be other potential sources of turbidity and nutrients near Town Jetty.

Nitrogen is often the limiting nutrient for plant and algal growth in marine systems. It is also one of the most common stressors of marine ecosystems causing nuisance algal growth in the form of phytoplankton, drift macroalgae and epiphytic algae, all of which can result in shading, displacing or smothering of marine habitats [Neverauskas 1987; Shepherd et al 1989; Westphalen et al 2004]. Total nitrogen (TN) concentrations were classified as good throughout the study region and in fact the results in this study showed some of the lowest median TN concentrations throughout any coastal region of South Australia monitored by the EPA [EPA 2003a, 2008; EPA unpublished data]. This is generally consistent with a lack of large industrial or riverine discharges in the region and the oligotrophic (very low nutrients) nature of the marine waters of southern Australia. Interestingly there was a decreasing trend at both North Shields and Point Boston (see later). Russell et al (2005) has observed that effects of increased nutrients can have a disproportionally large impact in oligotrophic waters which should result in a heightened awareness of eutrophication issues by management authorities.

A two-dimensional hydrodynamic model of water circulation patterns in Boston and Proper Bays indicated that Proper Bay can be seen as a separate hydrodynamic unit to Boston Bay, where exchange between the two bays is limited [Petrusevics 1993]. This supports the observation that when a particular nutrient parameter was elevated at one site, it was also elevated at all sites, with Proper Bay being the consistent exception. Proper Bay had the highest median TN concentration, and a relatively low 90th percentile, indicating little variation in the concentrations which are likely to be elevated as a result of the elevated chlorophyll concentrations at this site. This is likely due to the sheltered nature of the bay limiting the exchange of water. Both Point Boston and Billy Lights Point sampling sites are located in the main channels around Boston Island where water currents have been simulated to reach up to 25–30 cm/s [Petrusevics 1993]. This may act to flush water during the tidal cycles and enhance water exchange, particularly near the Billy Lights Point WWTP.

The low nutrient concentrations and small standard deviations at North Shields and Point Boston, particularly during large rainfall events, suggest that the Tod River discharge did not impact on water quality at these sites. However it is accepted that this monthly sampling program has not been designed to detect event-based pollution. This is further supported by the tidal and water flow modelling demonstrating that the general pattern of water movement is clockwise within Boston Bay [Petrusevics 1993]. North Shields has been highlighted as an area that may be impacted by regular natural blooms of *Trichodesmium erythraeum* [P Christy (EPA) pers comm]. General current movements in the predominant southerly wind pattern pushes water into North Shields where it may remain. These phytoplankton blooms are relatively short lived and when they die a large amount of nitrogen may be released into the waters and sediment for uptake by biota. Interestingly elevated nitrogen levels were not detected in the EPA sampling at North Shields and it is currently unknown whether our sampling program is too coarse to detect these blooms (spatially or temporally) or if the sediment or biota are taking up the nutrients at such a rate that they are not detected in the water samples.

Field observations (S Gaylard 29 May 2006) showed varied levels of epiphyte growth on seagrasses at the sampling sites in Boston and Proper Bays (Figs. 5, 6 and 7). Epiphyte growth on seagrass has been used as an indicator of nutrient status and ecological condition for many years [Neverauskas 1987; EPA 1998; Bryars et al 2003]. While only measured qualitatively on one occasion, seagrasses within Proper Bay (and Town Jetty to a lesser extent) appeared to have more epiphytic growth than at other monitoring sites (Figure 5). This is not surprising given that over the eight years of monitoring this site had slightly higher (although not statistically significant) nitrogen concentrations than all other sites. This site is also likely to have lower current speeds and possibly lower water exchange rates which would enhance epiphytic growth. The TN levels in Proper Bay are very similar to the TN concentrations seen in Western Cove (Kangaroo Island), which are generally considered to be eutrophic, and largely impacted by large riverine inflows [Edyvane 1997; Bryars et al 2003; Gaylard 2005]. Caution must be used when interpreting field information as in this case it was only qualitative measurements at one time of year. Significant quantitative fieldwork would be required to draw more definitive conclusions.


Figure 5 **Digital video screen capture of seagrass epiphytes at the ambient monitoring location in Proper Bay, 29 May 2006**
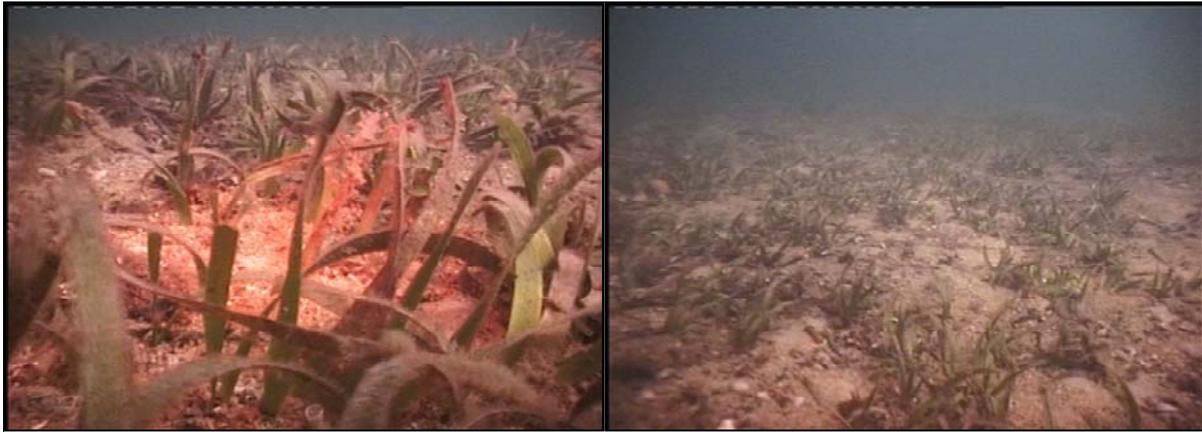
Figure 6   **Digital video screen capture of seagrass epiphytes at ambient monitoring location in Boston Bay (North Shields), 29 May 2006**
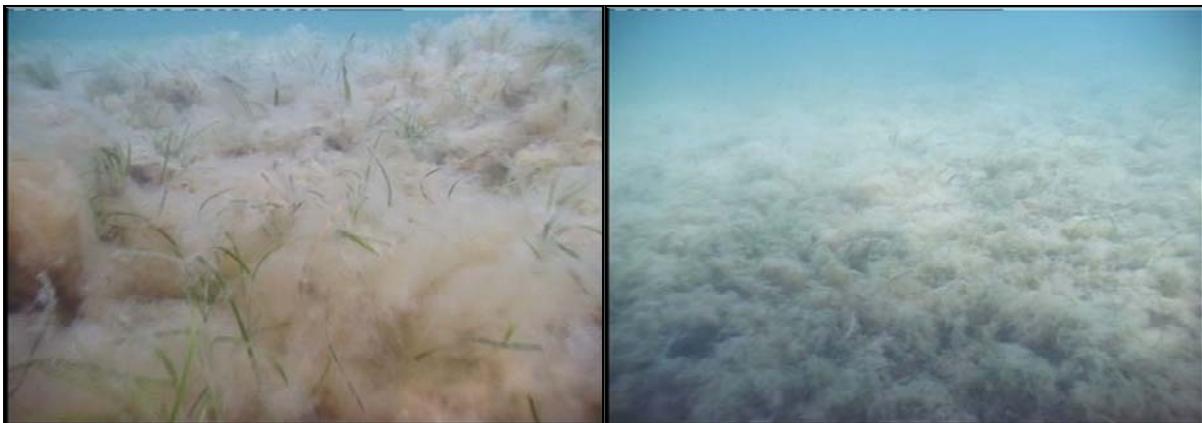
Figure 7   **Digital video screen capture of seagrass epiphytes adjacent fish processing factories discharge in Proper Bay, 29 May 2006**

Chlorophyll *a* concentrations were elevated across all sites in the study region and were significantly higher in Proper Bay and Town Jetty than the site located furthest from a known nutrient discharge at North Shields. Elevated phytoplankton in the water column suggests that there may be excessive nutrients present compared to what may be seen in a similar 'healthy' marine ecosystem. This is consistent with the observations of increased epiphytic growth on seagrass at these sites.

Sources of nitrogen discharged directly into Proper Bay are the wastewater effluent from fish processor factories discharged into the northwestern region of Proper Bay and some small regions of urban runoff. It is also possible that the Billy Lights Point WWTP discharge occasionally flows into Proper Bay under certain tidal regimes. The fish processing discharge, while not large in nitrogen load (~500 kg/year) has been linked to the loss of over 35–38 ha of seagrass from the bay, high epiphyte growth (Figure 6), degraded seagrass condition and an increase in 'nutrient tolerant algae' in the vicinity of the outfalls over the last 20 years [Caldwell Connell Engineers 1976; EPA unpublished data; EPA & DEHAA 1997]. The large impact in this region would likely to be exacerbated by low water movements in the region resulting in poor dispersion. Given these possible biological indicators of nutrient enrichment and the relatively low TN concentrations in Proper Bay compared to other locations around South Australia [EPA 2003a; 2008], the observed eutrophication symptoms may support the statement of Russell et al (2005) that increases in nutrient concentrations in oligotrophic waters may have disproportionately larger effects than in more eutrophic environments.

While these indicators suggest nutrient enrichment in Proper Bay, low epiphyte loads at sites with similar TN and chlorophyll *a* levels indicates that there are many other factors that could be influencing water quality and biological 'health/condition' indicators. Factors such as current speeds, biological interactions (such as high presence of grazers)

and uptake by epiphytic algae, macroalgae and/or seagrass, chemical speciation of the constituents and residence times also play a large part in the overall integrity of an aquatic environment. As stated earlier a qualitative study of seagrass/ecosystem condition would be required in Boston and Proper Bays in order to determine causal factors.

Looking at chemical concentrations alone, the median TN and chlorophyll *a* at North Shields, while not statistically significant at all sites, were the lowest concentrations of all sites in Boston or Proper Bays. Additionally North Shields had the lowest median TN and one of the lowest median chlorophyll *a* values of any site monitored in South Australia by the EPA [EPA 2003a; 2008; EPA unpublished data].

The areas of seagrass loss reported by Hart (1999) are largely around North Shields (Figure 3) with some smaller areas of loss around the western side of Boston Island, Porter Bay, Proper Bay and near Town Jetty. The pattern of loss illustrated in Hart (1999) excluding North Shields, could suggest that the loss outside Proper Bay is occurring predominantly in the deeper water. This could be indicating seagrass loss due to nutrient enrichment, acting by reducing the light penetration to the seagrass due to shading by epiphytic algae, which is a common mechanism of seagrass loss and has been observed in other locations such as Botany Bay, NSW [Larkum & West 1990] and Princess Royal Harbour, WA [Hillman et al 1990].

Figure 3 shows a large area of seagrass loss near North Shields which appears to be anomalous with a nutrient enrichment model due to the shallow waters (2–10m deep) and very low nutrient concentrations. Seddon et al (2002) observed a large-scale intertidal and shallow subtidal seagrass die back in the Spencer Gulf as a result of negative tides and extreme air temperatures exposing seagrass to desiccation, resulting in 127,000 ha of seagrass loss. This model of seagrass loss is also considered unlikely to account for all the loss in the North Shields region as deeper waters would not be exposed to desiccation in a negative tide situation.

A third model is admittedly complex and regarded as only a hypothesis at the moment. This theory is that a large pulse or discharge of nutrients entering the Bay prior to 1997 (when EPA water quality sampling started). This nutrient load possibly contributed to the observed seagrass loss at North Shields where modelling has indicated that this region is likely to be poorly flushed [Petrusevics 1993]. Similarly ground truthing of the region by P Pfennig (EPA) in 1998 showed large areas of drift macroalgae and large areas of bare sand where seagrass was seen from historical photos [Hart 1999]. It is possible that a large dose of nutrients could result in loading the sediments with nutrients and are likely to slowly leach out over time. Additionally this may also cause a large amount of epiphytic algae to grow on seagrass taking a significant proportion of the available nutrients in the water column resulting in low water concentrations observed during sampling.

Uptake of nutrients from the water column has been shown in nutrient enriched areas all over the world [Iizumi & Hattori 1982; Hemminga et al 1991; Udy & Dennison 1997; Romero et al 2006], and may be responsible for the low ambient water nitrogen concentrations at sites where there is documented heavy nutrient impacts on seagrass, such as Western Cove on Kangaroo Island [Bryars et al 2003; Gaylard 2005]. This may also account for the statistically significant decreasing trend in total nitrogen concentrations at the North Shields site and the decreasing trend in ammonia across the entire bay.

Finally the video footage of North Shields (Figure 5) may be a remnant area of seagrass not affected by a large nutrient input, or it is possible that the footage taken in 2006 is showing seagrass regrowth as it is likely that video footage was taken approximately 10 years after any original nutrient source has been removed and the system is showing signs of recovery. This is uncertain at this stage and more seagrass monitoring is required before any definitive conclusions are drawn.

If the above scenario is likely, then this would then lead to the conclusion that there has been a large nutrient load into the Bay that has, over the last 10 years, drastically reduced or stopped. There are two obvious possibilities; Fernandes et al (2007a) has shown that the high metabolic rate of Southern Bluefin Tuna leads to low retention of nitrogen in the fish tissues and results in high losses of nutrients to the environment. Estimates of nitrogen loads from SBT farming to the environment are up to 1,137 tonnes of N per year at the current annual production biomass, based on the nitrogen content of the feed and the majority of this is likely to be in a soluble form [Fernandes et al 2007a].

Between 1991 and 1996 the tuna industry operated within the sheltered waters of Boston Bay. In 1997 the majority of the tuna cages were moved outside Boston Island after a large water quality induced mortality event (see earlier). While it is likely that efficiencies in farming techniques would have improved over this period compared to current practice, the total allowable catch of SBT has not changed and the actual catch has varied little since about 1990 [IOTC 2007]. It is therefore possible that the above estimate of nitrogen discharge to waters is still appropriate for the period when the cages were inside Boston Island. This load of nutrients combined with the relatively sheltered and low current environment inside Boston Bay could have contributed to impacts particularly in the northern region and would account for the documented seagrass loss in the northern region and the decreasing trends in both total nitrogen and ammonia, particularly between 1997–98 (Figures 9 and 10).

The removal of the cages to outside of Boston Island and into deeper water with higher current speeds in 1997, may have facilitated a reduction of nitrogen concentrations which the EPA monitoring program only detected the final stage (hence the decreasing trend at North Shields) and the 2006 video footage may be indicating seagrass regrowth since the 1997 imagery from Hart (1999) and observations by P Pfennig in 1998.

A second possibility could be the Billy Lights Point WWTP which was upgraded in 1994 and has been discharging approximately 6.5 tonnes/yr of total nitrogen into the Bay. Prior to 1994 the effluent would have likely have been of poorer quality but lower in volume given the population size. Given the WWTPs relatively low loads being discharged, particularly compared to SBT, it would be considered unlikely that if there was a large nutrient input into Boston Bay, it could be attributed to the Billy Lights Point WWTP.

As stated above there is significant uncertainty in the accuracy of water quality data prior to 1998 and a lack of any water quality data in Boston Bay prior to this. Therefore it would be impossible to draw any conclusions based on the above hypotheses using this water quality data and limited seagrass cover information. There is a need to undertake a follow-up seagrass aerial photography or remote sensing study to look at seagrass coverage in Boston and Proper Bays as well as water quality monitoring that involves biotic indicators as well as abiotic.

Seagrass loss across the region would suggest that there are effects of nutrient enrichment across Boston Bay. However the resolution and classification of aerial photography, particularly at deeper waters edges is often variable in quality. The nutrient concentrations observed in this program are substantially lower than other locations across South Australia that are exhibiting seagrass loss as a result of nutrient enrichment, eg metropolitan Adelaide [Gaylard 2004; Bryars et al 2006] but other factors may be contributing to the observed results such as uptake of dissolved nutrients by epiphytic algae resulting in low nutrient concentrations in the water. The results in this program may further support the theory that increases in nutrient concentrations in oligotrophic waters may have disproportionately larger effects than in more eutrophic environments [Russell et al 05].

Bacterial water quality was shown to be good across all sites according to the trigger values set out in the NHMRC Guidelines for Managing Risks in Recreational Water (2008) for a low-risk region. This would imply that waters are generally safe for swimming. However the Department of Health generally advises against swimming near discoloured water after periods of heavy rain due to an increased risk of bacterial contamination of waters from stormwater discharges.

The faecal coliform levels were very low indicating that there is a low risk to shellfish harvesting, which is consistent with the event-based SASQAP sampling.

The National Water Quality Management Strategy

The current ANZECC trigger values for nutrients in estuaries and open oceans were set to represent of healthy ecosystems in that region (eg that the total nitrogen levels should be below 1.00 mg/L in order to maintain a healthy aquatic ecosystem).

The values adopted for South Australia (Table 3.3.8 in ANZECC 2000) were based on very limited water quality available at the time. This report and other EPA and scientific studies have demonstrated that biological parameters are indicating

that a system is under nutrient stress including large areas of seagrass being lost from previously healthy regions while most nutrient parameters are classified using the ANZECC criteria as good.

From this it is logical to conclude that the ANZECC trigger values for South Australia should be reviewed to allow for the oligotrophic (nutrient poor) nature of the marine environment seen in South Australia and the disproportionally high eutrophic response seen in oligotrophic waters.

The nationally accepted method for doing this is through establishing community agreed environmental values for the waterways via the National Water Quality Management Strategy (NWQMS 2000). This is where the community are asked what they would like to use the waters for, eg protecting ecosystems, recreation, seafood, etc. Once environmental values are established, water quality objectives and criteria (like ANZECC trigger values) can be set to protect those agreed environmental values. It is anticipated that these water quality guidelines will be somewhat site-specific to allow for the oligotrophic nature of locations such as Boston Bay. Appropriate trigger values will give a better indication of water quality and provide researchers, managers, industry and the public a more accurate and reliable measure of the conditions of the state's waters.

5   Conclusions

The results of this monitoring program show that the water quality in Boston and Proper Bays is broadly classified as good to moderate according to the ANZECC Guidelines for Fresh and Marine Waters (2000) for the protection of the ecosystem, aquaculture and recreational users.

In particular, nutrients were classified as good across all sites for the protection of ecosystem and aquaculture, even though there are indications of nutrient stress in some parts of the region. Chlorophyll *a* was classified as moderate across all sites and again is possibly indicating nutrient enrichment of some sites within the program. Turbidity was classified as good throughout all sites in Boston and Proper Bays for the protection of the ecosystem and recreational users of the waters.

Bacterial water quality was shown to be good across all sites according to the trigger values set out in the NHMRC Guidelines for Managing Risks in Recreational Water (2008). The faecal coliform levels were also very low indicating that there is a low risk to shellfish harvesting.

The results of this monitoring program suggest that while nutrient levels were very low, there are many different sources of nutrient pollution including the City of Port Lincoln itself. The Town Jetty site was significantly higher in chlorophyll *a* (to North Shields) and turbidity (to Proper Bay). It is possible that both nutrients and elevated turbidity would be sourced from urban stormwater runoff from Port Lincoln. Other sources of nutrients into the region include the Billy Lights Point WWTP, and the fish processing factories that discharge into Proper Bay. Other potential sources of nutrients and turbidity are aquaculture (both historical nutrient loads and current), poor materials handling practices at the wharves, and the high densities of commercial boats that may be discharging wastes into Boston and Proper Bays.

The *Code of practice for materials handling of wharves* (2007) has been published by the EPA which sets out acceptable practices for the wharf in order to reduce diffuse pollution and spills from activities on the wharf. It is expected that this will help to reduce diffuse pollution from the wharf regions which may lead to improvements in water quality.

Proper Bay also had significantly higher chlorophyll *a* concentrations compared to North Shields, in addition to this there was evidence of elevated seagrass epiphyte growth in this region. The inference from this report is that it is likely Proper Bay is under nutrient stress (or has been recently) and that poor water exchange and nutrient discharges, recent or historical, in the region are contributing to this state. Further research is needed on seagrass extent and condition in Boston and Proper Bays in order to make definitive conclusions about impacts of elevated nutrients.

The EPA has completed a review of its water quality monitoring program for all of South Australia, including Eyre Peninsula in order to examine the type and frequency of monitoring it undertakes across the state. This revised monitoring program will have a significant proportion of biological indicators to assess water quality (eg seagrass condition) as recommended in this report as well as others [Fox et al 2007]. The results will be published into a 'report card' for communication to the general public and be available on the EPA website <www.epa.sa.gov.au>. Monitoring for the Eyre Peninsula is expected to be undertaken in 2010 and will also aim to clarify uncertainties highlighted in this report.

A framework based on the National Water Quality Management Strategy (2000) is required to designate environmental values and water quality objectives for Boston and Proper Bays, which would be site specific and allow for the nutrient poor nature of the waters of Boston Bay. This would generate realistic indicators of good, moderate and poor water quality based on ambient water quality monitoring.

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# Appendix 1 Box plots for parameters measured in Boston and Proper Bays
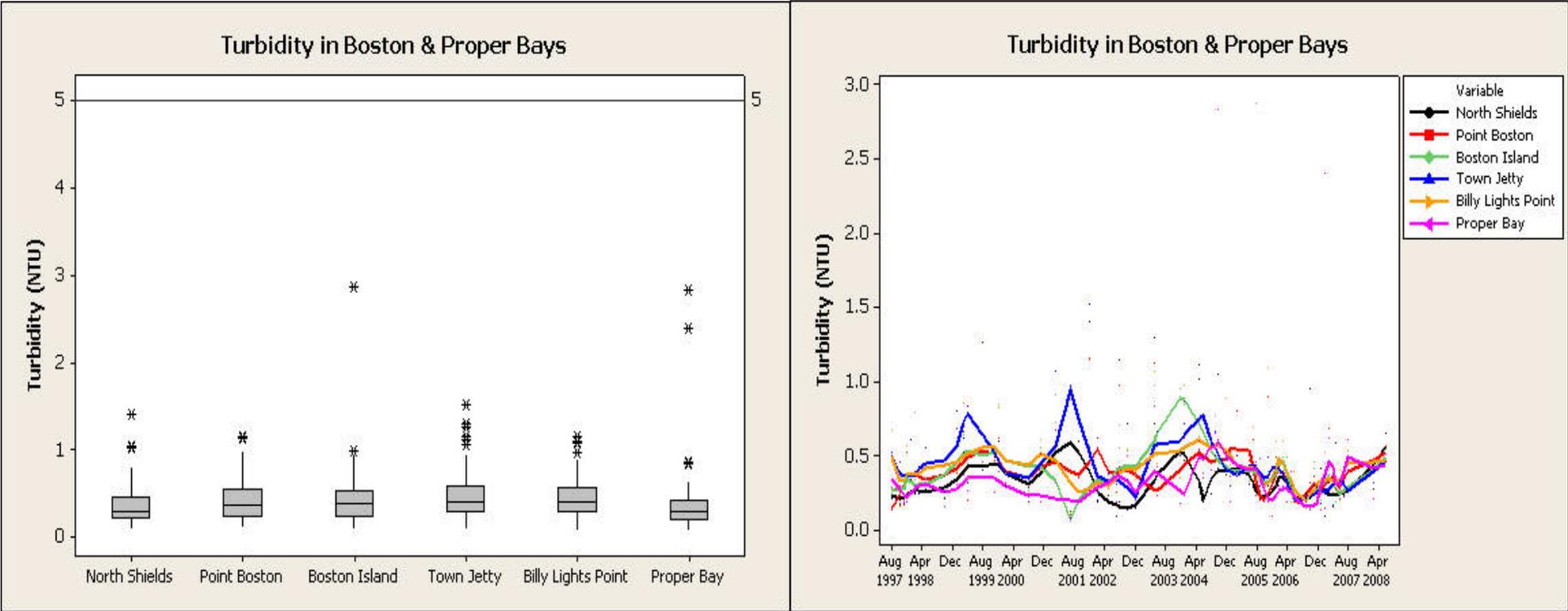
Figure 8 **Turbidity box plot and time series plots. Box plot boxes represent 25 & 75th percentiles, line within the box represents median (50th percentile) and the whiskers shows the extent of the data and asterisks represent anomalies in the population. The reference line represents the ANZECC Guideline value for protection of ecosystems. Time series graph is shown using a Lowess smoother at a rate of 0.1 with 2 passes.**
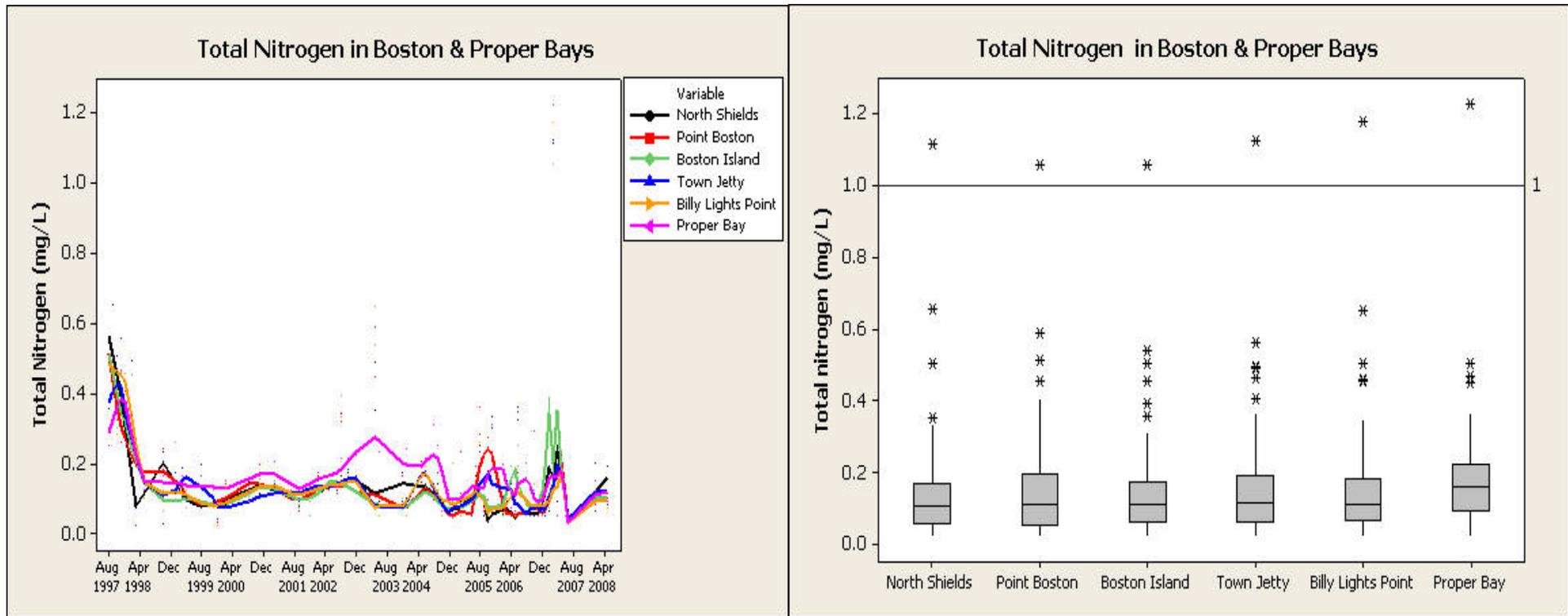
Figure 9   Total nitrogen box plot and time series plots. Box plot boxes represent 25 & 75th percentiles, line within the box represents median (50th percentile) and the whiskers shows the extent of the data and asterisks represent anomalies in the population. The reference line represents the ANZECC Guideline value for protection of ecosystems. Time series graph is shown using a Lowess smoother at a rate of 0.1 with 2 passes.
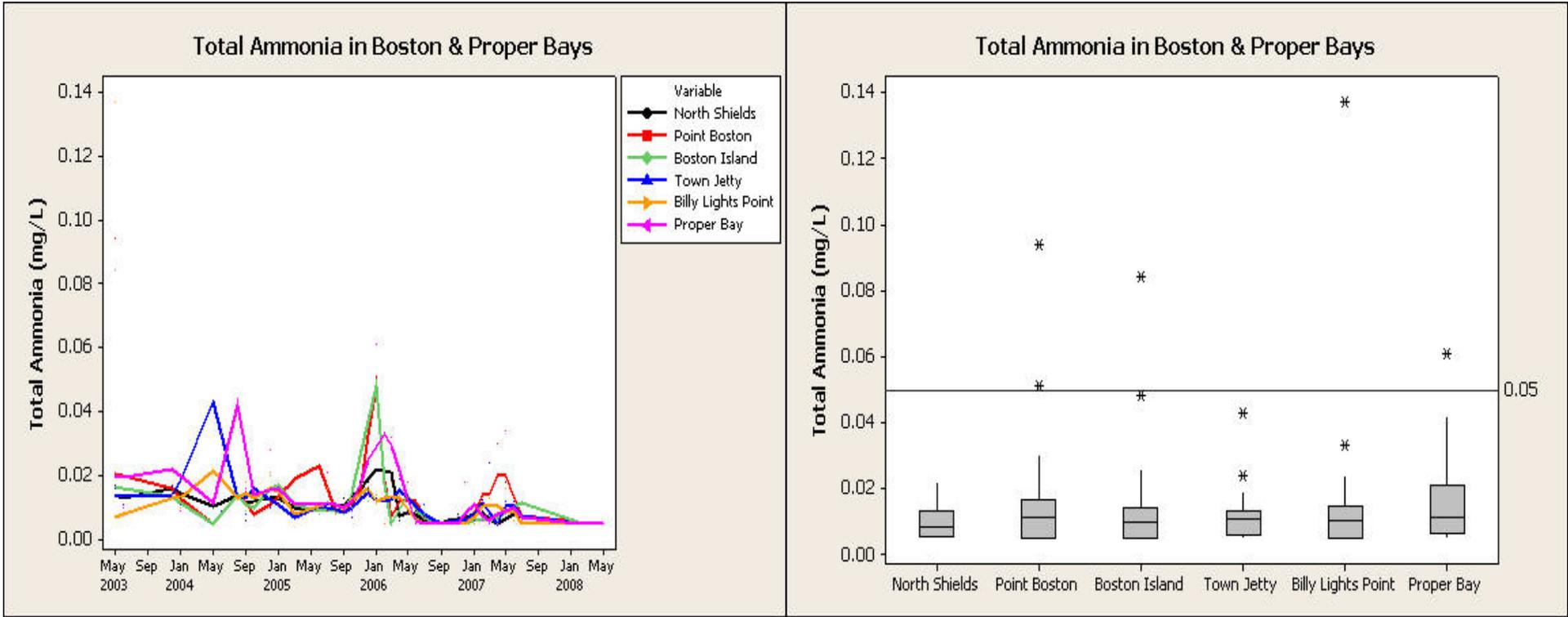
Figure 10 Total Ammonia box plot and time series plots. Box plot boxes represent 25 & 75th percentiles, line within the box represents median (50th percentile) and the whiskers shows the extent of the data and asterisks represent anomalies in the population. The reference line represents the ANZECC Guideline value for protection of ecosystems. Time series graph is shown using a Lowess smoother at a rate of 0.1 with 2 passes.
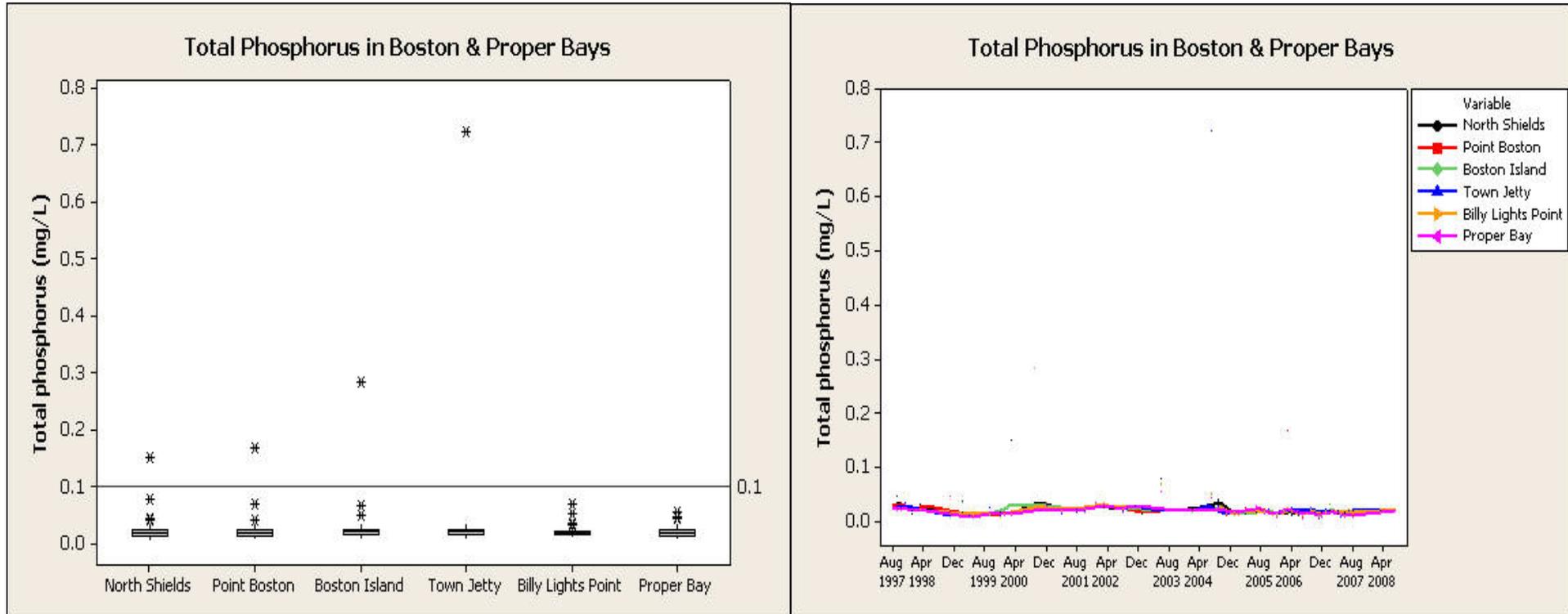
Figure 11 Total phosphorus box plot and time series plots. Box plot boxes represent 25 & 75th percentiles, line within the box represents median (50th percentile) and the whiskers shows the extent of the data and asterisks represent anomalies in the population. The reference line represents the ANZECC Guideline value for protection of ecosystems. Time series graph is shown using a Lowess smoother at a rate of 0.1 with 2 passes.
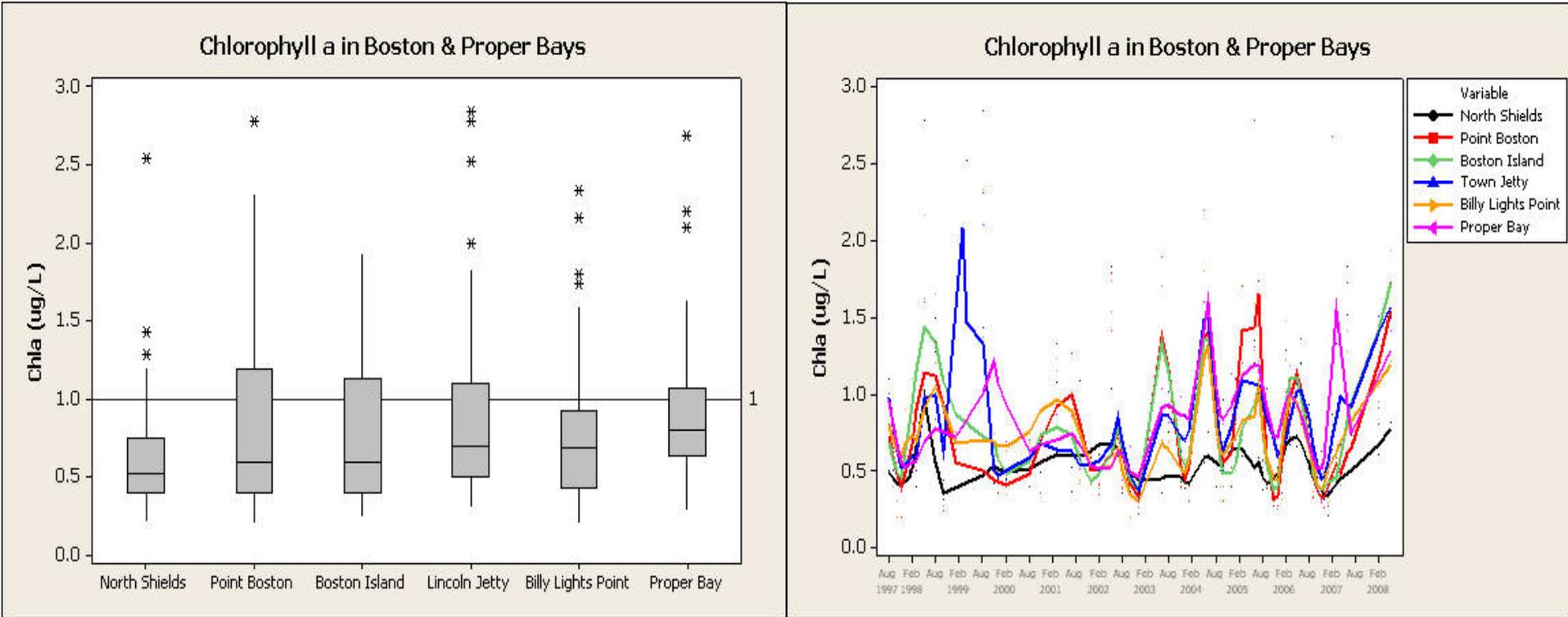
Figure 12 Chlorophyll a box plot and time series plots. Box plot boxes represent 25 & 75th percentiles, line within the box represents median (50th percentile) and the whiskers shows the extent of the data and asterisks represent anomalies in the population. The reference line represents the ANZECC Guideline value for protection of ecosystems. Time series graph is shown using a Lowess smoother at a rate of 0.1 with 2 passes.
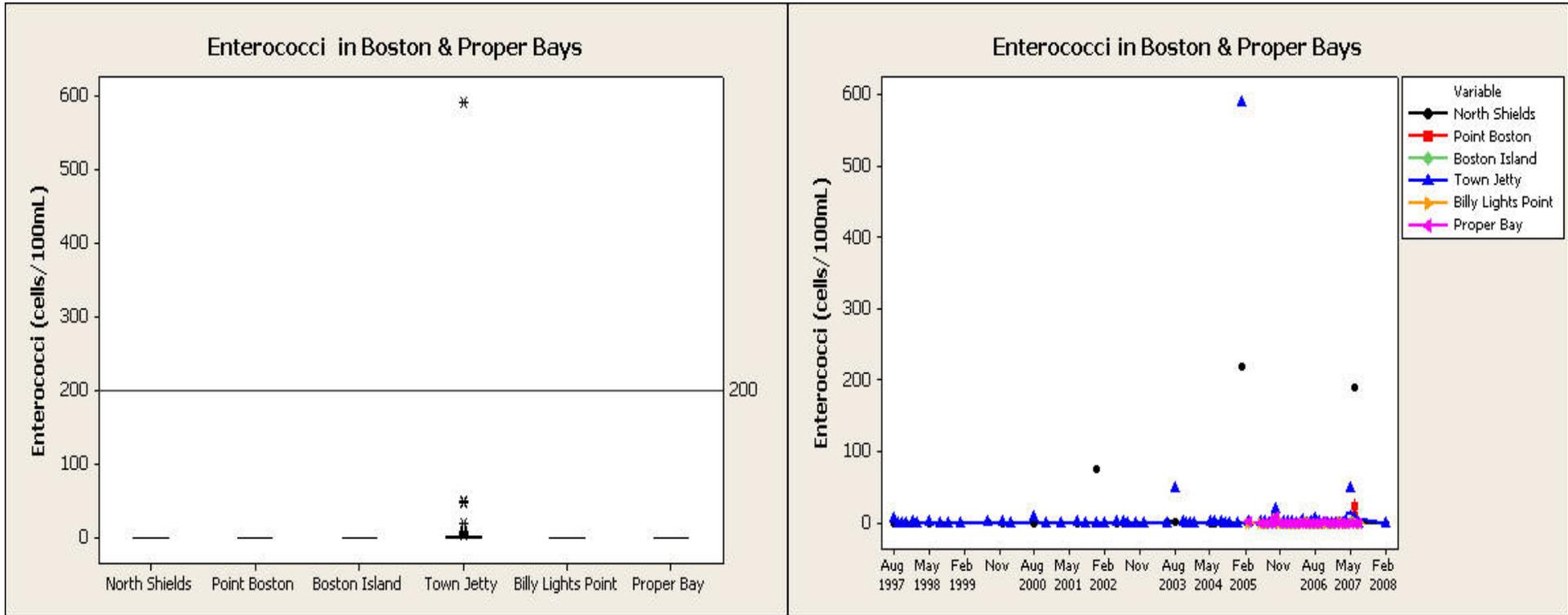
Figure 13 Enterococci box plot and time series plots. Box plot boxes represent 25 & 75th percentiles, line within the box represents median (50th percentile) and the whiskers shows the extent of the data and asterisks represent anomalies in the population. The reference line represents the ANZECC Guideline value for protection of recreational users. Time series graph is shown using a Llowess smoother at a rate of 0.1 with 2 passes.
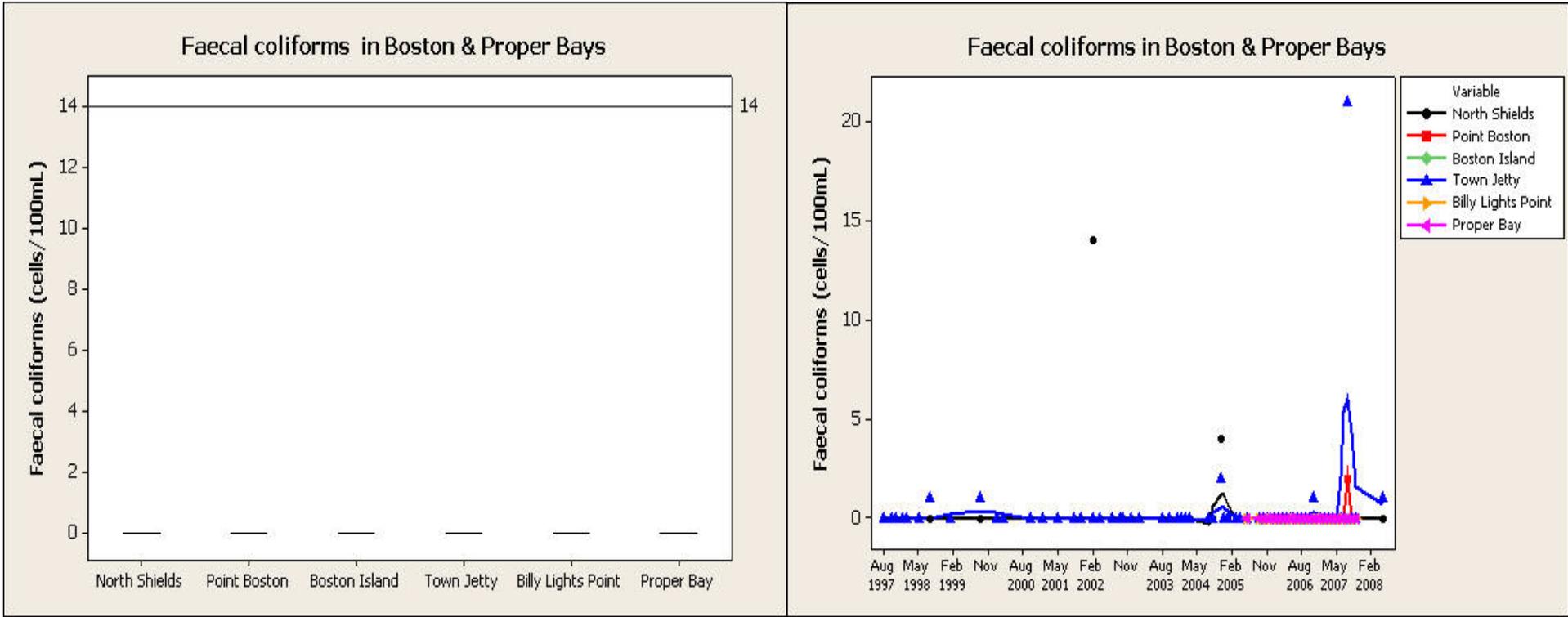
Figure 14 Faecal coliforms box plot and time series plots. Box plot boxes represent 25 & 75th percentiles, line within the box represents median (50th percentile) and the whiskers shows the extent of the data and asterisks represent anomalies in the population. The reference line represents the ANZECC Guideline value for protection of aquaculture (shellfish harvesting). Time series graph is shown using a Lowess smoother at a rate of 0.1 with 2 passes.

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