Final Evaluation Report

Salty Lagoon Monitoring Program: Pre/Post Closure of the Artificial Channel

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Executive Summary

GeoLINK and Aquatic Science and Management were engaged by Richmond Valley Council (RVC) to implement the *Salty Lagoon Monitoring Program: Pre-Post Closure of Artificial Channel* (MPPC). Trial closure of the artificial channel forms part of RVC ongoing Salty Lagoon rehabilitation strategy. The MPPC program was undertaken between March 2011 and June 2017, with the objectives of:

1. Confirming positive predicted changes in Salty Lagoon ecological and cultural values in response to the closure of the artificial channel.
2. Provide adaptive management response mechanisms before and after closure to inform future stages of the Rehabilitation Program.
3. Inform long term strategies with respect to the management of effluent from the Evans Head Sewage Treatment Plant (STP).

The primary management outcome of a successful (positive) trial based on the MPPC results is for the channel closure to be a permanent component of the Salty Lagoon rehabilitation strategy (Hydrosphere 2010a). Other key findings from the MPPC in relation to Evans Head STP discharge relevant to future management at Salty Lagoon include:

- The discharge from the Evans Head STP does not appear to increase the water levels in Salty Lagoon.
- It is unlikely that discharged effluent from the Evans Head STP is contributing significantly to faecal coliform measurements in Salty Lagoon.
- The majority of the nitrogen in discharged effluent appears to be processed by the ecosystems occurring along the drainage channel upstream of Salty Lagoon. It is possible that elevated nitrogen concentrations around Salty Lagoon may be partially maintained in the long term by the input from the Evans Head STP.
- It is not likely that current phosphorus concentrations in discharged effluent are sufficient to maintain the phosphorus concentrations in the waters of Salty Lagoon.

The MPPC program has found that, at current levels, continued discharge from the Evans Head STP has a minimal effect on bioavailable nutrient concentrations within Salty Lagoon. Residual nutrients from historic pollution are currently the primary contributor of nutrients causing periodic poor water quality episodes in the system, and continued discharge from the Evans Head STP is unlikely to adversely affect the overall health of the system.

Based on the MPPC findings and the *Salty Lagoon Rehabilitation Plan* recommendations (Hydrosphere 2009b; 2011), RVC propose to:

- Maintain permanent closure of the artificial channel between Salty Lagoon and Salty Creek.
- Continue to discharge of treated water from the Evans Head STP into the creek upstream of Salty Lagoon for the medium term (i.e. next 15 years).

On this basis the following recommendations are provided:

- Develop a long-term (>15 year) plan for the Evans Head STP, including a clear discharge strategy.

- Continue to liaise with regulatory agencies, Aboriginal stakeholders and other members of the community regarding future management of Salty Lagoon.
- Continue environmental monitoring at Salty Lagoon for the next 5 years (years 6 to 10 post closure of the artificial channel), with a review at completion of monitoring in 2021/2022.
- Continue to monitor and assess impacts of the head cut and work with stakeholders in regards to managing this as appropriate.

1. Introduction

1.1 Introduction

GeoLINK and Aquatic Science and Management (ASM) have been engaged by Richmond Valley Council (RVC) to implement *the Salty Lagoon Monitoring Program: Pre-Post Closure of Artificial Channel* (MPPC; Hydrosphere 2010a). The artificial channel is located between Salty Lagoon and Salty Creek and the trial closure of this channel forms part of RVC's Salty Lagoon rehabilitation strategy.

The primary purpose of the MPPC program is to confirm prediction that closure of the artificial channel will result in an overall improvement to the ecological and cultural values of Salty Lagoon. Assessment of the effectiveness of the channel closure against this objective is required to determine the overall success of the trial. Objectives of the MPPC program are summarised as follows:

1. Confirm positive predicted changes in Salty Lagoon ecological and cultural values in response to the closure of the artificial channel.
2. Provide adaptive management response mechanisms before and after closure to inform future stages of the Rehabilitation Program.
3. Inform long term strategies with respect to the management of effluent from the Evans Head Sewage Treatment Plant (STP).

This report, *Salty Lagoon MPPC – Final Evaluation Report (2017),* collaborates and analyses the results of the six year MPPC program undertaken between March 2011 and June 2017, upon completion of the trial closure of the artificial channel. The monitoring included:

- Pre-closure of artificial channel (baseline) monitoring from March 2011 to May 2012. The results of the preceding *Salty Lagoon Ecosystem Response Monitoring Program* (ERMP; Hydrosphere 2010b) also form part of the baseline monitoring data where appropriate.
- Post-closure of the artificial channel monitoring from June 2012 to June 2017.

Aerial photographs of the site pre and post artificial channel closure are provided in **Illustration 1.1**. Details of the MPPC monitoring methodology and results for each year are provided in the respective *Salty Lagoon Annual Monitoring Report* (GeoLINK 2012a, 2013a, 2014, 2015a, 2016, 2017a).

The structure of this report includes:

- An analysis of the results of each environmental attribute monitored, with a focus on an evaluation of the predictions of the MPPC program (Hydrosphere 2010a). This includes the results of monitoring of the following attributes:
  - Water quality.
  - Macroinvertebrates.
  - Vegetation.
  - Aquatic weeds.
  - Fish.
  - Waterfowl.

- Frogs.

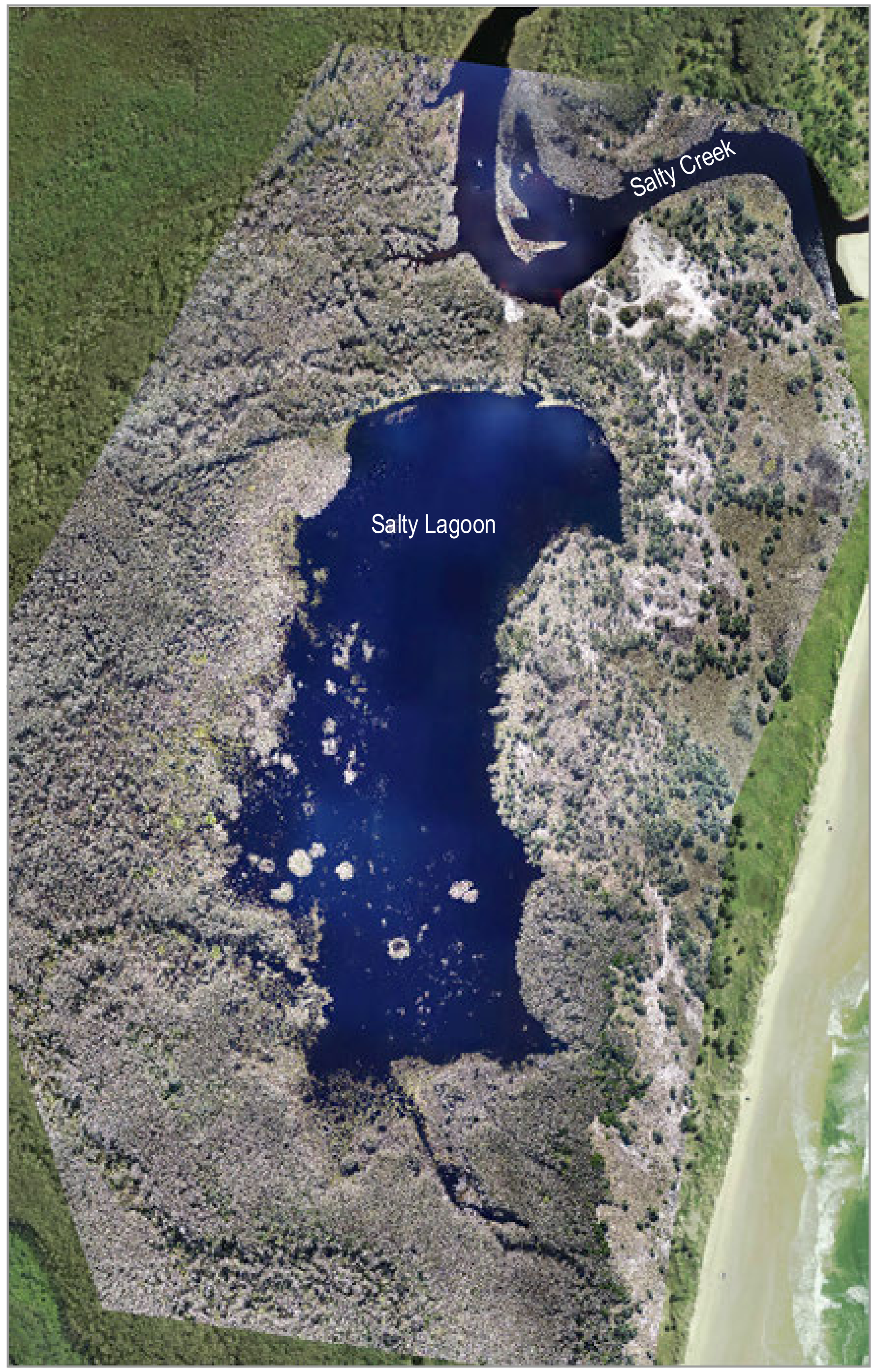
- An overall assessment of the effectiveness of closure of the artificial channel in achieving the rehabilitation objectives.
- Considerations and recommendations for future management of Salty Lagoon and Evans Head STP discharge.

Information shown is for illustrative purposes only

Drawn by: AB Checked by: RE Reviewed by: DSA Date: 13/10/2017
Source of base data: Richmond Valley Council

Salty Lagoon 2011: Pre-closure of the artificial channel
(Salty Creek channel closed)

Salty Lagoon 2013: Approximately 1 year post-closure of the artificial channel
(Salty Creek channel closed)



Salty Lagoon 2017: 5 years post-closure of the artificial channel
(Salty Creek channel closed)

North

0 150

Aerial Photographs of Salty Lagoon - Pre and Post Artificial Channel Closure

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1731-1283

Illustration 1.1

2. Water Quality

2.1 Introduction

Adequate water quality is important to the maintenance of ecosystem processes in Salty Lagoon. Previous monitoring of Salty Lagoon has highlighted issues with water quality such as high nutrient concentrations and rapid changes in conductivity and dissolved oxygen. Poor water quality in the past has led to fish kills, indicating ecosystem collapse (Hydrosphere 2009a). Water quality monitoring is central to the MPPC program as a method of assessing the health of the ecosystem and informing adaptive management responses.

A varied approach to water quality sampling involving permanent water quality monitors, discrete sampling of surface waters and additional sampling in response to specific environmental conditions formed the basis of water quality monitoring for the MPPC. The range of parameters covered by each of these approaches to water quality monitoring is described in **Table 2.1**.

Table 2.1 Approaches to Water Quality Monitoring and Parameters Measured for the MPPC

Approach	*Sampling Type*	*Parameters*
Permanent water quality monitoring stations/loggers (PWQMS)	Physico-chemical	Temperature, conductivity, dissolved oxygen (DO), pH, turbidity, water level
Monthly discrete sampling and adaptive management response sampling	Physico-chemical	Temperature, conductivity, dissolved oxygen (DO), pH, turbidity, secchi depth, redox
	Chemical	Total nitrogen, ammonia, nitrate, nitrite, total kjeldahl nitrogen, total phosphorus, orthophosphate
	Biological	Chlorophyll-a, blue green algae, faecal coliforms, enterococci

2.2 Methods

The methods for the Salty Lagoon MPPC project are described in detail by GeoLINK (2017a).

2.2.1 Permanent Water Quality Monitoring Stations

Two permanent water quality monitoring stations (PWQMS) were in place for the duration of the MPPC program, measuring water level, temperature, pH, conductivity, turbidity and dissolved oxygen (DO) concentration. Each PWQMS was fitted with an YSI Series 6 sonde and a CRS 800 data logger. Data from the PWQMS was sent to a RVC server via a telemetry system.

2.2.2 Routine Discrete Sampling

Discrete water quality samples were taken from surface water (approx. 0.2 metre depth) at four sites in Salty Lagoon (S1-S4) and a single site (S5) in Salty Creek on a monthly basis (76 events in total). An additional quality assurance (QA) replicate sample was collected from a randomly chosen site each month. The specific locations of all sites sampled are presented in **Table 2.2** and displayed in **Illustration 2.1**.

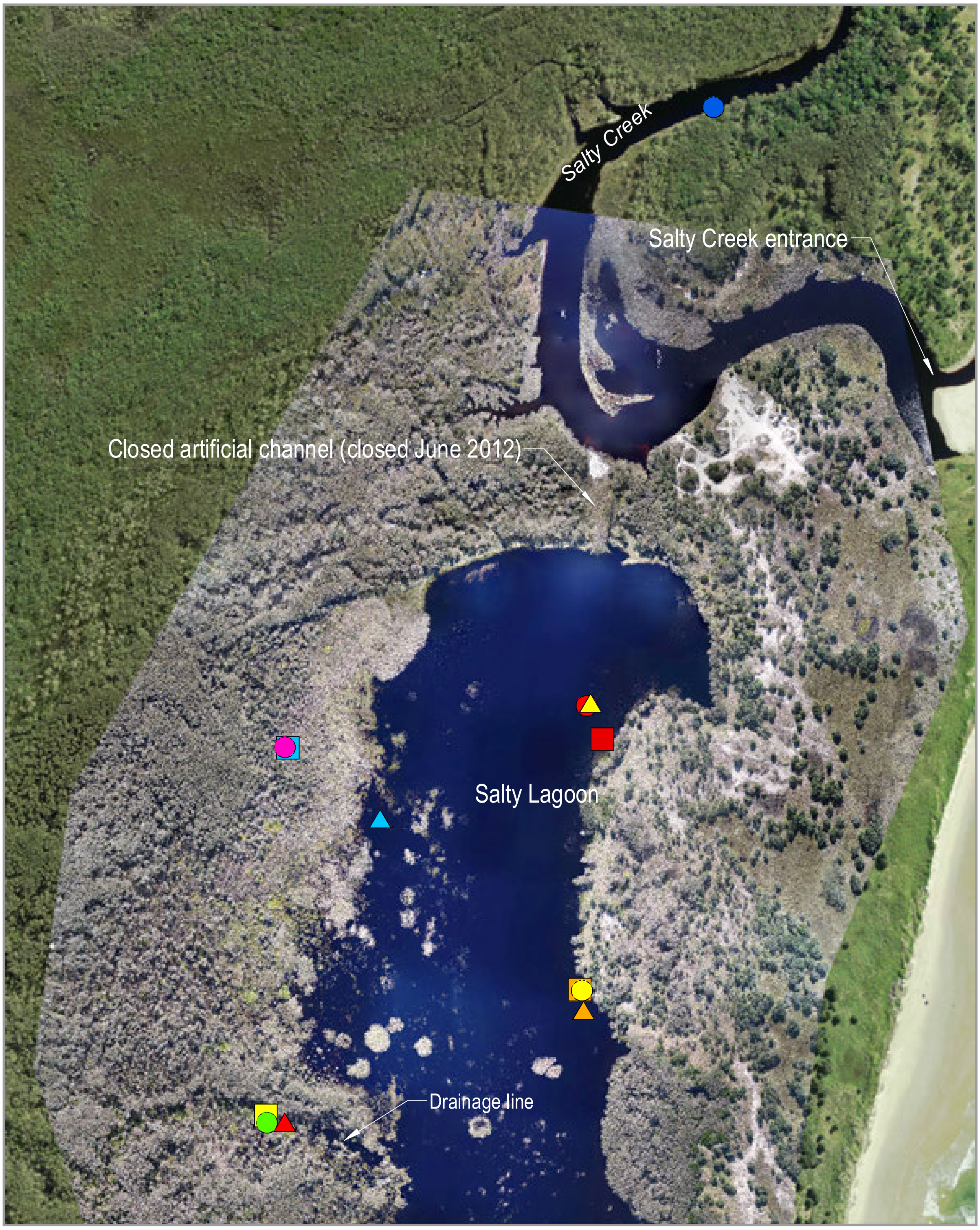
Table 2.2 Locations of Water Quality Sample Sites in Salty Lagoon and Salty Creek (WGS84)

Site	*S 1*	*S 2*	*S 3*	*S 4*	*S 5*
Easting	0542064	0541799	0542037	0541738	0542187
Northing	6782801	6782669	6783013	6783033	6783665
Site description	Salty Lagoon PWQMS	SE of drainage channel	NE area of lagoon	NW area of lagoon	Salty Creek PWQMS

Physico-chemical water quality parameters in discrete surface water samples were measured with an HORIBA U-52 hand held water quality meter. Depth profiling of physicochemical parameters was undertaken at one metre intervals at sites where depth was sufficient to allow it. Discrete samples were collected in jars for analysis of chemical and biological parameters at the Coffs Harbour Laboratory (CHL).

2.2.3 Adaptive Management WQ Sampling

The final water quality monitoring component of the MPPC was the '*adaptive management response*'. The response process is documented in detail in the *Environmental Incident Response Protocol* (Hydrosphere 2009a) that was developed previously for the ERMP (refer to Hydrosphere 2010b). A review of the response process was prepared in April 2013, with adjustments subsequently implemented for the remainder of the MPPC program.



LEGEND

Water quality site	Fish site	Benthic macroinvertebrate site
S1	F1	BM1
S2	F2	BM2
S3	F3	BM3
S4	F4	BM4
S5		

0 120

North

Location of Water Quality Microinvertabrate and Fish Monitoring Sites

2.2.4 Guiding Values

Guiding values were developed to assist with the contextualisation of monthly water monitoring results, rather than as a measure of the health of the waterway. They also provide a yardstick, around which the adaptive management of Salty Lagoon can be discussed.

Guiding values for the MPPC monthly reports were revised in September 2012 (GeoLINK 2012b) and were generated using water quality data collected between April 2011 and September 2012. Guiding values were developed separately for Salty Lagoon and Salty Creek, and based on data collected from surface water at all sites. They incorporated all parameters measured as part of the MPPC.

Guiding values were set at the 80th percentile value of the collected data set for Salty Lagoon and Salty Creek with the following exceptions:

- The guiding values for dissolved oxygen were set at the 20th percentile value.
- A guiding value range was developed for pH, conductivity and temperature in Salty Creek due to the varying influences of sea water and freshwater runoff. The outlying points for the guiding value ranges were set at the 10th and 90th percentile values.

The guiding values developed based on the above methodology are presented in **Table 2.3**.

Table 2.3 Guiding Values for all Water Quality Parameters

Measure		***Guiding Value***	
		Salty Lagoon	***Salty Creek***
Chemical	Total nitrogen (mg/L)	1.6	1.64
	Ammonia (mg/L)	0.05	0.11
	Nitrate (mg/L)	0.01	0.01
	Nitrite (mg/L)	0.01	0.01
	Total kjeldahl nitrogen (mg/L)	1.6	1.64
	Total phosphorus (mg/L)	0.14	0.04
	Orthophosphate (mg/L)	0.11	0.01
Biological	Chlorophyll-a (µg/L)	5	3
	Faecal coliforms (CFU/100mL)	135	150
	Enterococci (CFU/100mL)	170	40
	Blue green algae (cells/mL)	0	0
Physical	Dissolved oxygen (mg/L)	4.09	5.52
	Turbidity (NTU)	13.0	11.0
	pH	6.9	4.3 – 6.8
	Conductivity (mS/cm)	8.0	0.3 – 21.5
	Temperature (˚C)	25.9	13.1 – 28.8

2.3 Results and Discussion

2.3.1 Rainfall

Rainfall, or lack thereof, is a key factor influencing water quality in Salty Lagoon and Salty Creek. Monthly rainfall measurements during the MPPC program are displayed in **Figure 2.1**. The most notable events were unseasonably dry periods between December 2013 and March 2014, and September 2016 and January 2017. Both of these events led to very low water levels in Salty Lagoon and the wetland areas to the west of Salty Lagoon.

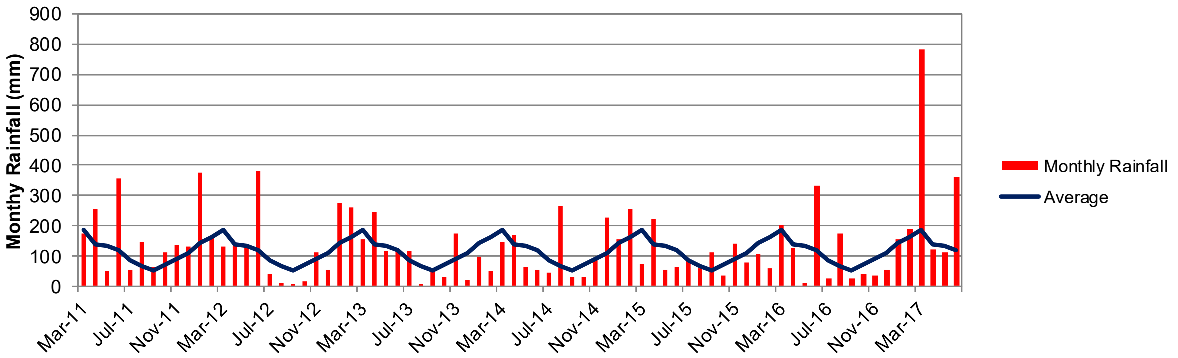


Figure 2.1 Monthly rainfall at the Evans Head BOM weather station for the extent of the project displayed against average monthly rainfall from the Woodburn BOM station (BOM 2017)

2.3.2 Permanent Water Quality Monitoring Stations

Over the course of the MPPC there were a number of gaps in the data from the PWQMS. These are either:

- Regular short-term gaps in the data set ranging from one 15 minute interval reading to over three hours;
- Gaps resulting from data loss;
- Gaps resulting from battery failure; or
- Gaps where erroneous data, occurring as a result of faulty water quality probes, have been highlighted within the dataset.

During the MPPC there were 18376 (8.1%) missed data points from the Salty Lagoon PWQMS and 6355 (2.8%) from the Salty Creek PWQMS.

As part of routine maintenance the logged results were compared in the field with data collected from a handheld water quality probe on a monthly basis. In general, the results correlated strongly.

Results from the Salty Lagoon PWQMS are presented in **Appendix B** and are discussed below.

Key findings from the logged dataset include:

- Freshwater input from Evans Head STP does not maintain water levels in Salty Lagoon. Evaporation, groundwater drawdown and runoff into Salty Creek have a greater impact.

- Salty Lagoon still drains into Salty Creek when water levels are above 1.80 m AHD, albeit very slowly.

- Conductivity variations in Salty Lagoon have reduced significantly since closure of the artificial channel but under a specific set of circumstances saline water can move from Salty Creek into Salty Lagoon.

- Flow from Salty Creek into Salty Lagoon is unlikely when the entrance berm to Salty Creek remains low.
- The key factors that influence dissolved oxygen (DO) concentration in Salty Lagoon are:
  - Diffusion: The surface of the water is exposed to the air and dissolves oxygen constantly through diffusion. For this reason, DO concentrations tend to be higher in surface waters.
  - Microalgal concentrations: Microalgae produce oxygen during the day through photosynthesis and consume it at night through respiration. Nutrient availability has an impact on DO concentrations indirectly through supporting microagal concentrations.
  - Light availability: This influences the photosynthetic activity of microalgae throughout the water column and attached to the benthos. Turbidity, therefore, is a key regulator of DO concentrations.
  - Wind and flow driven mixing: Mixing of the water column serves to bring well oxygenated water from the surface into lower parts of the water column. The stronger the wind or flow, the deeper the mixing. North and south winds have the greatest effect on Salty Lagoon due to the north-south orientation.
  - Water level: The depth of the water determines the impact of wind driven mixing and the availability of light at the bottom of the water column.
  - Salinity: The mechanism is not certain but there have been sharp reductions in DO concentration associated with saline water ingress in previous years.
- Although it is not apparent from the logged data, the water column in Salty Lagoon can be stratified with respect to DO concentration. At these times the water at the bottom of the water column can be hypoxic whilst the water at the surface is well oxygenated. This occurs most often when water levels are high and, therefore, is likely to occur with increasing regularity as a result of the closure of the artificial channel.
- The percentage of logged DO concentration measurements that are <1 mg/L has trended downwards since the closure of the artificial channel.
- There appears to be a mechanism of pH buffering in Salty Lagoon resulting in a tendency towards neutral pH. It is uncertain if this buffering mechanism is associated with natural features, deposition of buffering marine salts or long term use of buffering chemicals in the Evans Head STP.
- There is a relationship between water level in Salty Lagoon and the magnitude of daily temperature variation. When water levels are low, temperature variation tends to be greater. This can have a large impact on the overall ecology of Salty Lagoon, particularly during hot, dry summers. Water temperature impacts upon a number of other parameters such as DO and microalgal concentrations.
- Turbidity measurements fluctuate in response to various other factors such as wind driven sediment suspension and microalgal growth. Low water levels can contribute to the higher temperatures that encourage algal blooms and also increase the frequency of wind driven re-suspension of benthic material.

The Salty Creek PWQMS is important in the context of managing Salty Lagoon as it provides information about how water quality in Salty Creek can impact upon Salty Lagoon. The results from the Salty Creek PWQMS are presented in **Appendix B**. Key findings from the Salty Creek PWQMS include:

- The most important factor affecting the water level, pH and conductivity in Salty Creek is the status of its entrance.
- The water column in Salty Creek is often distinctly stratified.
- DO concentrations tend to be higher during periods of freshwater dominance and when water levels were low.
- Daily fluctuations in temperature are strongest when water levels are low.
- Turbidity measurements from the Salty Creek PWQMS are generally low, with periods of greater turbidity following seawater ingress and heavy rainfall.

2.3.3 Discrete Water Quality Samples

This section describes the results of discrete water quality samples collected during normal monthly water quality monitoring and extra water quality monitoring undertaken as part of the adaptive management protocols.

Some of the factors that have been found to influence nitrogen concentrations in Salty Lagoon and Salty Creek include seawater ingress, historical pollution and rainfall runoff. Current effluent discharge from the Evans Head STP does not appear to be a factor that strongly influences nitrogen concentrations in Salty Lagoon, as concentrations of total nitrogen (TN) at S2 (located closest to the STP) are often lower than those measured downstream.

The TN concentrations from all sites collected during the MPPC are displayed in **Figure 2.2**. The highest TN concentrations observed occurred during drought conditions in early 2014 and early 2017. In general, TN concentrations have reduced after heavy rainfall and increased during extended dry periods. This indicates that nitrogen stored in the sediment in Salty Lagoon is the major source of nitrogen in the system, not rainfall runoff or the release of treated effluent upstream. This observation is supported by a slight reduction in the average TN concentrations from the open water sites of Salty Lagoon since the highest averages were recorded in the year prior to June 2014 (**Figure 2.18**).

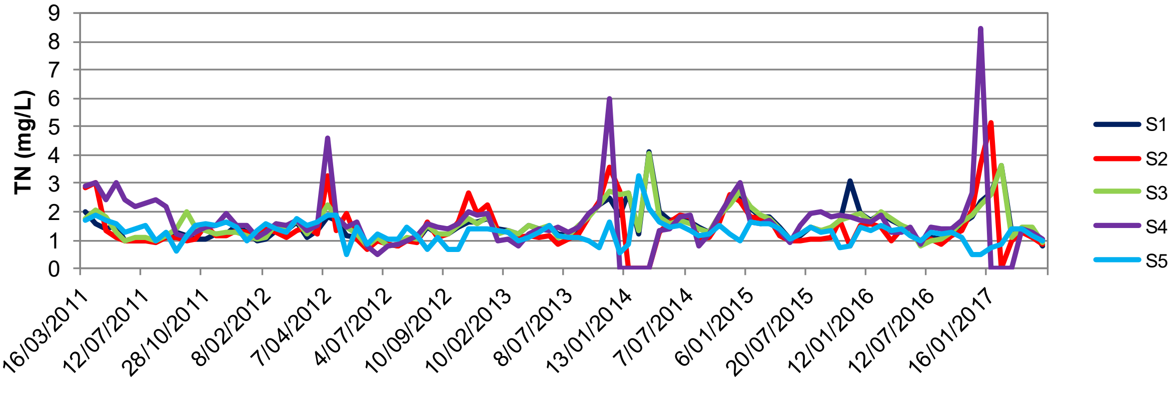


Figure 2.2 Time series of TN concentrations at all sites for the MPPC project

The highest dissolved inorganic nitrogen (DIN) concentrations recorded during the MPPC also occurred during drought periods (**Figure 2.3**). While the overall average DIN concentrations increased in the period after channel closure the annual average DIN concentrations appear to be trending downwards in the open water of Salty Lagoon (**Figure 2.20**).

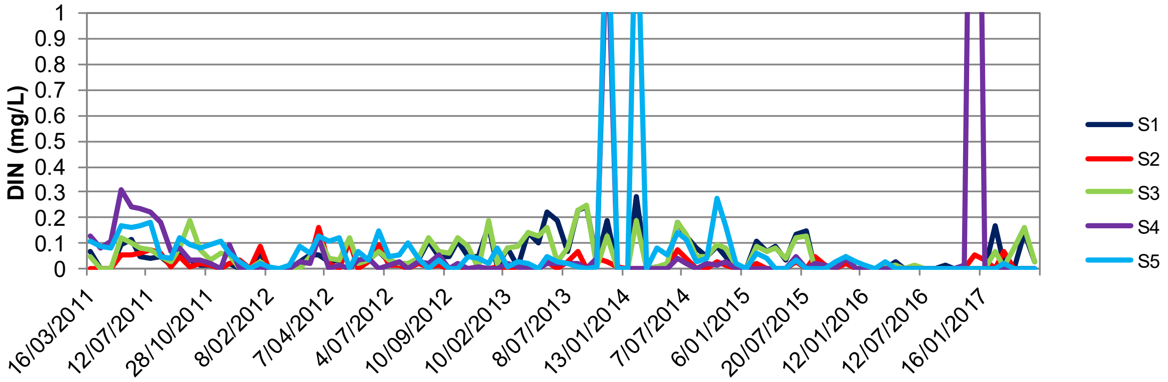


Figure 2.3 Time series of DIN concentrations at all sites for the MPPC project

2.3.3.1 Phosphorus

The highest phosphorus concentrations also occurred during drought conditions (**Figure 2.4**). Average total phosphorus and orthophosphate concentrations both increased in the post channel closure period at all the Salty Lagoon sites, mostly in response to the higher concentrations measured during the drought periods. However, in a similar fashion to the results for nitrogen, the average annual concentration of phosphorus has trended downwards in the open water of Salty Lagoon since the highest annual averages were measured in the year following channel closure (**Figure 2.15**). The data allows for some general observations:

- Site S2 is the site historically most influenced by discharged effluent from the Evans Head STP and is most often the site with the highest phosphorus concentration.
- Concentrations of phosphorus were highest at S1, S2 and S3 during the warmer months.
- TN and TP concentrations appear to have varied independently, indicating that the processes governing them are separate.
- For the majority of the results, the greater proportion of the total phosphorus present was present as orthophosphate. This has important implications for the growth of algal material, which requires phosphorus to be present in the bioavailable form of orthophosphate. However, the relationship between available phosphorus and algal concentrations is cryptic.

Phosphorus concentrations measured in Salty Creek have continued to reduce over the course of the MPPC (refer to results for S5 in **Figure 2.15**).

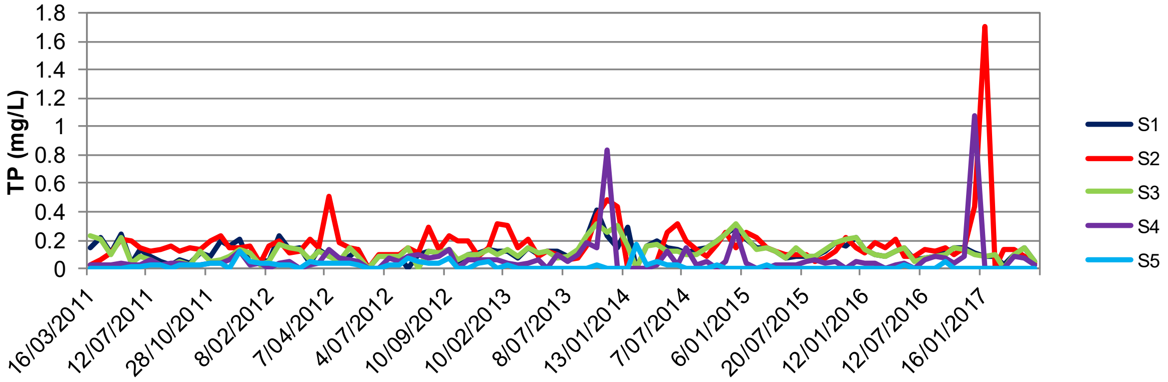


Figure 2.4 Time series of TP concentrations at all sites for the MPPC project

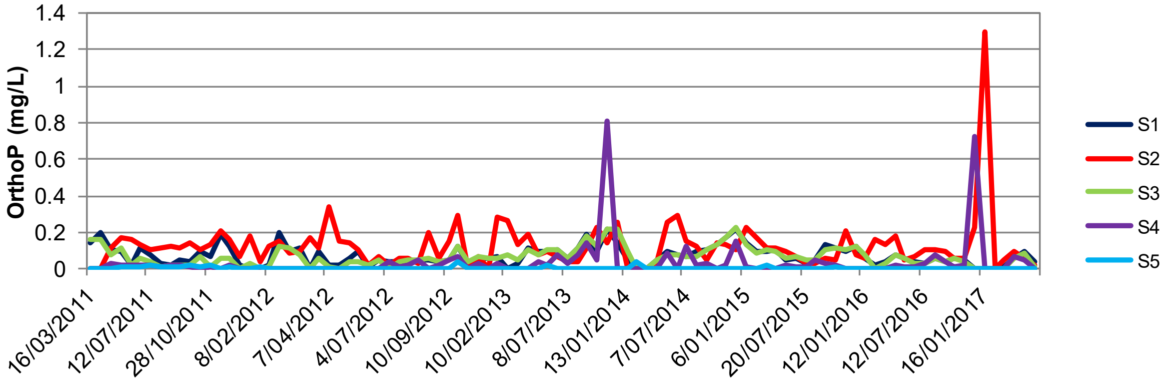


Figure 2.5 Time series of orthophosphate concentrations at all sites the MPPC project

2.3.3.2 Chlorophyll-a

The highest chlorophyll-a concentrations measured coincided with drought conditions and the highest nutrient concentrations (**Figure 2.6**). Average chlorophyll-a concentrations have increased at all sites in the post closure period (**Figure 2.12**) and although the trends are less clear, it appears that the very high concentrations measured during drought periods are the major factor driving this change. However, it is possible that the more stable freshwater conditions are contributing to an overall stabilisation of the microalgal population in the water column.

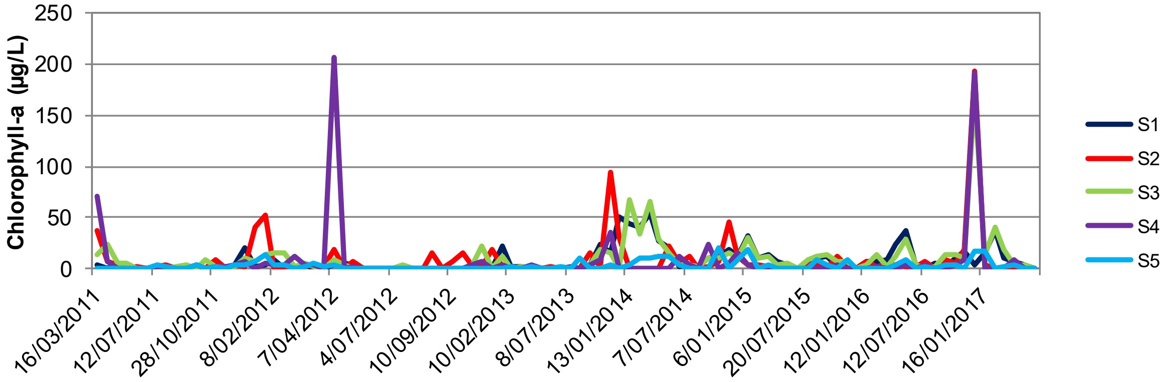


Figure 2.6 Time series of chlorophyll-a concentrations at all sites for the MPPC project

2.3.3.3 Blue Green Algae

Blue green algae have only been detected on two occasions during the MPPC. No patterns can be determined pre/ post closure in relation to blue green algae.

2.3.3.4 Faecal Indicator Organisms

There are no clear patterns to the variation in faecal indicator organism concentrations (**Figure 2.7** and **Figure 2.8**). Faecal indicator concentrations are mostly effected by rainfall and waterbird use of Salty Lagoon and Salty Creek. The sources of faecal pollution in Salty Lagoon are most likely to be terrestrial fauna and avifauna utilising the lagoon and its immediate catchment. The results do not suggest that discharge from the Evans Head STP or leaks from the Evans Head sewerage system are strongly influencing the concentrations of faecal indicator organisms.

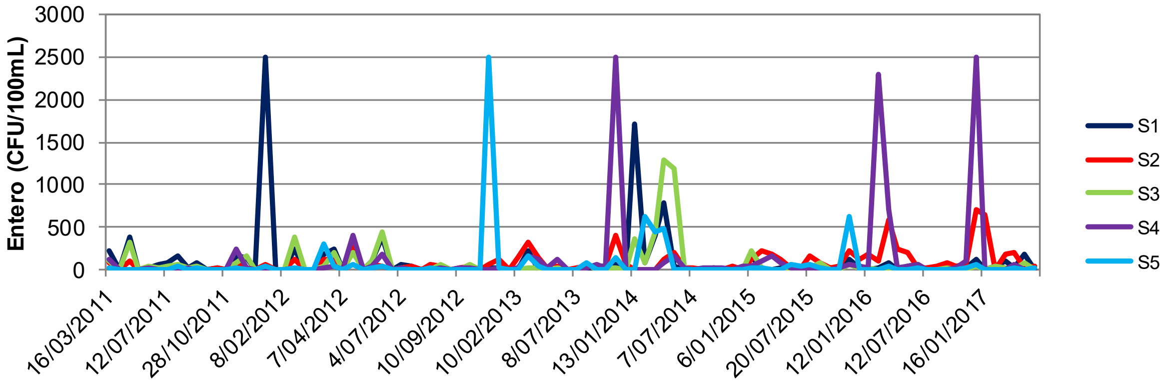


Figure 2.7 Time series of enterococcus concentrations at all sites for the MPPC project

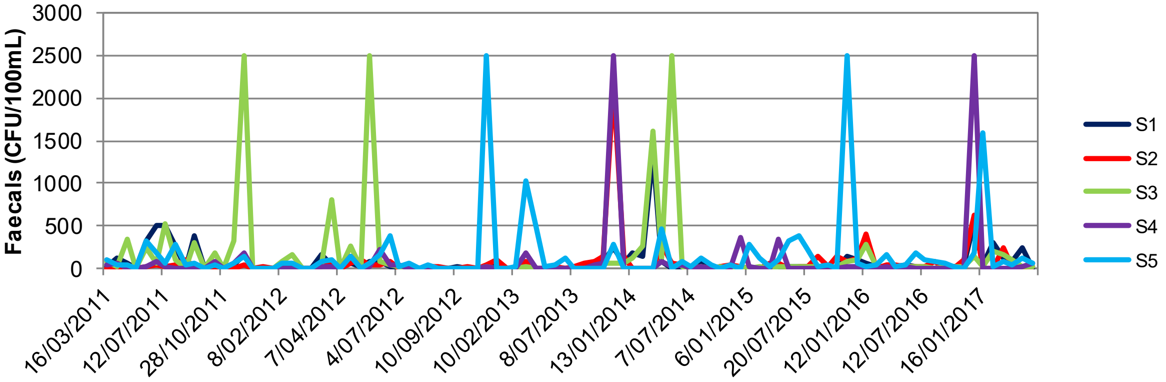


Figure 2.8 Time series of faecal coliform concentrations at all sites for the MPPC project

2.3.4 STP Discharge Monitoring

The vast majority of results from the Evans Head STP comply with the licence conditions set by the NSW EPA. The discharge from the Evans Head STP does not appear to increase the water levels in Salty Lagoon. There have been many occasions where water levels have decreased in Salty Lagoon at times of no rainfall and when Salty Lagoon is not flowing directly out to Salty Creek. In effect, STP discharge is not enough to maintain water levels and water losses to evaporation and groundwater are larger than the input from the STP.

In general, faecal coliform concentrations in discharged effluent are very low. The measured concentrations of faecal coliforms in the discharged effluent are typically lower than those measured in samples collected from Salty Lagoon as part of the MPPC project. This, in combination with the fact that faecal coliforms do not persist in the environment for a long period of time, indicates that it is highly unlikely that discharged effluent is contributing significantly to faecal coliform measurements in Salty Lagoon.

The concentrations of TN in discharged effluent are generally two to four times higher than those measured at any site within Salty Lagoon. Thus, it appears that the majority of the nitrogen in discharged effluent is processed by the ecosystems occurring along the drainage channel upstream of Salty Lagoon (as described in the ERMP project, Hydrosphere 2010b). It is also likely that dilution with unpolluted water from around the catchment contributes to this effect. It is possible that elevated nitrogen concentrations around Salty Lagoon may be partially maintained in the long term by the input from the Evans Head STP.

In contrast to TN concentrations, the concentrations of TP in discharged effluent are generally comparable to those measured at S2, where the drainage channel opens out into Salty Lagoon and where phosphorus concentrations are highest. However, it is not likely that current phosphorus concentrations in discharged effluent are sufficient to maintain the phosphorus concentrations in the waters of Salty Lagoon. Hydrosphere (2010b) found an increasing trend of TP concentration along the drainage channel from the STP to Salty Lagoon and linked it to the release of phosphorus stored in sediments after years of effluent discharge rather than a lack of ecosystem processing of phosphorus released from the STP along the drainage channel. It is likely that this is still the case and that it will continue for some time into the future.

2.3.5 Comparison against Rehabilitation Targets

Closure of the artificial channel was anticipated to have a dramatic effect on the hydrology and water quality of Salty Lagoon (Hydrosphere 2011). Alongside the general goal of improved water quality Hydrosphere (2010a and 2011) listed a number of anticipated benefits and changes resulting from channel closure. These followed on from an ecosystem response model (ABER 2010) and are as follows:

- More natural hydrology and salinity regime including higher water levels – 1.9 m AHD in Salty Lagoon for approximately 63% of the time.
- A reduced magnitude and rate of water level variation.
- Less frequent saline water ingress.
- Improved productivity of the benthic microalgal assemblage resulting in nutrient assimilation reduced algal blooms and reduced potential for deoxygenation.
- A reduced water column algal biomass.
- Improved water quality generally with a risk of poor water quality episodes in the period immediately following the channel closure.
- Less temperature variability.
- Reduced average and maximum pH values.
- Generally higher DO concentrations with a reduction in dramatic DO crashes and more predictable diurnal variation of DO.
- Potential for low DO occurring as a result of high BOD of the marsh sediments and/or increased photo-oxidation of tannins in the warmer months.
- Reduced probability of wind driven turbidity increases and no draining related turbidity spikes.
- Reduced TP concentrations over time resulting from greater benthic microbial uptake and higher burial rates.
- Poor water quality episodes around high risk periods such as low water levels and high temperatures.
- Reduced TN concentrations and continued dominance of DON.
- Reduced severity of Salty Creek drawdown during draining events.
- Less protracted entrance opening of Salty Creek.

In general, the data indicates that many of the predicted changes are being realised but that some are not. The data from the post-closure period are strongly affected by extreme dry weather between September 2013 and March 2014, and November 2016 and January 2017 when water quality became very poor and water levels very low. There was no comparable weather scenario during the pre-closure period. This is important to consider in the context of considering changes to water quality and hydrological conditions.

A comparison of the results obtained during the MPPC and the predicted changes to the Salty Lagoon environment follows.

More natural hydrology and salinity regime including higher water levels – 1.9 m AHD in Salty Lagoon for approximately 63% of the time.

This change has been realised. From January 2011 until channel closure in June 2012 the mean water level was 1.33 mAHD and the water level was >1.85 mAHD for approximately 2% of the time.

The average water level for the period from the closure of the artificial channel until the end of the MPPC in June 2017 is 1.82 mAHD and the water level was >1.85 mAHD for approximately 64% of the time.

A reduced magnitude and rate of water level variation.

There has been a reduction in the variation of water level in Salty Lagoon. The difference between the 10^{th} and 90^{th} percentile water levels since the channel closure has reduced from 0.65 mAHD to 0.47 mAHD.

Less frequent saline water ingress.

This anticipated change has been realised. There were five incidences of saline water ingress into Salty Lagoon in the five years from closure of the artificial channel until the end of the MPPC. In the 14 months prior to closure there were over 20. Since closure the average logged conductivity has reduced from 15.97 mS/cm to 2.04 mS/cm and the 90^{th} percentile conductivity value has reduced from 44.1 mS/cm to 6.16 mS/cm.

Improved productivity of the benthic microalgal assemblage resulting in nutrient assimilation reduced algal blooms and reduced potential for deoxygenation.

It is uncertain if the productivity of the benthic macroalgal assemblage has changed since the closure of the artificial channel. The data that would be used to assess this is conflicting. For example, the average logged DO concentrations at the bottom of the water column have reduced (from 4.63 mg/L to 3.84 mg/L) and variation in DO concentrations at the bottom of the water column has reduced (standard error of the mean has reduced from 0.013 to 0.008) since the channel closure. However, turbidity has reduced (**Figure 2.9**) and the reduced incidence of saline water ingress has created a more stable environment for benthic macroalgae. Average DO concentrations at the surface of the water column have remained relatively stable in the open water area of Salty Lagoon since channel closure (**Figure 2.10**) but nutrient concentrations have increased slightly (**Figure 2.11**).

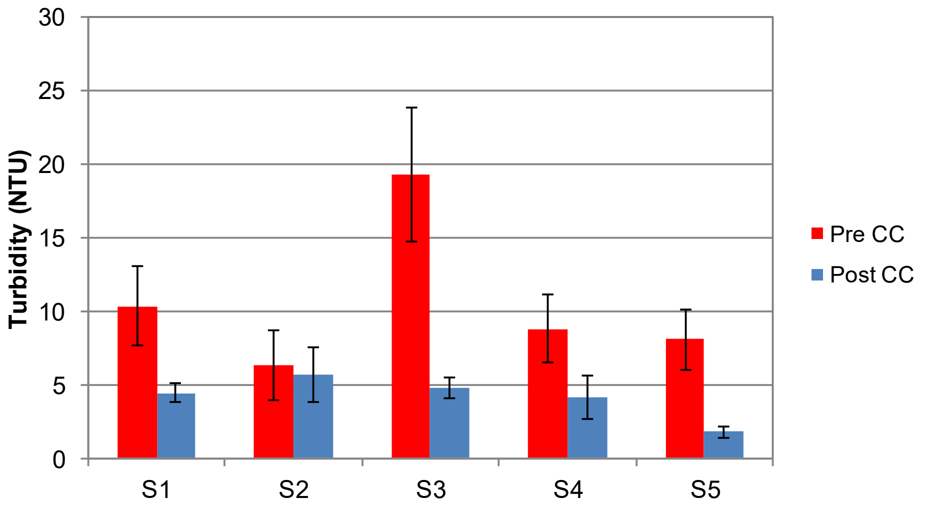


Figure 2.9 Mean ± SE turbidity concentrations at all sites before and after channel closure

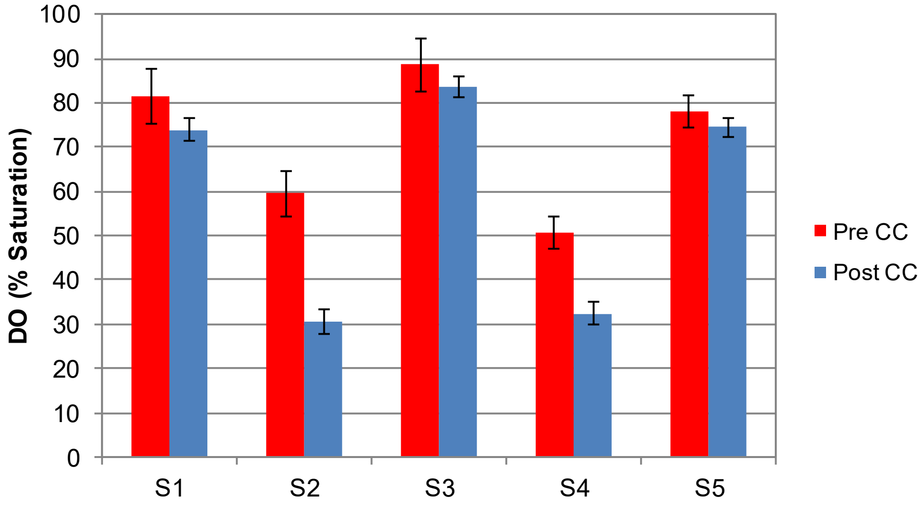


Figure 2.10 Mean ± SE DO concentrations at all sites before and after channel closure

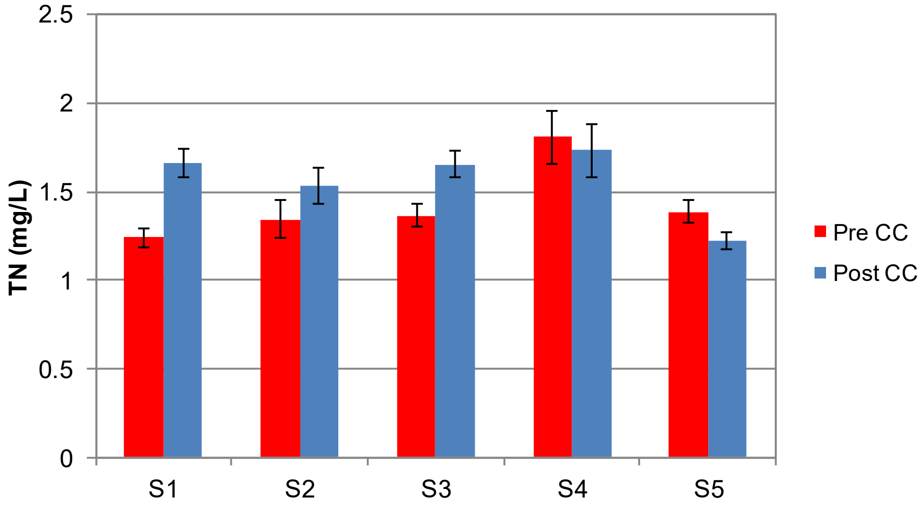


Figure 2.11 Mean ± SE TN concentrations at all sites before and after channel closure

A reduced water column algal biomass.

This anticipated change has not been realised. Using chlorophyll-a as a proxy for water column algal biomass there has been a significant increase in algal biomass in the open water of Salty Lagoon (**Figure 2.12**). This is likely to be related to a number of other changes, including increased nutrient concentrations and a more stable freshwater environment.

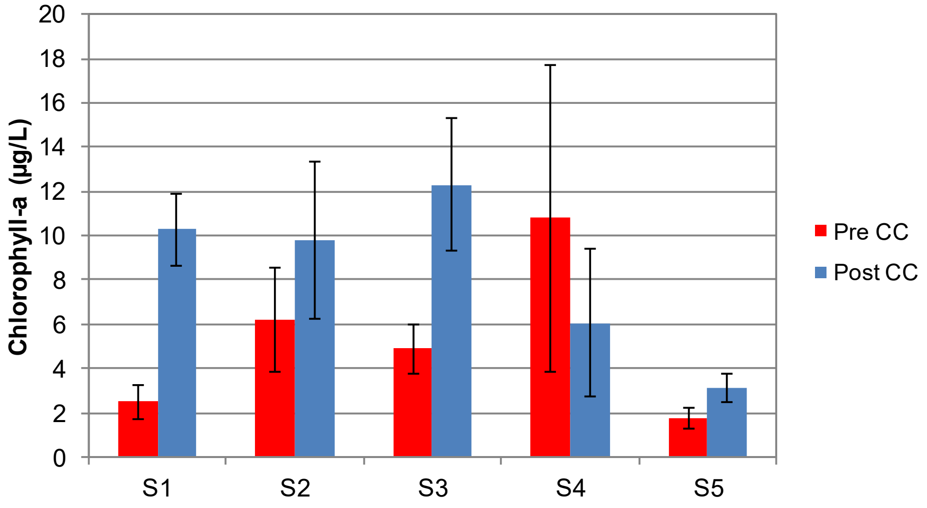


Figure 2.12 Mean ± SE chlorophyll-a concentrations at all sites before and after channel closure

Improved water quality generally with a risk of poor water quality episodes in the period immediately following the channel closure.

With respect to nutrient and microalgal concentrations there has not been an improvement in the average water quality conditions since the closure of the artificial channel. With respect to DO concentrations there has not been a significant change in the average condition since channel closure, although the DO concentrations improved in the later years of the MPPC. With respect to turbidity and pH there has been an improvement and stabilisation of water quality. The risk of poor water quality episodes in the period following the channel closure was realised during the drought conditions that persisted between October 2013 and March 2014, and January and March 2017. Poor water quality conditions resulted in algal blooms but have not resulted in a fish kill or other ecological incident.

Less temperature variability.

The logged data from the Salty Lagoon PWQMS indicates that this has been realised (see **Appendix B**). The standard error of the mean for temperature at the Salty Lagoon PWQMS reduced from 0.021 to 0.012. However, the difference between the 10th and 90th percentile logged temperatures has increased slightly since the closure of the artificial channel (from 11.78 °C to 12.35 °C).

Reduced average and maximum pH values.

There has been a significant reduction in the average measured surface water pH at sites S2 and S4 since channel closure but only slight reductions at S1 and S3 (**Figure 2.13**). Since closure of the channel there have been no incidences of the high pH maxima that occurred with seawater ingress prior to closure and there has been less variability in the pH results in surface waters.

Prior to channel closure the average logged pH was 6.88 with a 90th percentile value of 7.42 and a 10th percentile value of 6.34. From channel closure until the end of the MPPC in June 2017 the average logged pH increased to 7.02 with a 90th percentile value of 7.40 and a 10th percentile value of 6.4.

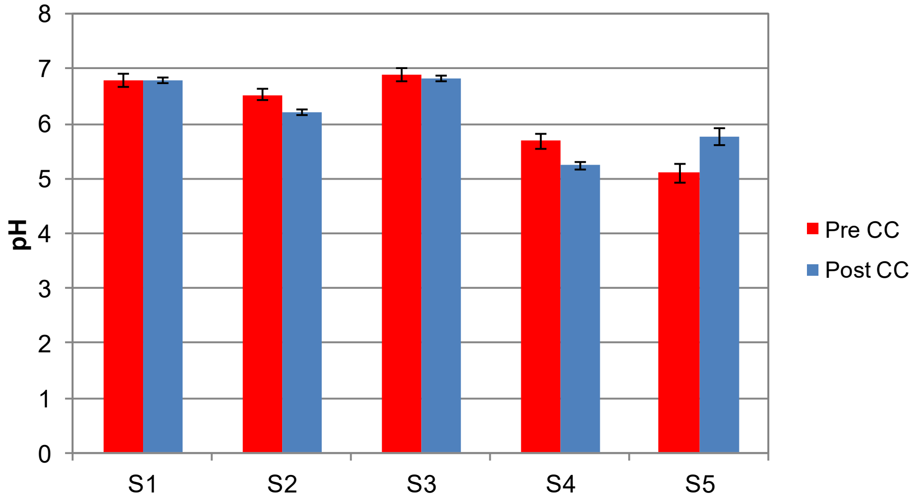


Figure 2.13 Mean ± SE pH at all sites before and after channel closure

Generally higher DO concentrations with a reduction in dramatic DO crashes and more predictable diurnal variation of DO.

The DO concentrations in surface waters have not increased since channel closure (**Figure 2.10**). However, for the period of the MPPC prior to channel closure the DO concentrations measured in surface waters were relatively healthy in the open water of Salty Lagoon. In addition, the average DO concentrations in the open water area of Salty Lagoon have improved over the last two years of the MPPC, indicating a possible trend towards improved DO concentrations (**Figure 2.14**).

At sites S2 and S4 there has been a significant reduction in the DO concentrations measured since the closure of the artificial channel. However, this is thought to reflect the natural conditions at these sites and probably reflects the more natural hydrological regime since channel closure.

While regular periods of low DO concentrations measured at the Salty Lagoon PWQMS have continued post channel closure, the DO crashes that were associated with fish kill events prior to channel closure have not eventuated.

Diurnal variation in DO concentrations is evident in the data from the PWQMS (**Appendix B**) but when water levels are high, wind driven mixing and freshwater flow are the dominant features driving DO concentrations.

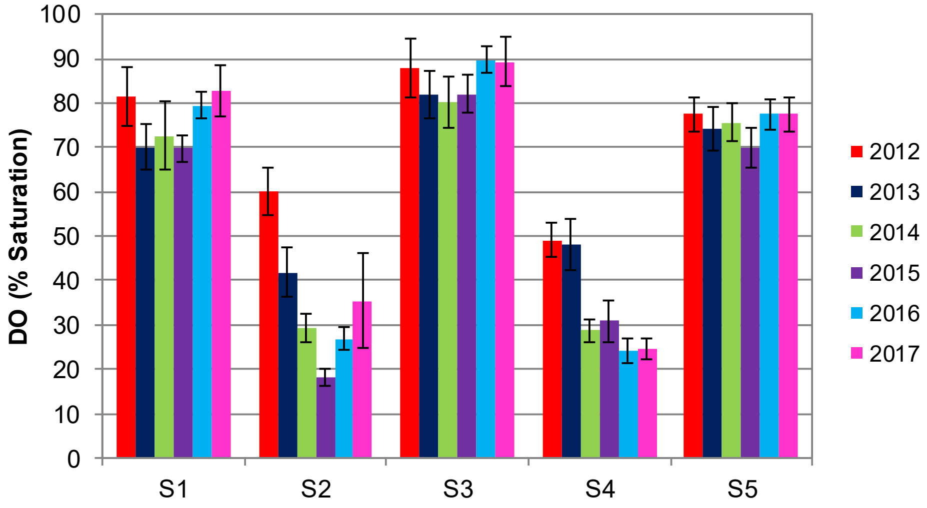


Figure 2.14 Mean ± SE DO concentrations at all sites for the annual reporting periods

Potential for low DO occurring as a result of high BOD of the marsh sediments and/or increased photo-oxidation of tannins in the warmer months.

These anticipated changes have been realised to an extent and provide a good insight into the DO patterns that have been observed since channel closure. Persistent low DO concentrations at sites S2 and S4, particularly since channel closure are likely to be widely related to the BOD of the rich organic sediments at these sites, along with the naturally low DO runoff from the catchment upstream of these sites. Also, although the pattern is not entirely clear, maximum daily DO concentrations in the summer months have tended to be lower than the winter months since channel closure.

Reduced probability of wind driven turbidity increases and no draining related turbidity spikes.

Turbidity has reduced significantly at S1 and S3 since channel closure (**Figure 2.9**). There have been no draining related turbidity spikes since channel closure and wind driven turbidity increases have been reduced with the exception of the period of very low water levels between December 2013 and March 2014, and January and March 2017.

Reduced TP concentrations over time resulting from greater benthic microbial uptake and higher burial rates.

This prediction has not yet been realised (**Figure 2.15** and **Figure 2.16**). However, there is a trend towards reduced TP concentrations in the open water part of Salty Lagoon since channel closure. **Figure 2.17** shows that between the pre channel closure monitoring and final post channel closure monitoring year, there has been a small decrease in the average TP concentrations at S1 and S3, and increases at S2 and S4.

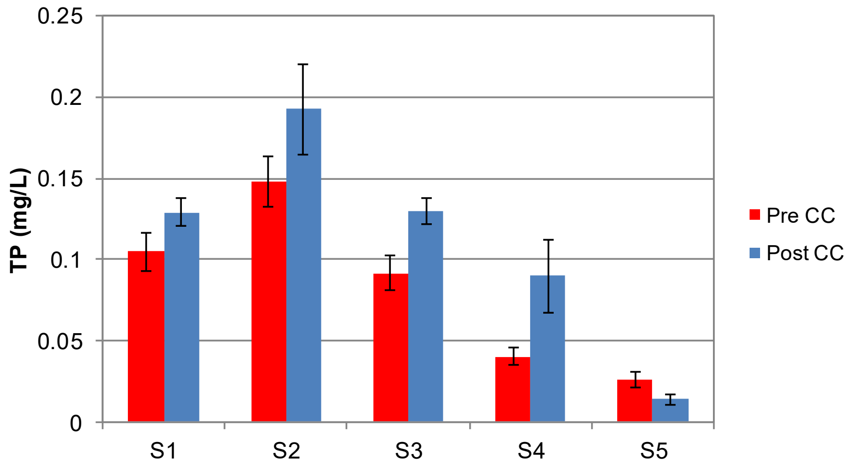


Figure 2.15 Mean ± SE TP concentrations at all sites before and after channel closure

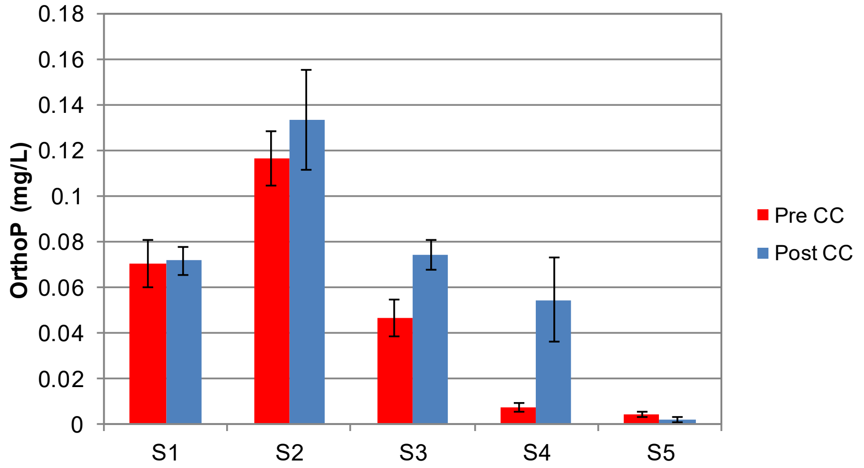


Figure 2.16 Mean ± SE orthophosphate concentrations at all sites before and after channel closure

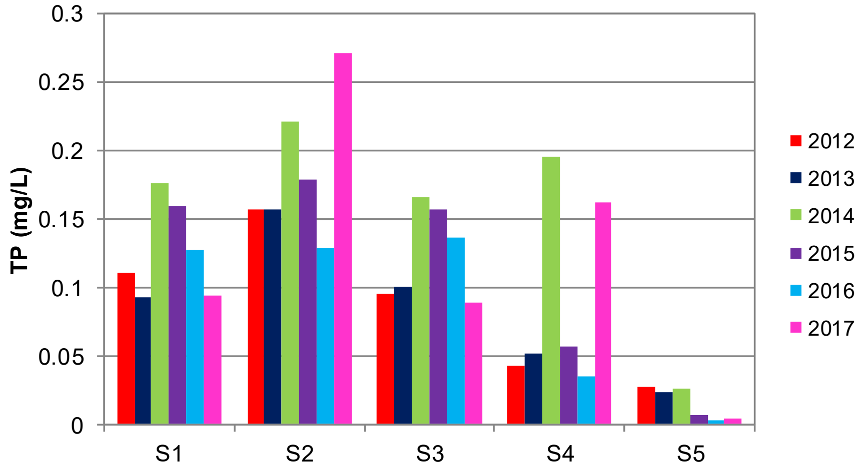


Figure 2.17 Mean ± SE TP concentrations at all sites for the annual reporting periods

Poor water quality episodes around high risk periods such as low water levels and high temperatures.

This predicted risk has been realised. During the summer months of 2013/2014 and 2016/2017 water quality became very poor when water levels were at extreme lows and temperatures were very high. There are a number of factors that lead to poor water quality scenarios during periods of low water levels. These are:

- Increased nutrient concentrations resulting from evaporative distillation as water levels reduce.
- Increased temperature variation and increased daily maximum temperatures due to reduced overall volume of water.
- Increased algal concentrations and increased frequency of algal bloom conditions resulting from increased nutrient availability and increased temperatures.
- Increased turbidity resulting from wind driven resuspension of sediments and increased algal concentrations.
- Reduced minimum DO concentrations due to increased algal respiration at nights.

Reduced TN concentrations and continued dominance of DON.

The predicted reduced TN concentrations have not yet been realised (**Figure 2.18**). However, the extreme dry conditions that have characterised a large proportion of the post closure period have clearly contributed to higher average nitrogen concentrations.

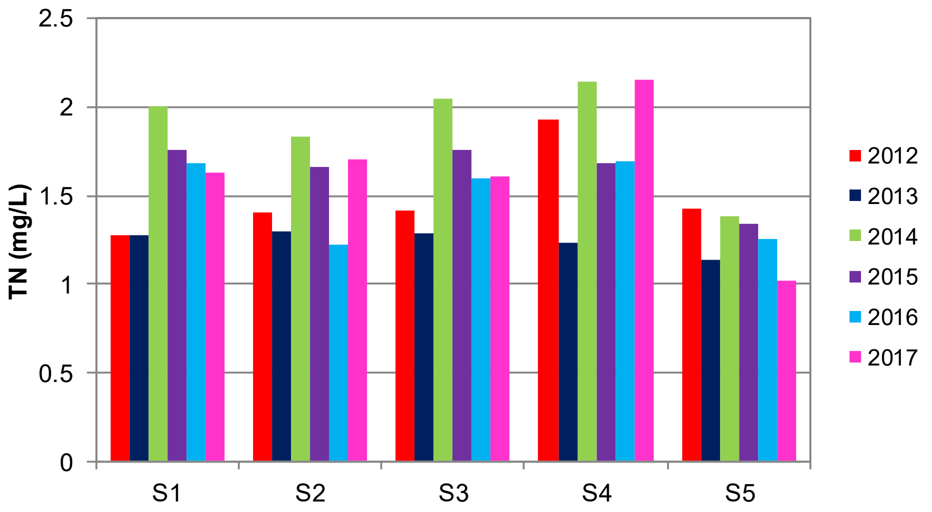


Figure 2.18 Mean ± SE TN concentrations at all sites for the annual reporting periods

The predicted continued dominance of DON as the major form of nitrogen in samples has continued post closure of the artificial channel, although at S1 and S3 the proportion of TN as DIN increased slightly in the post closure period.

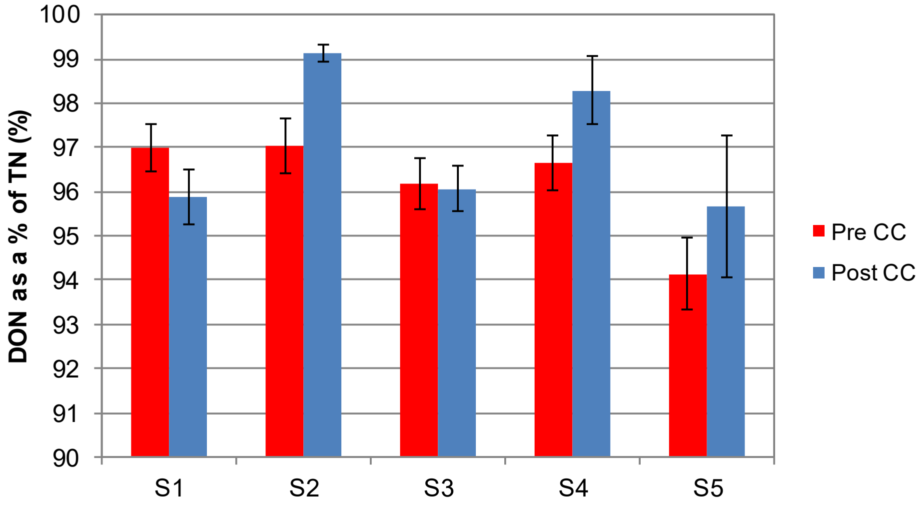


Figure 2.19 Mean ± SE DON concentrations as a percentage of TN at all sites before and after channel closure

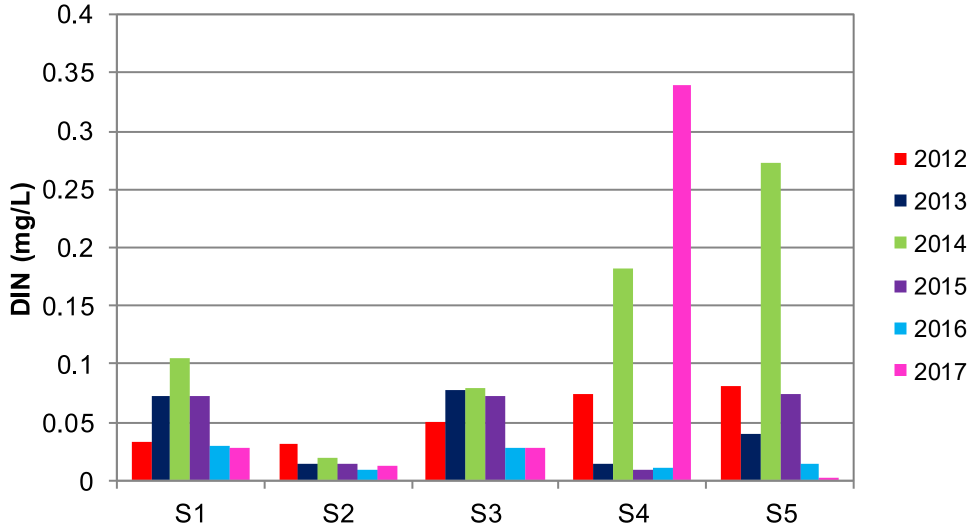


Figure 2.20 Mean ± SE DIN concentrations at all sites for the annual reporting periods

Reduced severity of Salty Creek drawdown during draining events.

Although the highest maximum drawdown rates have occurred during the post closure period this change has been realised. The 98th and 95th percentile values for drawdown over 15 minutes and 1 hour at the Salty Creek PWQMS were all higher from the pre-channel closure period than the post-channel closure period (**Table 2.4**).

Table 2.4 Summary of drawdown events from the Salty Creek PWQMS

Statistic	Drawdown over 15 mins		Drawdown over 1 hour	
	Pre CC	Post CC	Pre CC	Post CC
Max Drawdown	5.5	8.4	13.7	15.4
98th % Drawdown	0.9	0.4	2.2	1.2
95th % Drawdown	0.4	0.2	1.1	0.5

Less protracted entrance opening of Salty Creek.

This anticipated change has not been consistently realised. Although it is difficult to assess the change due to differences in the conditions that cause entrance opening and closing there appears to have been a change in the dynamics of the entrance and the trends of opening and closing. Since channel closure the entrance to Salty Creek has more often been very shallow and narrow and only very slowly draining. Prior to channel closure the entrance was more likely to close completely but when open the entrance was more likely to be deeper and/or wider.

The minimum level of Salty Creek during the pre-closure period was 0.963 mAHD and the 2nd percentile level was 1.0 mAHD. In the post closure period the minimum and 2nd percentile levels were higher, 1.099 mAHD and 1.185 mAHD respectively. These figures indicate that the entrance to Salty Creek has been opened to a lesser extent in the post-closure period.

The entrance to Salty Creek has been more stable over the last two years of the MPPC. In the period from March 2011 until channel closure in July 2012, the entrance opened 17 times. In the five years from channel closure until the end of the MPPC the entrance opened a total of 39 times, approximately half as frequently.

3. Macroinvertebrates

3.1 Introduction

Benthic macroinvertebrates are part of all aquatic systems, and fulfil various roles in the ecosystem and food chain. Benthic macroinvertebrate communities are known to respond, over relatively short timeframes, to changes in the physical, chemical and biological makeup of ecosystems. Different species of benthic macroinvertebrate communities are more or less tolerant to particular environmental conditions such as nutrient availability, water quality, depth, flow and various classes of pollution. For this reason they are widely utilised as an indicator of ecosystem health status and change (Boulton & Brock 1999).

In Salty Lagoon, benthic macroinvertebrate communities have previously been monitored to assess the effects of improvements to the operation and discharge from the Evans Head STP (Hydrosphere 2010b). The closure of the artificial channel between Salty Lagoon and Salty Creek was predicted to improve the diversity and robustness of communities and lead to related changes in the distribution and abundance of benthic macroinvertebrates (Hydrosphere 2010a). As a part of the MPPC project, benthic macroinvertebrate communities were monitored to confirm predicted changes, inform assessments of ecosystem health and adaptive management and to contribute to the overall picture of medium to long term ecosystem change in Salty Lagoon following the closure of the artificial channel.

3.2 Methods

3.2.1 Site Location

Macroinvertebrates were collected from four sites within the Salty Lagoon (referred to as BM1 – BM4 and displayed in **Illustration 2.1**). The sites were distributed at points around the study area that broadly reflect the different physical, chemical and biological processes that occur in Salty Lagoon. The four sites differ in respect to the benthic material present and the key physical, chemical and biological processes that drive them. For this reason the monitoring is designed to assess changes within sites over time as opposed to changes between sites.

Benthic macroinvertebrates were sampled once per season throughout the MPPC program (25 events in total). At each site, three benthic cores were collected at horizontal intervals of between one and two metres. The cores were taken using a 10 cm diameter round corer inserted to a depth of 10 cm. Cores were field rinsed over a one millimetre sieve using water from the immediate environment, prior to being transferred into a labelled sample bag with minimal water. Once all samples had been collected they were fixed with 70% ethanol solution and transported to the laboratory.

3.2.2 Sample Processing

At the laboratory, samples were re-rinsed over a one millimetre sieve and transferred into jars in a 70% ethanol solution. Samples were sorted over a binocular microscope and all fauna removed, identified to family level (subfamily level for non-biting midges [family – Chironomidae] and subclass for springtails [Collembola]), counted and stored. Pupating individuals were not included in counts, nor were invertebrates known to be terrestrial or restricted to the water surface. Sorted sediment was retained and 20% of the sorted sample checked for missed animals. If animals were found a further 20% was re-sorted until such time as no animals were found.

A detailed description of methods and sites is provided in GeoLINK (2017a).

3.3 Results and Discussion

3.3.1 Diversity

A total of 26 macroinvertebrate taxa were identified during the MPPC program. A list of recorded taxa and the number of individuals recorded during each reporting period is provided in **Appendix C**. The number of all taxa collected and the number of individuals recorded each survey event is presented in **Table 3.1**.

Of the 26 recorded taxa, seven have only been observed in one of the 25 seasonal surveys undertaken. Only 14 of the 26 taxa were collected during the five surveys prior to channel closure. Twenty-three taxa have been collected in the 20 surveys since channel closure. Only one of the 26 taxa collected (*Capitellidae*) has been observed in each of the 25 surveys. One of the taxa has been collected in 24 of the 25 surveys (*Chironominae*) and two in 18 of the 25 surveys (*Hydrobiidae* and *Ceratopogonidae*). The greatest number of taxa were recorded towards the end of the MPPC in the summer 2017 (13 taxa) and spring 2016 (12 taxa) surveys.

Table 3.1 Total Number of Benthic Macroinvertebrate Taxa and Individuals Captured During Each Survey

Survey	*Number Taxa*	*Number of Individuals*
Autumn 2011	6	43
Winter 2011	10	143
Spring 2011	7	14
Summer 2012	6	66
Autumn 2012	8	137
Winter 2012	9	43
Spring 2012	10	105
Summer 2013	7	159
Autumn 2013	8	303
Winter 2013	6	79
Spring 2013	11	136
Summer 2014	10	270
Autumn 2014	8	418
Winter 2014	10	56
Spring 2014	10	110
Summer 2015	8	66
Autumn 2015	8	50
Winter 2015	9	283

Survey	Number Taxa	Number of Individuals
Spring 2015	9	84
Summer 2016	8	133
Autumn 2016	7	192
Winter 2016	10	425
Spring 2016	12	451
Summer 2017	13	564
Autumn 2017	7	168

The diversity of taxa in macroinvertebrate samples varied within sites over time. However, there are no obvious patterns in the variation of species diversity with respect to either seasonal changes or environmental conditions at the time of sampling. The number of macroinvertebrate taxa recorded at all sites in all surveys during the MPPC program is displayed in **Figure 3.1**. These graphs show a slight trend towards an increase in diversity at all sites over the course of the MPPC project.

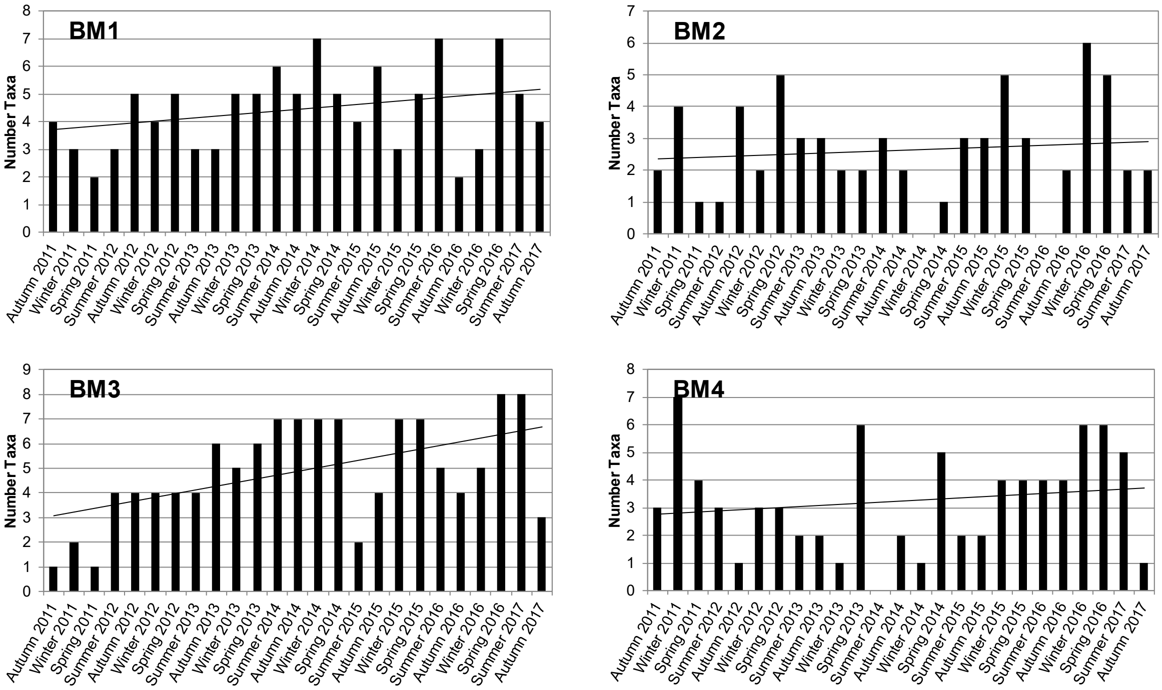


Figure 3.1 Number of macroinvertebrate taxa at all sites in all surveys during the MPPC project

With respect to the whole Salty Lagoon system, the clearest changes over time have been the increase in the number of *Chironominae*, *Tanypodinae*, *Leptoceridae* and to a lesser extent *Ceratopogonidae* captured; and a reduction in the number of *Spionidae* and *Capitellidae* (**Figure 3.2**). Over the course of the MPPC the *Capitellidae* were found mostly at BM3 (corresponding to the open water discrete water quality site S3 in Salty Lagoon) and the reduction in observed abundance is likely to reflect the greater depths and more stable lower salinity since the closure of the artificial channel. A number of taxa have now been observed in numbers at all four sites, including the *Chironominae*, *Tanypodinae* and *Ceratopogonidae*. These taxa appear to be adapting well to changing conditions.

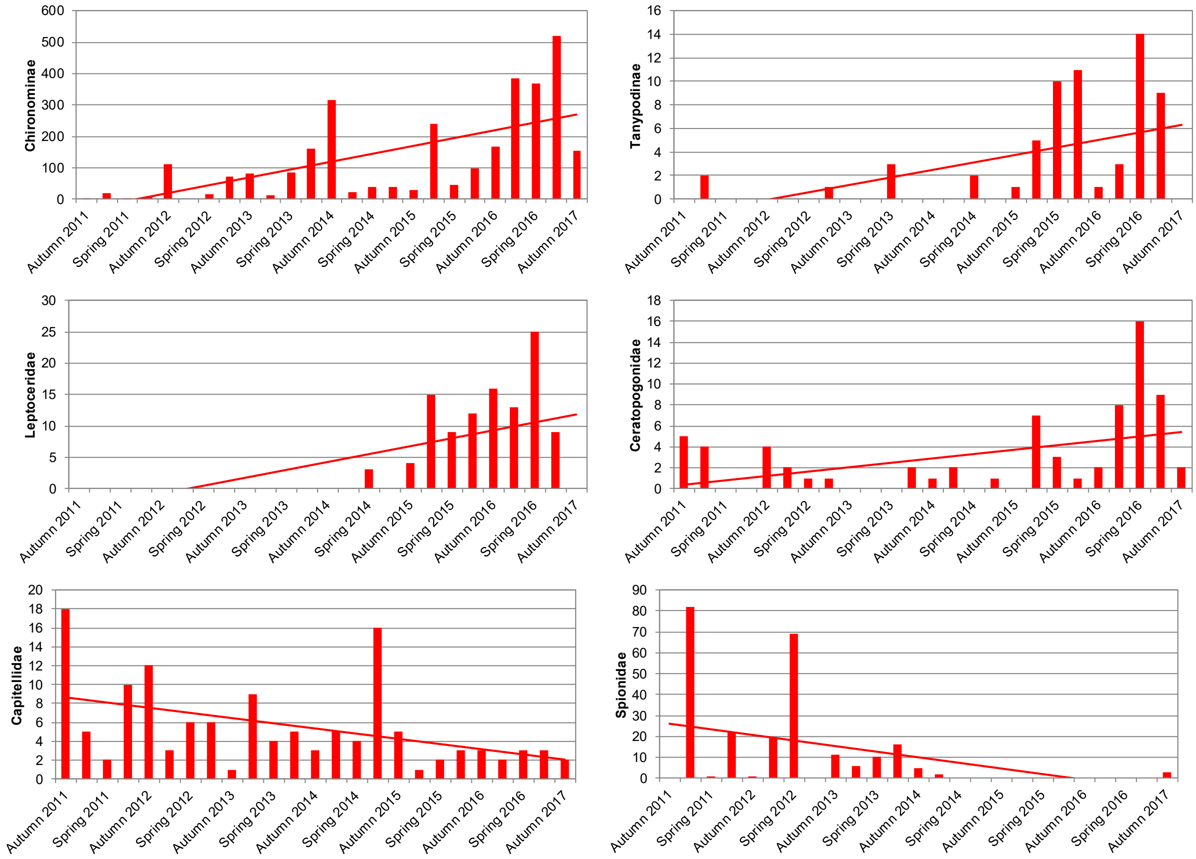


Figure 3.2 Numbers of individual taxa per survey for all surveys during the MPPC project

3.3.2 Abundance

Over the course of the MPPC 4502 individual macroinvertebrates were captured. The most common taxa were the *Chironominae* (2992), *Mytilidae* (326), *Hydrobiidae* (288) and the *Spionidae* (247). The numbers of benthic macroinvertebrates captured at each site have varied over time (**Figure 3.3**). However, again there are no strong patterns evident in the data set, despite a week trend towards increasing abundance at all sites over the course of the MPPC program.

At BM1 (which corresponds with the open water discrete water quality monitoring site S1 in Salty Lagoon) there does not appear to be a distinct trend with respect to overall abundance. However, except for large numbers of *Spionidae* observed in the winter 2011, *Mytilidae* observed in the autumn 2013 and *Chironominae* in the summer 2014, autumn 2014 and summer 2017 surveys, the numbers have been relatively stable since the beginning of the MPPC. There has been a reduction in the numbers of brackish water taxa, such as *Spionidae*, and an increase in the captures of *Tanypodinae*, *Leptoceridae* and *Chironominae* (all predominantly freshwater taxa) over time indicating a move towards a more stable freshwater environment (**Figure 3.4**, **Figure 3.5**, **Figure 3.6** and **Figure 3.7**).

At BM2 (which corresponds with the south-east drainage channel at discrete water quality monitoring site S2) there does not appear to be a distinct trend with respect to overall abundance (**Figure 3.3**). The majority of the variation in the total number of individuals is explained by spikes in the numbers of *Chironominae* and, to a lesser extent, *Hydrobiidae* captured. Despite this, there is an increasing trend in the numbers of *Chironominae* over the course of the MPPC (**Figure 3.4**). While the observed variation is not adequately explained by the collected environmental factors, this site dried out completely on two occasions during the MPPC (summer 2014 and summer 2017) leading to temporary collapse in the macroinvertebrate populations. Prior to the site drying out in summer 2017 there appeared to be an increasing trend in the numbers of Planorbidae (**Figure 3.9**).

At BM3 (which corresponds with the open water discrete water quality monitoring site S3 in Salty Lagoon) there is no apparent pattern to the overall variation of abundance (**Figure 3.3**). As with the other sites the variation is mostly explained by short term spikes in the numbers of individual taxa. However, there are some indications of a return to a more stable freshwater ecology, such as a reduction in the number of saltwater tolerant taxa such as *Spionidae* and *Capitellidae* (**Figure 3.7** and **Figure 3.8**) and an increase in the numbers of freshwater taxa such as *Chironominae*, *Tanypodinae* and *Leptoceridae* (**Figure 3.4**, **Figure 3.5** and **Figure 3.6**) since the closure of the artificial channel. In addition, during the latter 2016 and 2017 reporting periods, the first individuals were collected from the predominantly freshwater taxon *Ecnomidae*.

At BM4 (which corresponds with discrete water quality monitoring site S3 in the north-west of Salty Lagoon) there is a weak trend towards an increase in overall abundance (**Figure 3.3**), though abundances have generally been low throughout the MPPC program. This site also dried out completely on two occasions during the MPPC (summer 2014 and summer 2017) leading to a collapse of macroinvertebrate populations. At BM4 there has also been a shift in the dominant taxa, from *Hydrobiidae* to *Chironominae* and *Ceratopogonidae* since closure of the artificial channel (**Figure 3.4** and **Figure 3.10**).

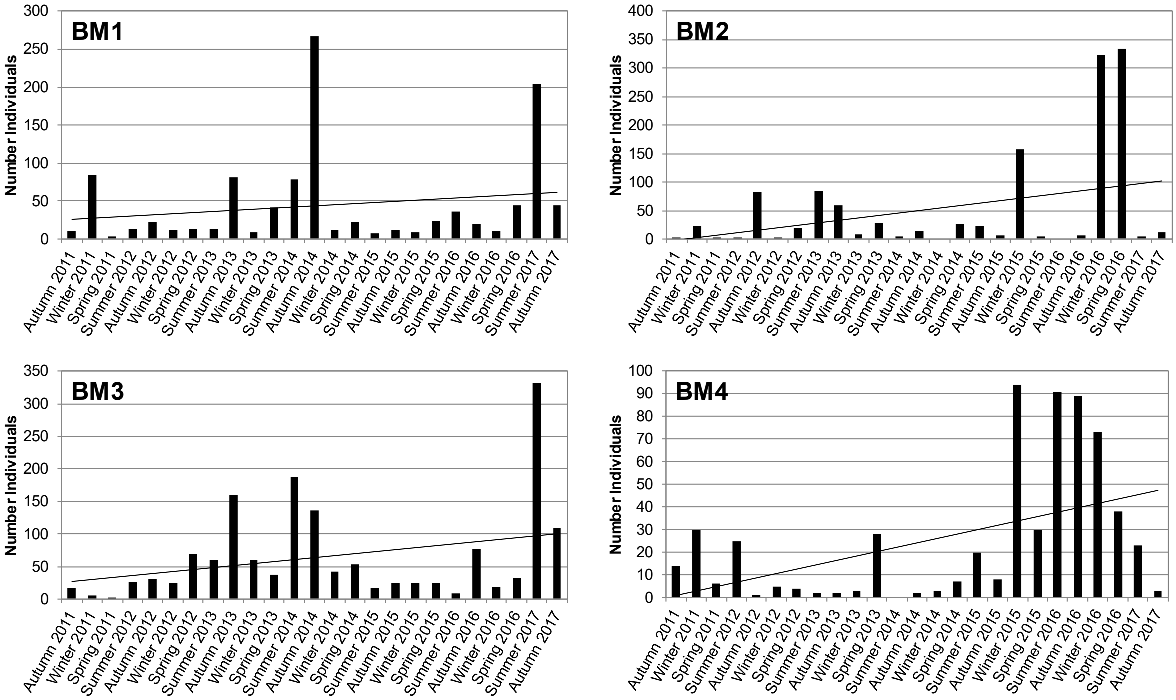


Figure 3.3 Number of macroinvertebrate individuals at all sites in all surveys during the MPPC program

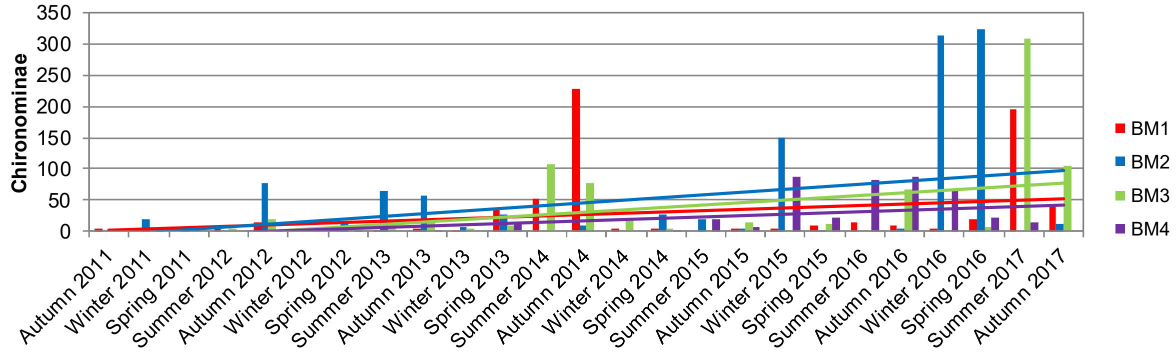


Figure 3.4 **Number of *Chironominae* captured at each site during each survey of the MPPC**

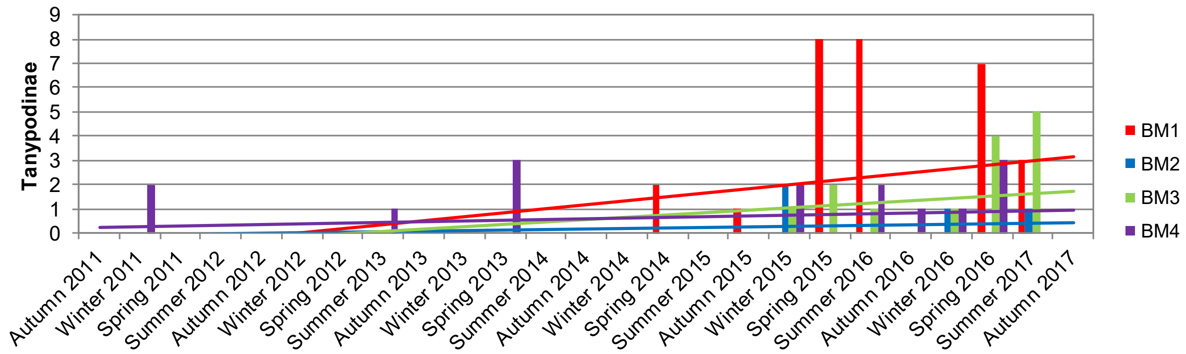


Figure 3.5 **Number of *Tanypodinae* captured at each site during each survey of the MPPC**

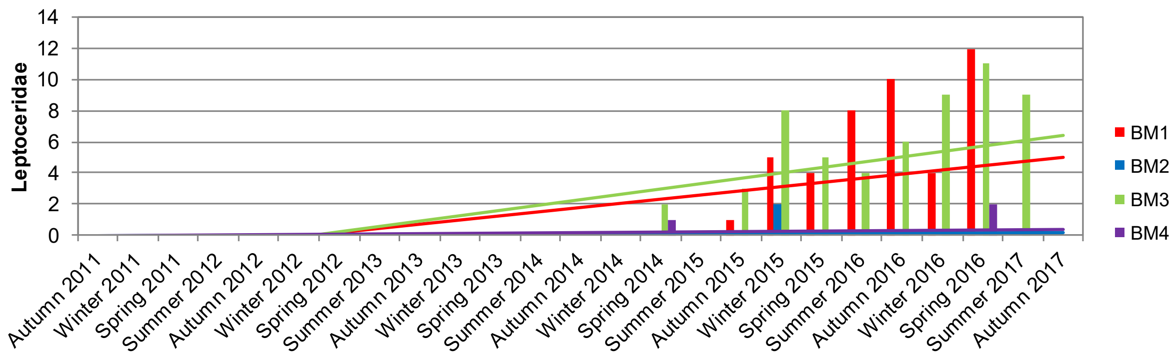


Figure 3.6 **Number of *Leptoceridae* captured at each site during each survey of the MPPC**

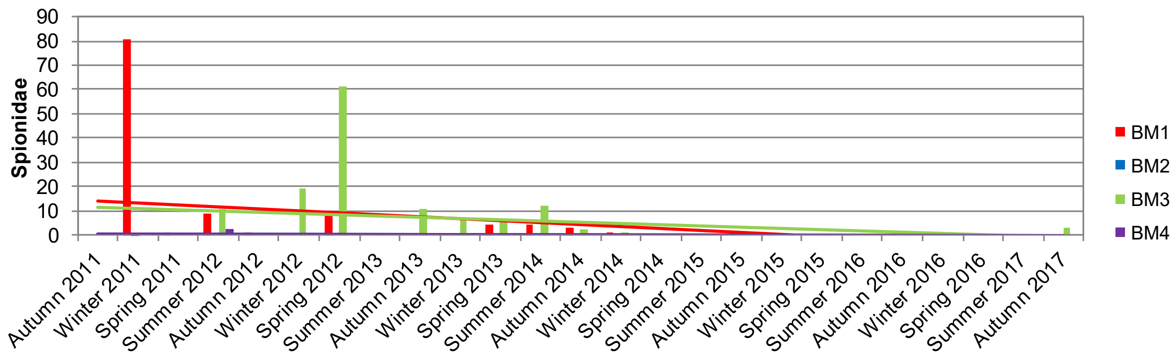


Figure 3.7 **Number of *Spionidae* captured at each site during each survey of the MPPC**

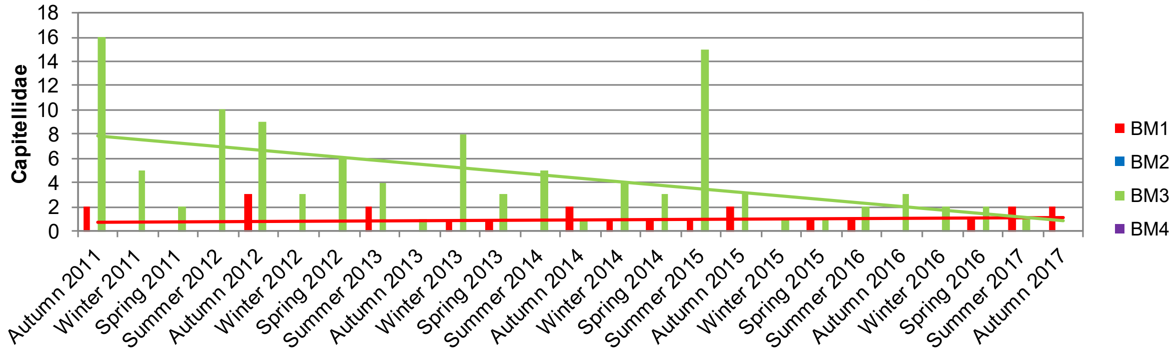


Figure 3.8 Number of *Capitellidae* captured at each site during each survey of the MPPC

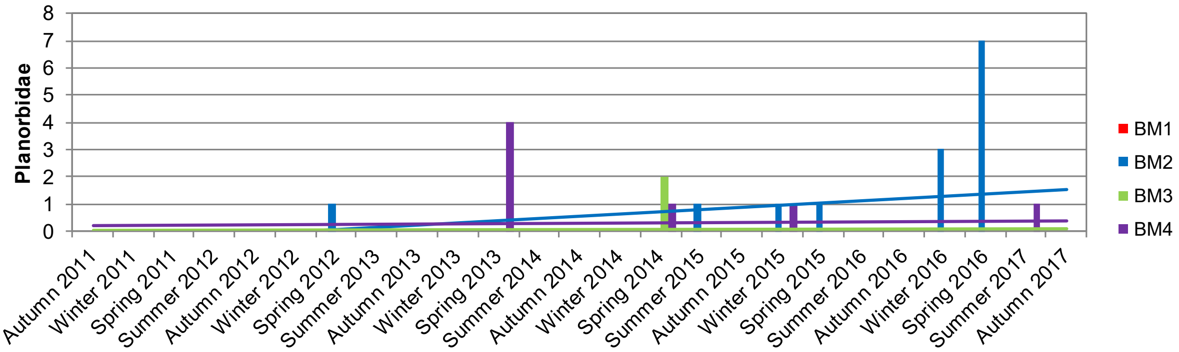


Figure 3.9 Number of *Planorbidae* captured at each site during each survey of the MPPC

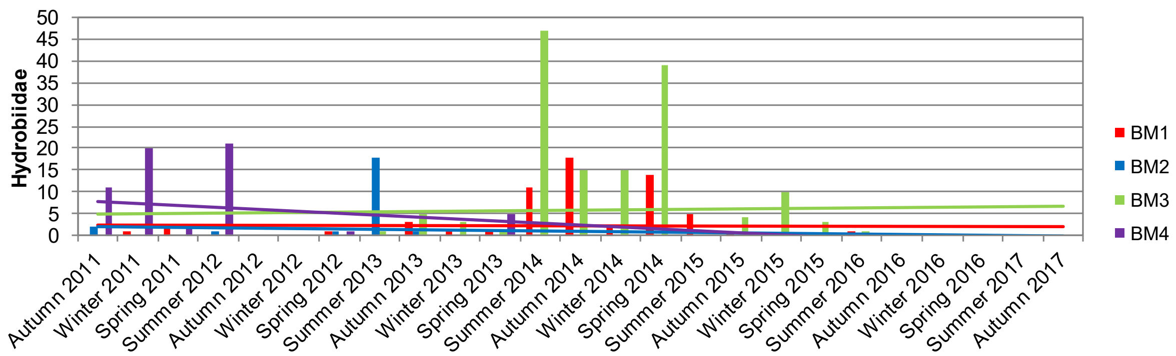


Figure 3.10 Number of *Hydrobiidae* captured at each site during each survey of the MPPC

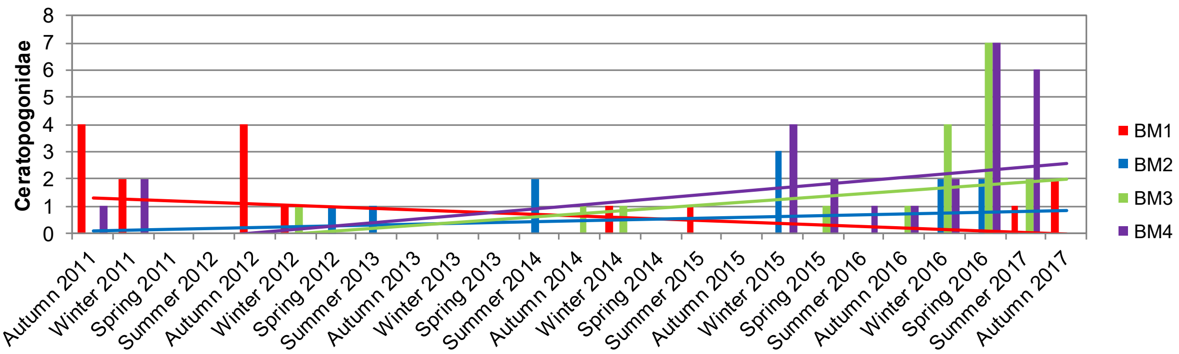


Figure 3.11 Number of *Ceratopogonidae* captured at each site during each survey of the MPPC

3.3.3 Conclusions

There has been continued variation in the diversity, abundance and species makeup of benthic macroinvertebrates collected during seasonal surveys. Some of the changes observed are providing insight into the changes occurring in Salty Lagoon as a result of the closure of the artificial channel.

There has been considerable variation in the numbers of individual macroinvertebrates and the numbers of taxa captured at each site over time, indicating that macroinvertebrate abundance and diversity has fluctuated throughout Salty Lagoon throughout the MPPC. The direction of change has varied over time and between sites. While most of the variation in individual numbers observed has been in the form of short term spikes in the numbers of individual taxa, there does appear to be an increasing trend over time in the numbers of both individuals and taxa sampled.

The specific makeup of benthic macroinvertebrate communities in Salty Lagoon continues to change over time. There is a strong indication that taxa usually associated with freshwater are increasing in abundance in the open water area of Salty Lagoon and taxa associated with brackish water are decreasing in abundance. This trend is reflective of a shift from an intermittently open and closed waterbody to a freshwater wetland. The reduction in the numbers of polychaetes collected and increased numbers of chironomids and trichoptera are good indicators of this.

The observed variation in abundance and diversity of taxa may reflect a response to a combination of a large number of factors. Some of these factors include:

- Stochastic factors associated with the sampling procedures.
- Long term changes in the environment due to improved sewage treatment at the Evans Head STP.
- Long term changes to the environment due to reduced variation in salinity.
- Short term changes to the environment resulting from seasonal changes and the weather, such as the drought conditions prevalent between September 2013 and March 2014 and between November 2016 and February 2017.

In attempting to understand the observed variation in diversity and abundance it should be noted that the above factors complicate data interpretation and are likely to be working in combination rather than as individual impacts.

3.3.4 Comparison against Rehabilitation Targets

Closure of the artificial channel was anticipated to have an impact on the ecology of Salty Lagoon (Hydrosphere 2011). With respect to macroinvertebrates the key change specified was a return to a freshwater dominated, more robust, more diverse aquatic ecology. The data collected from the MPPC program indicates that this predicted change is happening to an extent.

Although there has not been a consistent overall increase in the diversity of the system there has been an increase in the number of freshwater taxa collected and a number of freshwater taxa were collected for the first time during the last three years of the MPPC. There has also been a reduction in the abundance and diversity of the saltwater tolerant taxa that have been captured, particularly in the final (2017) reporting period (**Figure 3.4** through to **Figure 3.11**).

With respect to the robustness of the macroinvertebrate ecology the changes have been inconsistent, though the short-term spikes in the populations of individual taxa that have characterised data in the earlier reporting periods appears to have become less prevalent over time.

The average number of animals in each macroinvertebrate sample has been greater in the post closure environment at all sites (**Figure 3.12**). This would also indicate that the anticipated changes have been realised with respect to robustness of the macroinvertebrate population.

It is noteworthy that the drying out of sites BM2 and BM4 following droughts in 2013/14 and 2016/17, which led to collapsed macroinvertebrate populations at those sites, occurred during the post channel closure period and negatively impacted the abundance and diversity averages.

The average number of taxa in each macroinvertebrate sample has increased at the two sites in the open water of Salty Lagoon (BM1 and BM3) but not at the two western sites (BM2 and BM4 – **Figure 3.13**). Overall, these results indicate that the macroinvertebrate fauna has become more diverse and more robust since closure of the artificial channel.

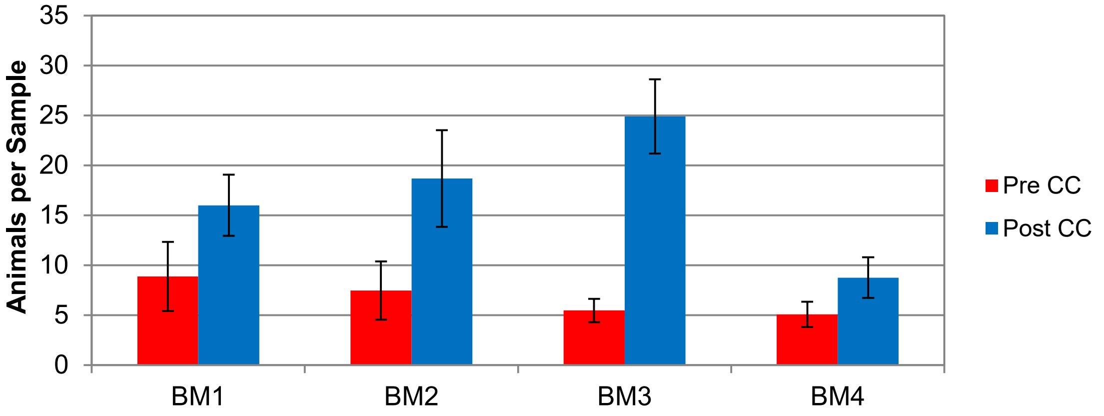


Figure 3.12 Mean ± SE numbers of macroinvertebrates per sample at all sites before and after channel closure

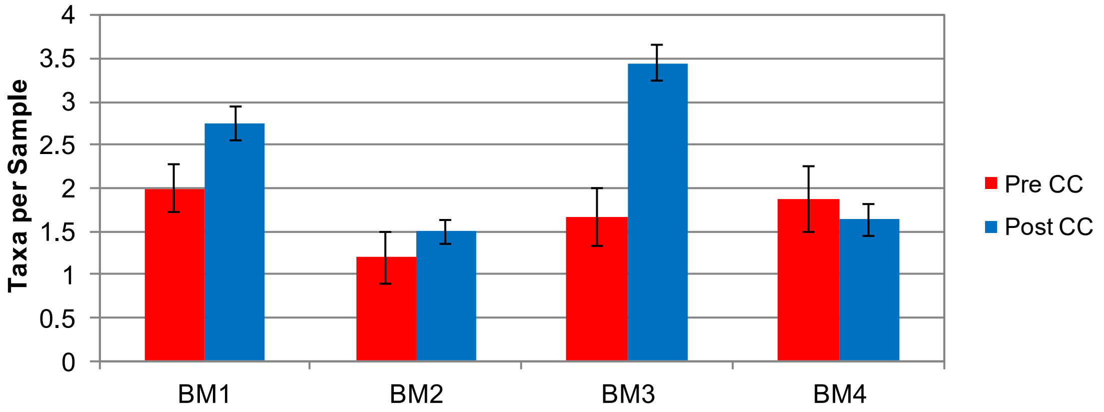


Figure 3.13 Mean ± SE numbers of macroinvertebrate taxa per sample at all sites before and after channel closure

The observed increase in individual macroinvertebrates captured since closure of the channel has not been steady at any of the sites. **Figure 3.14** shows that there have been increases and decreases in the average number of animals per sample in different individual years at each of the sites. However, the average numbers of macroinvertebrates captured in the last year of the MPPC were higher than the pre-channel closure period at all sites.

In contrast, the observed increase in macroinvertebrate taxa captured since the closure of the artificial channel at BM1 and BM3 appears to be clearly part of a trend towards increasing diversity at these two sites (**Figure 3.15**). Additionally, the average number of taxa per sample at all sites during the last two years of the MPPC was greater than the pre-channel closure period.

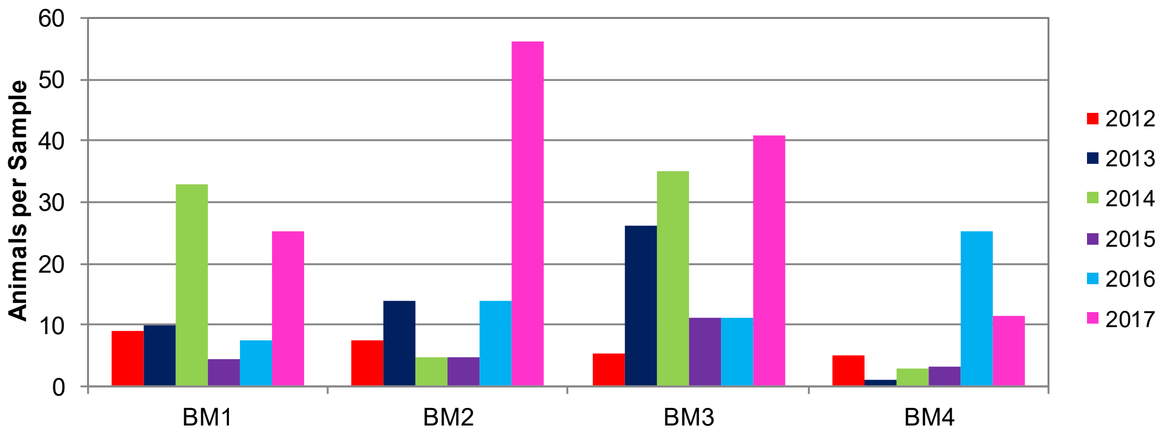


Figure 3.14 Mean macroinvertebrates per sample at each site displayed by annual reporting period

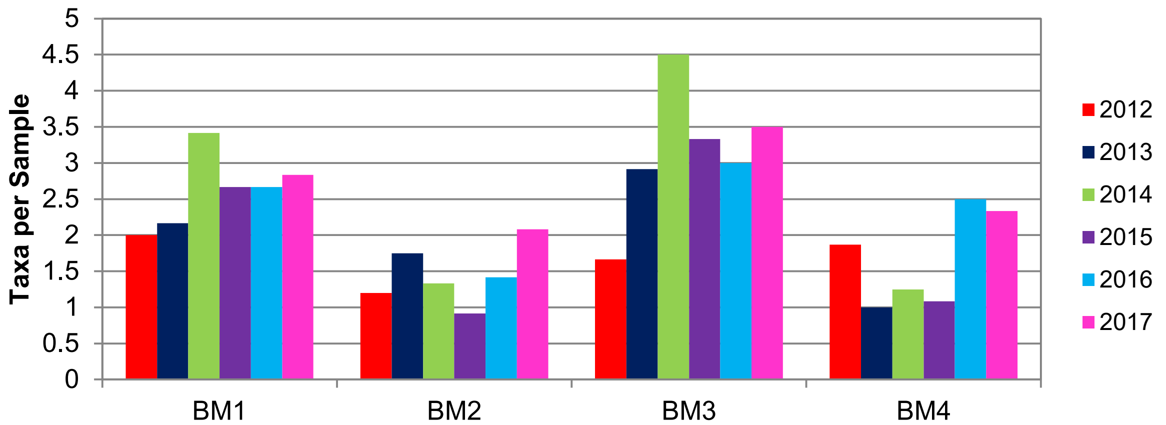


Figure 3.15 Mean macroinvertebrate taxa per sample at each site displayed by annual reporting period

4. Vegetation

4.1 Introduction

Vegetation communities were anticipated to change in response to the closure of the artificial channel (Hydrosphere 2010a, 2011). The three main vegetation habitat zones potentially affected by the closure of the channel are located on the western side of Salty Lagoon and consist of:

- Fringing Marsh.
- Swamp Forest.
- Sedge Swamp.

Predictions of expected changes (Hydrosphere 2010a, 2011) include:

- An increase in the area of open water.
- Colonisation of the central portions of the lagoon and fringes by Waterlilies (*Nymphaea spp.*).
- Domination by mixed sedges and rushes such as *Juncus spp*. and *Baumea spp*. in the western area currently occupied by Fringing Marsh.
- Expansion of Broad-leaved Paperbark (*Melaleuca quinquenervia*) to the east. Historical information and evidence on site (i.e. several large tree stumps in the lagoon) indicates that Broad-leaved Paperbark once occurred further east, closer to the lagoon.
- Establishment of *Gahnia spp.* and Broadleaf Cumbungi (*Typha orientalis*) in the deeper depressions that occur on the western shore.
- Drier extremities of the lagoon, where water levels will be less than 0.1 metre deep to remain largely unchanged.
- Other vegetation habitat zones that occur below 2.0 mAHD to be potentially affected along the drainage channel (Sedge Swamp/ open water) and along the eastern edge of the lagoon (Fringing Marsh and Banksia Woodland).

4.2 Methods

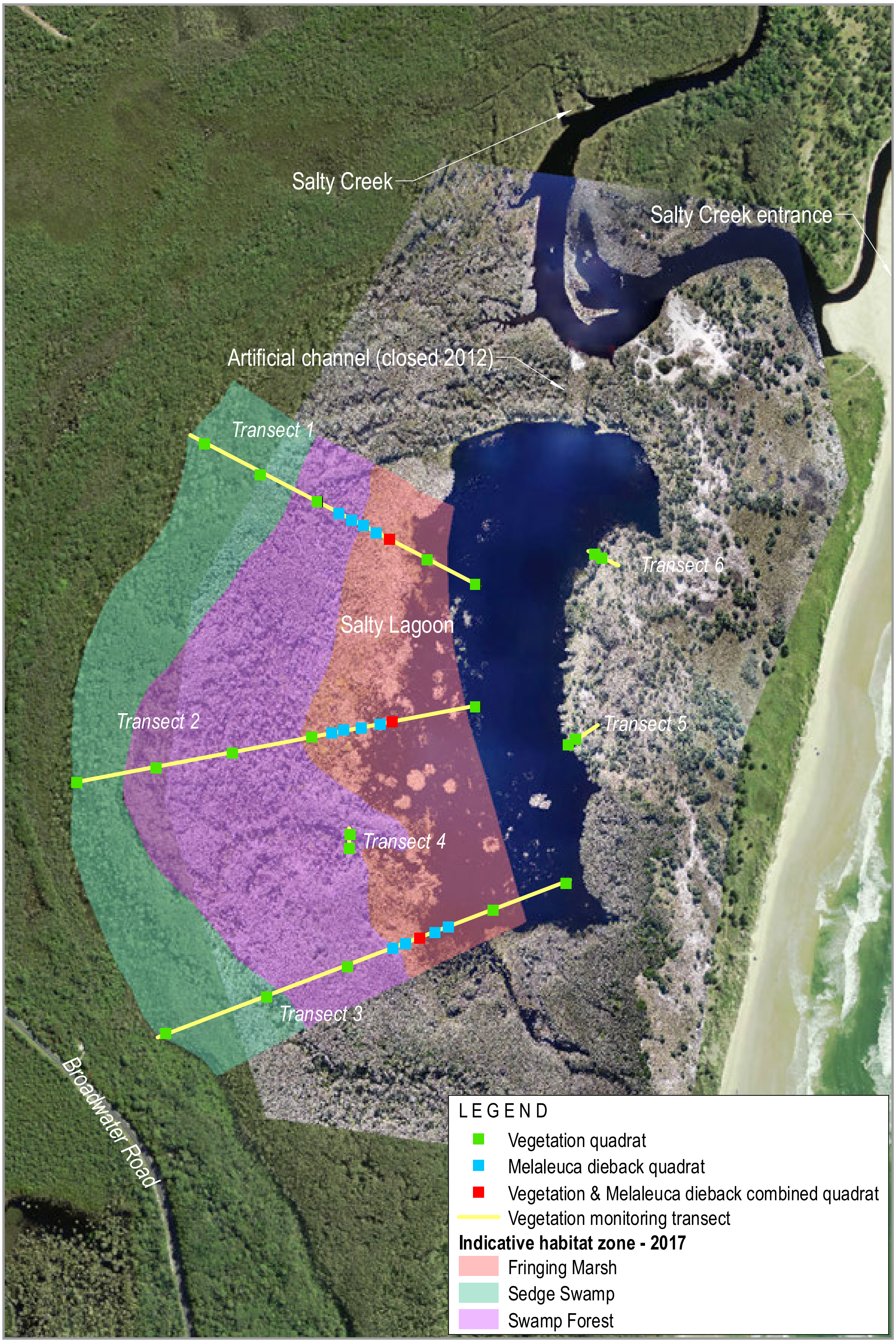
Vegetation monitoring was undertaken on four occasions over the MPPC program, including:

- One pre-artificial channel closure (baseline survey) event in 2011 (GeoLINK 2012c).
- Three post-artificial channel closure events in 2013, 2015 and 2017 (GeoLINK 2013b, 2015b and 2017b respectively).

The surveys included monitoring of floristic diversity, cover, health, composition and structure along six fixed transects (**Illustration 4.1**), with a focus on monitoring changes to identified indicator species (identified during baseline surveys or from Hydrosphere [2010a]). Changes in the location of vegetation boundaries were also monitored. Monitoring was also undertaken along three melaleuca dieback/regeneration transects. Specific details of the vegetation monitoring survey methodology and conditions during each event are provided in the corresponding vegetation monitoring report (e.g. GeoLINK 2012c, etc.).

Information shown is for illustrative purposes only

Drawn by: GJM Checked by: DSA Reviewed by: DSA Date: 13/10/2017
Source of base data: Richmond Valley Council



Vegetation Sampling Sites

GeoLINK environmental management and design

Final Evaluation Report
Salty Lagoon Monitoring Program: Pre/ Post Closure of the Artificial Channel
1731-1285

Illustration 4.1

4.3 Results and Discussion

Vegetation monitoring data is pooled between the larger Transects 1-3 (western side of Salty Lagoon) and the smaller Transects 4-6 (Transect 4 on the western side of Salty Lagoon and Transects 5 and 6 on the eastern side of Salty Lagoon) (refer to **Illustration 4.1**).

4.3.1 Transects 1–3

4.3.1.1 Vegetation Habitat Zonation

Transects 1-3 extend across the three distinct vegetation habitat zones of Fringing Marsh, Swamp Forest and Sedge Swamp. Since closure of the artificial channel, the total length occupied by the vegetation habitat zones along each transects has varied, and overall decreased (**Illustration 4.2**). This is primarily due to Fringing Marsh being converted to open water as water levels in the lagoon have increased and stabilised. The extent of Fringing Marsh has varied depending on the water levels within Salty Lagoon in the months preceding and at the time of each survey. While overall less than the pre-closure extent, the Fringing Marsh increased between the 2015 and 2017 monitoring events, with freshwater sedges and rushes re-colonising the shallow areas of open water along the western edge of Salty Lagoon.

Variation in the extent of Sedge Swamp and Swamp Forest since baseline monitoring has not been significant, reflecting that the primary driving factor for vegetation change is related to the rising water level in Salty Lagoon and associated lowering of salinity levels as the system has changed to being more freshwater dominated.

4.3.1.2 Species Diversity of Vegetation Habitat Zones

The total number of species recorded within each vegetation habitat zone at Transects 1 to 3 during the MPPC vegetation monitoring is shown in **Table 4.1**. Overall, the total number of species in each habitat zone as well as in total has decreased since closure of the artificial. This is attributed to both:

- The higher and more stable water levels within the lagoon system.
- The system being more stable in terms of water quality (particularly conductivity) and overall being freshwater dominant.

There was a minor increase in the overall number of flora species recorded between the 2015 and 2017 monitoring events. This was the first increase in species diversity since the baseline monitoring and was attributed to the lower water levels in the spring-summer in the lead up to the 2017 monitoring event.

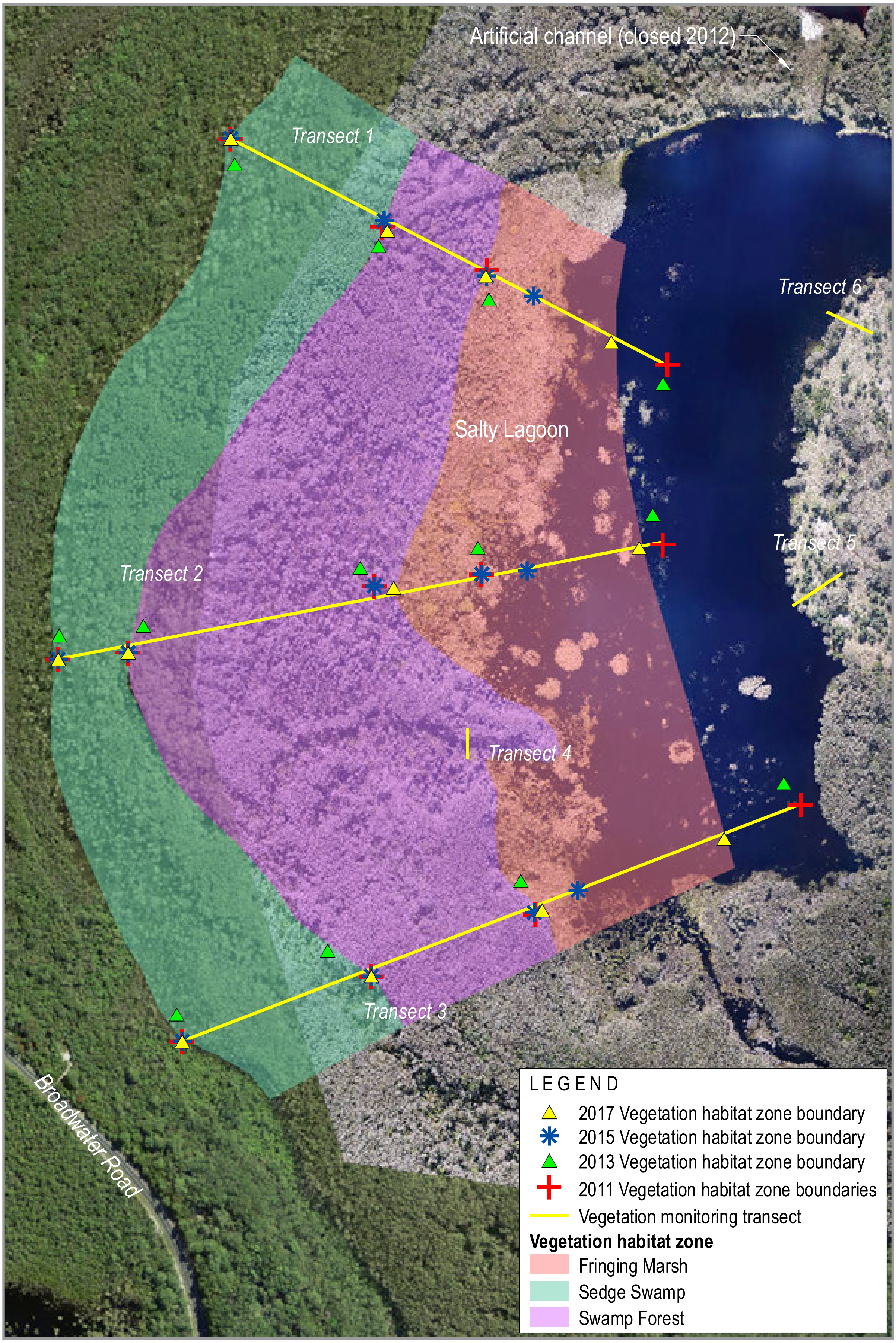
Table 4.1 Flora Species Numbers – Transects 1-3

Vegetation Habitat Zone	*Total Number of Species*			
	2011	*2013 (Change since 2011)*	*2015 (Change since 2011)*	*2017 (Change since 2011)*
Fringing Marsh	28	7 (-21)	11 (-17)	16 (-12)
Swamp Forest	36	30 (-6)	27 (-9)	29 (-7)
Sedge Swamp	40	32 (-8)	26 (-14)	31 (-9)
Total Flora Species	**73**	**55 (-18)**	**47 (-26)**	**58 (-15)**

4.3.1.3 Species Dominance

Since closure of the artificial channel, species dominance in the Fringing Marsh community has changed substantially, with a decline in the cover of Sea Rush (*Juncus kraussii* subsp. *australiensis*) and Saltwater Couch (*Paspalum vaginatum*) and an increase in the cover of Common Reed (*Phragmites australis*), Shore Club-rush (*Schoenoplectus subulatus*), Fringe Rush (*Fimbristylis ferruginea*), Broadleaf Cumbungi and Enydra (*Enydra fluctuans*), *Cyperus polystachyos* and Brown Beetle Grass (*Diplachne fusca*). Overall, species dominance within the Fringing Marsh has shifted from saltmarsh/salt tolerant species to freshwater species.

In contrast, the dominant flora species in the Swamp Forest and Sedge Swamp communities has not changed substantially. Dominant flora species in the Swamp Forest community include Broad-leaved Paperbark, Bare Twig-rush (*Baumea juncea*) and Tall Sedge (*Carex appressa*). Dominant flora species in the Swamp Forest community include Broad-leaved Paperbark, Plume Rush (*Baloskion tetraphyllum subsp. meiostachyum*) and Swamp Twig-rush (*Baumea arthrophylla*).



Vegetation Habitat Zone Boundaries

4.3.2 Transects 4–6

Transects 4-6 each traverse the following distinct vegetation habitat zones:

- Transect 4: Sedge Swamp/ open water and Swamp Forest.
- Transect 5 and 6: Fringing Marsh and Banksia Woodland.

4.3.2.1 Vegetation Habitat Zonation

At Transect 4 there was no noticeable change in vegetation habitat zone boundaries during the MPPC program. At Transects 5 and 6, as the water level of the lagoon has increased following closure of the artificial channel, the extent of the Fringing Marsh community has decreased, being replaced by open water. No change to the extent of Banksia Woodland was observed.

4.3.2.2 Species Diversity of Vegetation Habitat Zones

The total number of species recorded within each vegetation habitat zone at Transects 4 to 6 during the MPPC vegetation monitoring is shown in **Table 4.2**. Whilst species numbers have fluctuated each year, an overall increase in the total number of flora species present has been recorded since closure of the artificial channel. The increases in species diversity were recorded in both the Banksia Woodland and Fringing Marsh (eastern side of the lagoon at Transects 5 and 6). Conversely, an overall decrease or no change in the total number of species was recorded in the Sedge Swamp/ Open Water and Swamp Forest vegetation community zones (western side of Salty Lagoon at Transect 4).

It is noted that following Bitou Bush (*Chrysanthemoides monilifera*) spraying between the 2011 and 2013 monitoring events, the cover of this species within the Banksia Woodland notably decreased.

Table 4.2 Flora Species Numbers – Transects 4-6

Vegetation Habitat Zone	*Total Number of Species*			
	2011	*2013 (Change since 2011)*	*2015 (Change since 2011)*	*2017 (Change since 2011)*
Fringing Marsh	14	20 (+6)	17 (+3)	20 (+6)
Swamp Forest	13	6 (-7)	10 (-3)	13 (0)
Sedge Swamp/ Open Water	15	12 (-3)	13 (-2)	7 (-8)
Banksia Woodland	14	17 (+3)	14 (0)	24 (10)
Total Flora Species	**32**	**38 (+6)**	**28 (-4)**	**41 (+9)**

4.3.2.3 *Species Dominance*

Species dominance at Transects 4 to 6 was relatively stable between monitoring events, with the exception of the Fringing Marsh community in which the dominant species have shifted from Saltwater Couch and Shore Club-rush in 2011 to Shore Club-rush post closure of the artificial channel. This reflects the higher water levels and associated stronger freshwater influence following channel closure.

Blady Grass (*Imperata cylindrica*) and Coast Banksia (*Banksia integrifolia subsp. integrifolia*) remained dominant species in the Banksia Woodland community both pre and post closure of the artificial channel.

4.3.3 Indicator Species (Transects 1-6)

The average cover abundance value for each indicator species identified during baseline surveys (GeoLINK 2012b) or from Hydrosphere (2010a) for each vegetation habitat zone from all transects during the MPPC program is shown in **Figure 4.1**. The results indicate the following:

- Sea Rush: This saline or brackish water tolerant species has decreased in cover in all vegetation habitat zones since closure of the artificial channel, particularly within the Fringing Marsh and Swamp Forest where it remains present. The species was not present within the Banksia Woodland. Occurrences of Sea Rush within the Sedge Swamp have been minor and the species was absent during the 2017 monitoring event.
- Saltwater Couch: This saline or brackish water tolerant species has overall decreased in cover since closure of the artificial channel. Moderate reductions in cover are apparent within the Fringing Marsh and Swamp Forest. Occurrences within the Sedge Swamp and Banksia Woodland have been minor and therefore show no obvious trend.
- Shore Club-rush: This species is tolerant of both brackish and freshwater environments. Localised variations to this species distribution and cover have occurred during the MPPC program, however no major overall trends pre/ post closure of the artificial channel are present.
- Bare Twig-rush: This species is tolerant of both brackish and freshwater environments. Occurrence of this species within all vegetation habitat zones has overall remained stable throughout the MPPC. Only localised increases in cover have been recorded in the Swamp Forest and Swamp Forest/ Fringing Marsh ecotone.
- Broad-leaved Paperbark: Occurrence of this freshwater species within all vegetation habitat zones has overall remained stable throughout the MPPC.
- Plume Rush: This freshwater species has only been recorded within the Sedge Swamp. Cover of this species has remained stable throughout the MPPC program.
- Saw-sedge (*Gahnia spp.*): Localised variations to this freshwater species distribution and cover have occurred during the MPPC program, however no major trends pre/ post closure of the artificial channel are present.
- Coast Banksia: This terrestrial species has only been recorded within the Banksia Woodland. Cover of this species has remained stable throughout the MPPC program.

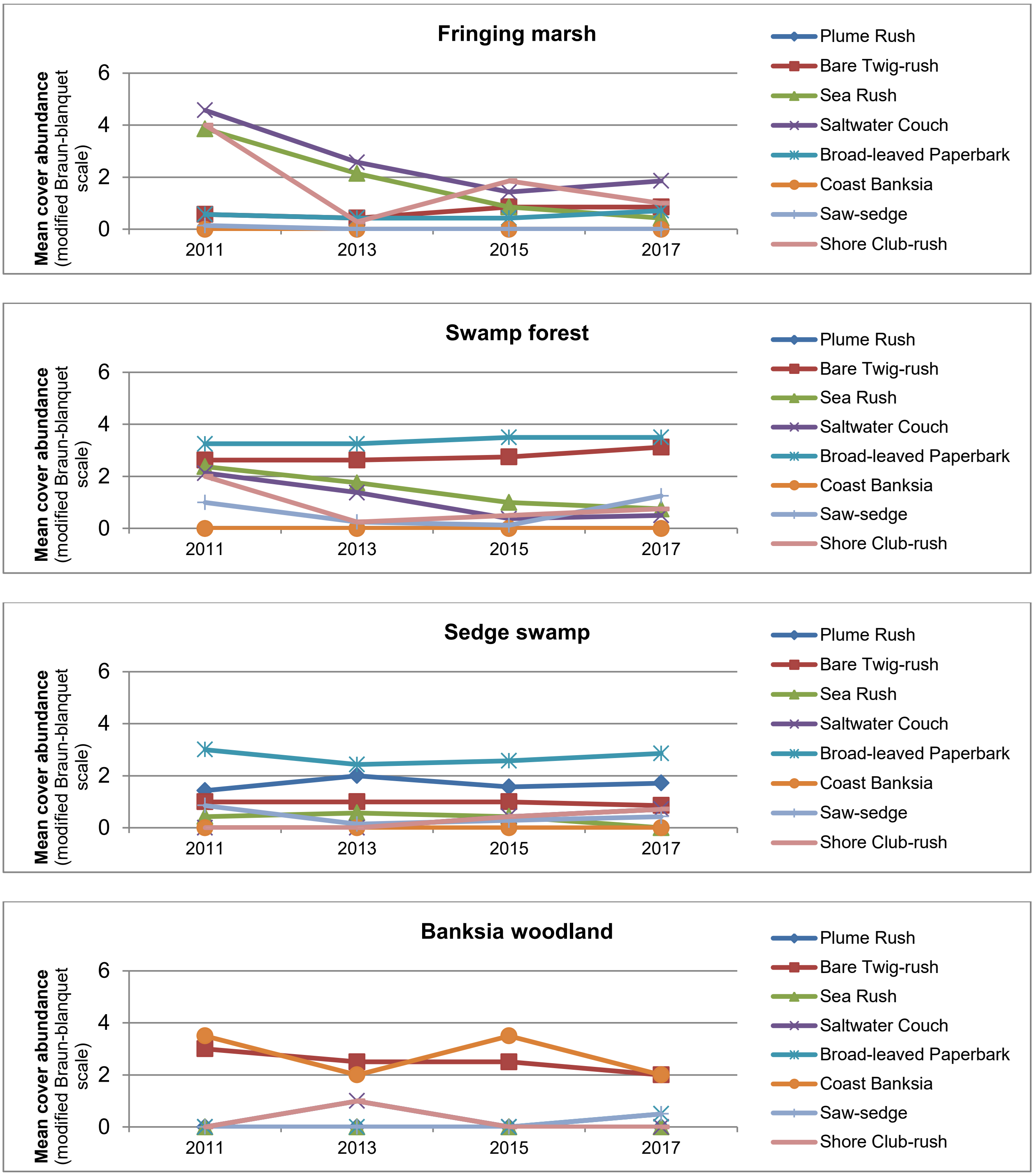


Figure 4.1 Cover abundance scores for indicator species for all sites in vegetation habitat zones during the MPPC program (Transects 1-6)

4.3.4 Melaleuca Dieback/ Recolonisation Monitoring

Results of the MPPC Melaleuca dieback/ recolonisation monitoring overall shows little evidence of regeneration of Broad-leaved Paperbark or that any further dieback has occurred. The mean number of plants per category pooled from each quadrat from all transects over time during the MPPC program is shown in **Figure 4.2**. The variations shown are minor and more a reflection of plants growing and therefore being captured within the next category during subsequent monitoring events, saplings/seedlings not maturing and minor data collection discrepancies (particularly with multi-stemmed plants identification when water levels are variable).

The overall health of the Broad-leaved Paperbark plants has improved and been maintained in good condition since closure of the artificial channel. Trees in the melaleuca dieback zone have generally grown thicker foliage and no signs of stress were observed on any trees during the final monitoring event in 2017. Although recruitment has not been significant, in some quadrats Broad-leaved Paperbark trees have grown substantially.

It has been postulated that with the generally elevated water level in Salty Lagoon following closure of the artificial channel, suitable conditions for regeneration by Broad-leaved Paperbark may now occur less frequently (assuming that for germination to occur, seeds must be able to contact with moist, bare soil). Suitable conditions for germination may now occur only during prolonged dry periods when water levels within Salty Lagoon recede. Such prolonged dry conditions would be expected to occur relatively infrequently, and consequently, substantial regeneration of the lagoon edge by Broad-leaved Paperbark may only be apparent following long-term monitoring (significantly longer than the timeframe of the MPPC program). As emergent vegetation within the open water (former Fringing Marsh) migrates further east, the growth of large amounts of vegetation in this zone (i.e. Broad-leaved Cumbungi, Common Reed) may facilitate the build-up of sediments and further facilitate the potential for recolonisation of this area by Broad-leaved Paperbark.

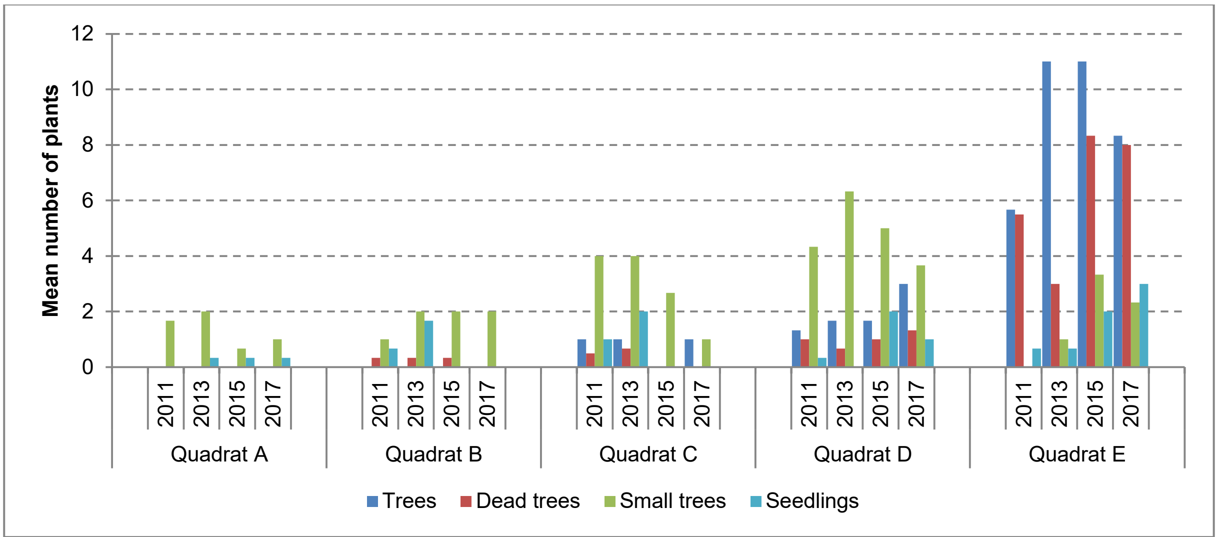


Figure 4.2 Mean number of plants per category pooled from each quadrat from all transects over time during the MPPC program

Notes:

- *Data has been recorded from the Melaleuca dieback transects, with all Quadrat A data from each transect pooled, all Quadrat B data from each transect pooled, etc. Quadrats are in sequence from A to E, east to west along each transect respectively.*

- *Data from the 2015 and 2017 monitoring in the category 'saplings' (GeoLINK 2015b and 2017b) are grouped with small trees for the analysis.*

4.3.5 Photo-point Monitoring

A representative sample of the vegetation monitoring photo points captured during the MPPC program is provided in **Appendix G**. All photo points correspond with vegetation monitoring quadrats. Key observations include:

- Reductions in the extent of Fringing Marsh as water levels within Salty Lagoon have increased, transforming areas into open water. Subsequent colonisation of the open water with emergent rushes is apparent.
- Transformation of the Fringing Marsh from a salt water species dominant community to a freshwater species dominant community.
- No substantial floristic or structural changes in the Swamp Forest and Sedge Swamp.
- Reduction in the extent of Bitou Bush in the Banksia Woodland between 2011 and 2013 (following weed management by NSW National Parks and Wildlife Services [NPWS]).
- No significant dieback or regeneration within the Melaleuca dieback zone.

4.3.6 Comparison against Rehabilitation Targets

In Hydrosphere (2010b) it was discussed that vegetation communities around Salty Lagoon are anticipated to change in response to water level and salinity changes. The main changes were that there would be a replacement of Saltmarsh communities on the western shore of the Lagoon with a freshwater macrophyte community, and potential for *Melaleuca* recolonisation within the dieback area.

Specific predicted outcomes on vegetation following the closure of the artificial channel (Hydrosphere 2010a) and comparison with the findings of the MPPC terrestrial vegetation monitoring are shown in **Table 4.3**.

Table 4.3 Predicted Terrestrial Vegetation Changes and Outcomes for the MPPC

Predicted Major Changes to the System	***MPPC Monitoring Findings***
Change of saltmarsh community to freshwater macrophyte/ macro algae in Salty Lagoon with change to freshwater	This prediction has been realised. Since closure of the artificial channel the Saltmarsh community has been converted to freshwater dominated community.
An increase in the area of open water.	This prediction has been realised. Large areas of former Fringing Marsh have been converted to open water.
Colonisation of the central portions of the lagoon and fringes by Waterlilies.	This prediction has been realised. Aquatic weed monitoring (refer to **Section 5**) has recorded Waterlilies and other similar aquatic plants (eg. Water Ribbons *Triglochin sp.*) within the open water portion of Salty Lagoon that have colonised post closure of the artificial channel.
Domination by mixed sedges and rushes such as *Juncus spp.* and *Baumea spp*. in the western area currently occupied by Fringing Marsh.	This prediction has been realised (refer to **Table 4.4**).
Melaleuca re-colonisation & reduction in area of dieback	This prediction has not occurred to any significant extent. No obvious substantial regeneration of the dieback area with Broad-leaved Paperbark has occurred. Some positive changes have been noted including observation of low numbers of regenerating seedlings and improved canopy cover of Broad-leaved Paperbark at the edge of the Swamp Forest/ dieback zone interface. Additionally no increase in dieback has been recorded. Longer term monitoring would be required to determine prediction eventuates to any significant extent.
Establishment of *Gahnia spp.* and Broadleaf Cumbungi in the deeper depressions that occur on the western shore.	This prediction has essentially been realised. Species such as Common Reed, Broadleaf Cumbungi, Fringe Rush and Shore Club-rush have established within the western shore, including the deeper depressions. While *Gahnia spp.* have not specifically colonised this area, the above species occupy similar habitats.
Drier extremities of the lagoon, where water levels will be less than 0.1 metre deep to remain largely unchanged.	This prediction has effectively been realised. Vegetation changes within the Swamp Forest in the higher areas, the Sedge Swamp habitat zone and Banksia Woodland habitat zone have been relatively minor.
Other vegetation habitat zones that occur below 2.0 m AHD to be potentially affected along the drainage channel (Sedge Swamp/ open water) and along the eastern edge of the lagoon (Fringing Marsh and Banksia Woodland).	This prediction has effectively been realised. Variable vegetation changes within other vegetation habitat zones below 2.0 mAHD have been recorded post closure of the artificial channel, though habitat zones above 2.0 mAHD such as the Banksia Woodland remain largely unaffected.

Specific predicted trends for indicator species identified during baseline surveys (GeoLINK 2012b) and outcomes for the MPPC are discussed in **Table 4.4**.

Table 4.4 Predicted Trends of Indicator Species and Outcomes for the MPPC

Predicted Major Changes to the System	*MPPC Monitoring Findings*
Sea Rush: Expected to decrease in the area occupied in the: ▪ Fringing Marsh and Swamp Forest at Transects 1-3. ▪ Sedge Swamp/ open water habitat zone along Transect 4.	This prediction has overall been realised. The overall occurrence of this species has reduced significantly since closure of the artificial channel. However periods of low water levels and saltwater ingress events from Salty Creek into Salty Lagoon appears to have sustained this species within the lagoon system.
Saltwater Couch: Expected to decrease in the area occupied in the: ▪ Fringing Marsh and Swamp Forest at Transects 1-3. ▪ Swamp Forest along Transect 4 and Fringing Marsh along Transect 5.	This prediction has overall been realised. The overall occurrence of this species has reduced since closure of the artificial channel, however it still remains widespread despite periods of prolonged inundation and the absence of saline influence. This indicates that it may persist at the Salty Lagoon into the future. Being a grass this species is capable of increasing in cover fairly rapidly if/when suitable conditions occur.
Shore Club-rush: Expected to decrease in the area occupied in the: ▪ Fringing Marsh and Swamp Forest at Transects 1-3. ▪ Fringing Marsh vegetation habitat zone along Transects 5 and 6.	This prediction has overall not been realised. While localised variations to this species distribution and cover have occurred during the MPPC program, no major trends pre/ post closure of the artificial channel are present. The may be due to the species tolerance of both brackish and freshwater environments.
Bare Twig-rush: expected to increase in the area occupied in the Fringing Marsh at Transects 1-3.	This prediction has been realised to a minor extent. In general the occurrence of this species within all vegetation habitat zones has remained stable throughout the MPPC. Localised increases have been recorded within the Swamp Forest and Swamp Forest/ Fringing Marsh ecotone in the Melaleuca dieback zone.
Saw-sedge: Expected to increase in the area occupied in the Sedge Swamp/open water at Transect 4.	This prediction has indirectly been realised. No detectable increase in density cover of Saw Sedge has been recorded along Transect 4. However localised increases in Saw Sedge distribution has been recorded in both the Sedge Swamp and Swamp Forest communities elsewhere.
Broad-leaved Paperbark: Expected to increase in the area occupied in the Fringing Marsh at Transects 1-3.	This prediction has overall not been realised. Refer to **Section 4.3.4**.
Coast Banksia: Expected to retain density within the Banksia Woodland at Transects 5-6.	This prediction has been realised. The density of Coast Banksia at Transects 5 and 6 maintained a similar cover throughout the MPPC program.

5. Aquatic Weeds

5.1 Introduction

Aquatic weed invasion is considered a significant risk during the period following the closure of the artificial channel as Salty Lagoon makes the transition to a permanently fresh water system. To assess the response of aquatic vegetation to the changes and to provide a mechanism for adaptive management of aquatic weeds a regular survey is undertaken as part of the MPPC program. Incidental observations of aquatic weeds noted during the monthly site inspections are also recorded.

5.2 Methods

Aquatic weeds were monitored on a seasonal basis across all seasons except winter. The aquatic weed surveys involved following a meandering transect selected to cover most of the open water areas of Salty Lagoon. Each species of aquatic plant, weedy or otherwise, encountered during the survey was recorded. The position of any aquatic weed encountered was recorded with a hand-held GPS unit and the aerial extent of the weed population estimated and recorded. Plants that could not be identified in the field were sampled and transported back to the laboratory for identification.

A detailed description of methods and transects surveyed each season is provided in the respective annual monitoring report for that year (GeoLINK 2012a; 2013a; 2014; 2015a; 2016; 2017a).

5.3 Results

A total of 38 aquatic plant taxa were observed during the aquatic weed surveys during the MPPC program (**Table 5.1**). Four types of native aquatic plant sometimes regarded as nuisance plants have been encountered. These were blue green algae (BGA, various species), Ferny and Pacific Azolla (*Azolla pinnata* and *A. filiculoides*) and Duckweed (*Lemna sp*.).

BGA have not been observed since the early surveys prior to channel closure and have only been detected in water samples twice during the MPPC. Pacific Azolla and Duckweed have been encountered at varying densities to the west of Salty Lagoon, particularly around discrete water quality site S2. The abundance of these two plants tends to fluctuate in response to temperature and freshwater flow. They are less likely to be observed growing at high densities during the winter months.

There were no notable aquatic weeds observed during the final (2017) reporting period. An individual species of introduced plant, Cape Waterlily (*Nymphaea capensis*) was identified, but this is widely considered to be naturalised to the area and is seldom thought of as a weed.

Table 5.1 List of all Aquatic Plant Species Detected During Aquatic Weed Surveys and an Assessment of Abundance

Species Name	Common Name	Survey																		
		Aut '11	Spr '11	Sum '12	Aut '12	Spr '12	Sum '13	Aut '13	Spr '13	Sum '14	Aut '14	Spr '14	Sum '15	Aut '15	Spr '15	Sum '16	Aut '16	Spr '16	Sum '17	Aut '17
Avicennia marina	Grey Mangrove	UC	UC	UC	UC	UC														
Azolla filiculoides	Pacific Azolla											C	VC	VC	VC	VC	C	UC	C	UC
Azolla pinnata	Ferny Azolla	UC	VC	UC	UC	UC	UC	UC	UC											
Bacopa monnieri	Water Hyssop	C	VC	C	UC	C	C	UC	C	C	VC	VC	C	VC	UC	VC	VC	UC	VC	UC
Baumea articulata	Jointed Twig-rush		UC				UC	UC	UC				UC				C	C	UC	C
Baumea sp.	A Rush								UC	C	C	C	C	C	VC	VC	VC	C	VC	VC
Baumea sp.2	A Rush														UC			UC		
Carex appressa	Tall Sedge																		UC	
Ceratophyllum demersum	Hornwort																		UC	
Cyperus difformis	Dirty Dora	UC		UC	UC		UC	UC		C	VC		C	UC		C	UC		VC	C
Cyperus exaltatus	Giant Sedge	UC		UC							C						UC		UC	
Diplachne (Leptochloa) fusca	Brown Beetle Grass										VC									
Enteromorpha sp.	Enteromorpha					C	VC		VC				VC		VC	VC			VC	
Enydra fluctuans	Enydra	UC	UC					UC	C	UC	C	C	C	C	C	C	C	UC	UC	UC
Ficinia nodosa	Noddy Club-rush																	UC		
Gahnia sieberiana	Red-fruit Saw-sedge						UC	UC	UC		UC		C	UC	UC	C	UC	C	UC	C
Hydrocotyle verticillata	Shield Pennywort		UC			UC			C	UC	C	C	UC	UC	C	VC	C	C	C	UC
Juncus krausii	Sea Rush	VC	VC	VC	VC	VC	VC	C	C	C	UC	C	C	VC	C	C	C	UC	C	
Juncus usitatus	Common Rush						UC		C								UC			
Lemna sp.	Duckweed								UC			C	VC	VC	VC	VC	C	UC	C	UC
Lobelia anceps	Angled Lobelia	UC		UC											UC			UC	UC	
Lomandra sp.	A Mat-rush							UC												

Species Name	Common Name	Survey																		
		Aut '11	***Spr '11***	***Sum '12***	***Aut '12***	***Spr '12***	***Sum '13***	***Aut '13***	***Spr '13***	***Sum '14***	***Aut '14***	***Spr '14***	***Sum '15***	***Aut '15***	***Spr '15***	***Sum '16***	***Aut '16***	***Spr '16***	***Sum '17***	***Aut '17***
*Nymphaea capensis^*	Cape Waterlily											UC	UC	UC						UC
Nymphoides indica	Water Snowflake												UC	C	UC	C	C	UC	C	UC
Paspalum vaginatum	Saltwater Couch	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC		VC	VC	VC	VC	VC	VC
Persicaria decipiens	Slender Knotweed		UC																	
Phragmites australis	Common Reed	VC	C	C	C	C	C	C	C	C	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC
Rhizophora stylosa	Red Mangrove	UC																		
Sarcocornia quinqueflora	Bead Weed	UC	UC																	
Schoenoplectiella mucronata	Marsh Club-rush	VC	VC	UC	UC						C									
Schoenoplectus validus	River Club-rush	VC	VC	VC	VC	VC	C	C		C	C	VC	C	VC	VC	C	C	VC	VC	C
Sesuvium portulacastrum	Sea Purslane	UC	UC																	
Sporobolus virginicus	Saltwater Couch	C	C	C	C									VC						
Suaeda australis	Seablite	UC																		
Triglochin sp.	Water Ribbons																UC			
Typha orientalis	Cumbungi		UC	UC		UC	UC	UC	C	C	UC	UC	C	C	VC	C	UC	C	VC	VC
Utricularia spp.	Bladderwort													VC	VC		C	C	UC	VC
Various	Blue Green Algae	C	C	C	UC	UC														

Note *UC = Uncommon, C = Common, VC = Very Common*
^ *Introduced Species*

5.4 Discussion

The aquatic weed surveys did not detect any significant aquatic weeds. Despite this, the risk of weed invasion into Salty Lagoon remains, particularly as the system continues the transition to a freshwater ecosystem.

The continued transition to a stable freshwater ecosystem appears to be resulting in a change to the overall aquatic plant community in Salty Lagoon. There are a variety of freshwater plants that have only been observed in the later reporting periods, including Water Ribbons, Water Snowflake, Cape Water Lily, Bladderwort and Duckweed. There have also been a variety of plants previously observed that were not recorded during the later reporting periods. The majority of these were plants usually associated with saline or brackish water such as Mangroves, Sea Purslane, Bead Weed and Seablight.

The targeted weed surveys, in addition to incidental observations made during normal monthly sampling, are a cost-effective way to address the continuing risk of aquatic weed invasion and to assess vegetation changes over a relatively short time scale.

5.4.1 Comparison against Rehabilitation Targets

With respect to aquatic plant life there was one relevant predicted change and one risk identified prior to the start of the MPPC. The predicted change to a freshwater dominated, more robust, more diverse aquatic ecology has been consistently realised with respect to the aquatic plants identified during aquatic weed surveys. There have been a number of specialist freshwater plants observed since the closure of the artificial channel that were not observed in the pre-closure surveys. The risk of aquatic weed invasion has not been realised during the MPPC program. There have been no significant freshwater weed species observed since the closure of the artificial channel.

6. Fish

6.1 Introduction

Fish were monitored as part of the MPPC due to their iconic status, importance to ecosystems and sensitivity to environmental change. The fish populations of Salty Lagoon were expected to be impacted positively in the long term as a result of the closure of the artificial channel (Hydrosphere 2010a). The aims of sampling fish fauna throughout the MPPC project are as follows:

- To confirm predicted positive effects of closing the artificial channel upon fish fauna.
- To monitor for potential negative impacts arising from closure of the artificial channel.

Prior to the closure of the artificial channel, Salty Lagoon operated as part of an ICOLL (intermittently open and closed lakes and lagoons) and regular changes in the fish populations resulted in response to the entrance status and rainfall runoff. This is typical of ICOLLs, where fish populations are highly variable (Hadwen & Arthrington 2006).

It is important to note that the structure of the sampling effort set up for the MPPC facilitates comparison of samples from individual sites over time as opposed to comparisons of results between sites.

6.2 Methods

A full description of the fish fauna survey methods and locations is provided in GeoLINK (2017a). Fish fauna were sampled at four separate sites within Salty Lagoon (referred to as F1–F4) using five baited traps at each site set in the morning and checked in the late afternoon. The sites were selected in order to cover the major physical, chemical and ecological zones throughout the lagoon (refer to **Illustration 2.1**). Monitoring was undertaken on a seasonal basis once every three months, with 25 events in total. As expected, some of the sites changed with respect to habitat and conditions in response to the higher water levels and greater influence of freshwater since the closure of the artificial channel.

6.3 Results

6.3.1 Fish Diversity

The number of fish species captured at each site has been used as a measure of fish diversity. A total of eight fish species have been recorded during the MPPC program. A list of fish species captured is presented in **Appendix D**.

Variation in the diversity of fish species captured at each site during the MPPC program is displayed in **Figure 6.1**. The number of species captured at each of the sites has varied over time. There is no clear pattern to the observed variation in overall captured fish diversity although in the final two reporting periods (2016 and 2017) there have generally been more diverse captures in spring and summer than in autumn and winter.

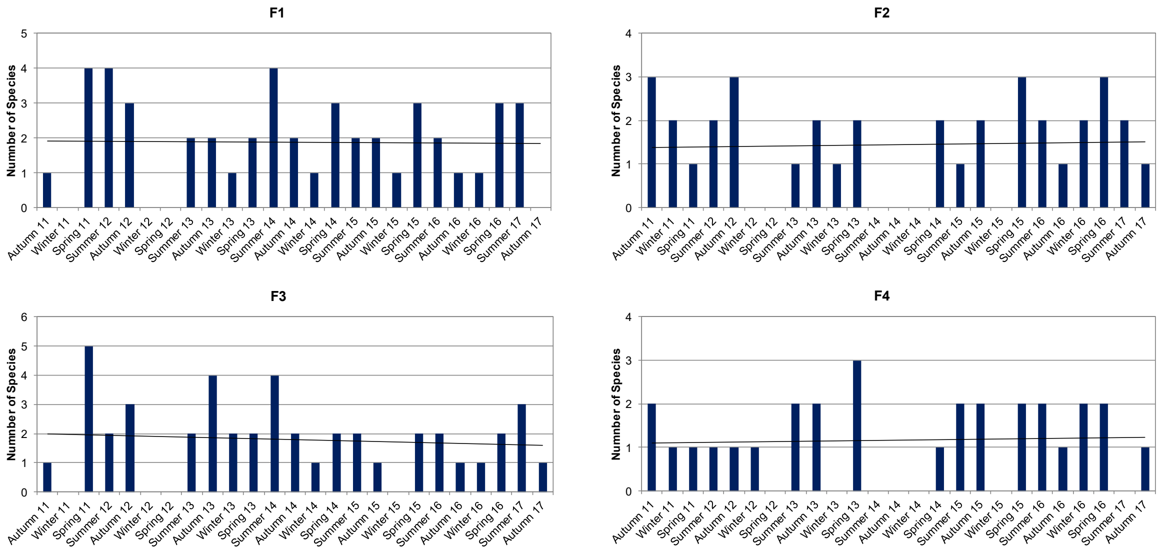


Figure 6.1 Number of fish species captured at all sites in all surveys during the MPPC program

6.3.2 Fish Abundance

The number of individual fish captured at each site is used as a measure of abundance for the MPPC. There was variation in the number of fish captured at each site over time (**Figure 6.2**). With respect to the overall number of individual fish captured at each site, the only patterns evident from the assembled data are:

- Lower numbers of fish captured during the winter surveys.
- Higher numbers of fish captured in spring and summer at F1 and F3.
- Greater variation in the numbers of fish captured were recorded at F2 and F4, mostly coinciding with the numbers of Mosquitofish captured at those sites.

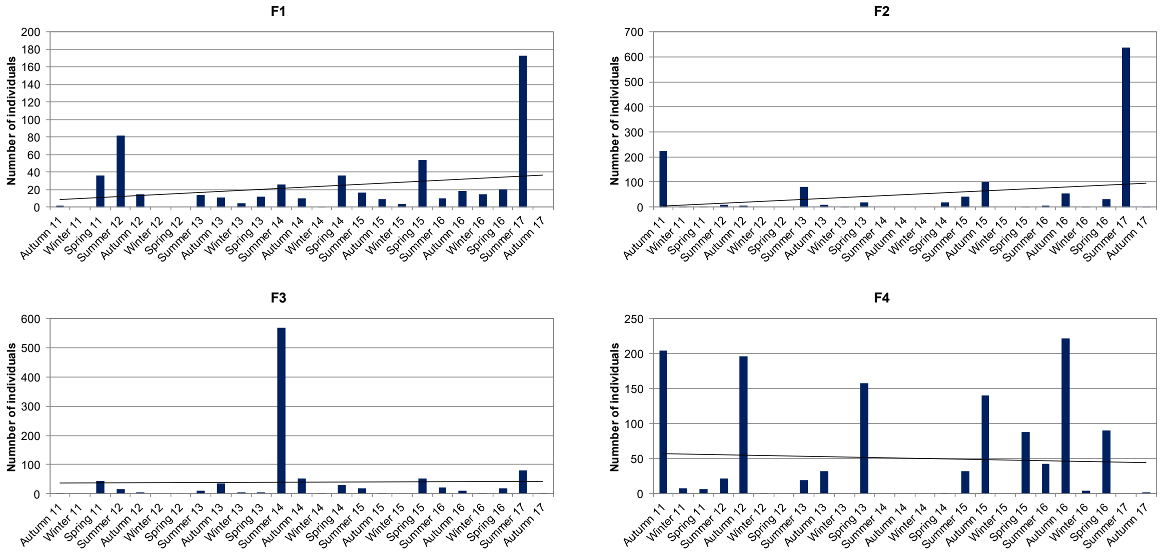


Figure 6.2 Number of individual fish captured at all sites in all surveys during the MPPC program

6.4 Discussion

Fish monitoring has provided another useful measure of the status of the Salty Lagoon system. Because of the differences between the available habitats and the water quality at each site, the fish monitoring program is designed to facilitate comparison of changes within sites over time rather than changes between sites. Whilst the responses of fish to environmental changes vary among species, due to their mobility and longer breeding cycles, variation in fish communities tends to be more difficult to detect over the short term compared with benthic invertebrates.

A considerable degree of within site variation in fish abundance and diversity has been detected during the 25 fish surveys. Detecting long-term trends in the variation of fish communities using the collected data is complicated by the variation in background factors such as hydrology and water quality. For example, the drying out of the wetlands to the west of Salty Lagoon caused by the drought conditions between September 2013 and March 2014, and December 2016 and February 2017 led to fish seeking drought refuge in the deeper waterholes, as evidenced by the high numbers and/or greater diversity of fish captured at F1 and F3 in the summer 2014 survey and the high numbers captured at F1, F2 and F3 in the summer 2017 survey. The same conditions led to a drying out of sites F2 and F4 and no fish were captured at either of these sites during the summer 2014 and autumn 2014 surveys. The overall diversity of fish captured at all sites combined has decreased since closure of the artificial channel. It appears that there is a reduction in the number of species generally associated with brackish water utilising Salty Lagoon following closure of the artificial channel. As an example, the Tamar River Goby has not been captured at any site since the autumn 2013 survey.

Fish abundance at each site has varied throughout the MPPC program and there has not been a clear trend to the observed variation. There are a number of factors that may be impacting results at the scale of the individual site in addition to the general changes to the Salty Lagoon ecosystem that have occurred since the closure of the artificial channel. These include:

- Stochastic factors associated with fish capture.
- Fluctuating water levels. This factor is particularly relevant in consideration of the results from the summer 2014 and summer 2017 surveys. At these times, most of the wetlands in Broadwater National Park were dry. The results from F1, F2 and F3 indicate that Salty Lagoon was acting as a drought refuge for fish from the surrounding wetlands as high numbers (and, in some cases, diverse species) were captured during those surveys. The opposite trend is also notable; when water levels increase the available habitat increases quickly and fish become more dispersed throughout the wetlands surrounding Salty Lagoon. Water levels also impact the types of fish captured. Mosquito fish are a surface species and are more likely to be captured when water levels are low and the entrances to the fish traps are located near the surface of the water.
- Fluctuations in conductivity. The conductivity of the water in Salty Lagoon has not been as stable as may have been expected due to incidences where saline water stored in Salty Creek has flowed back into the lagoon after rainfall events. The water quality changes associated with these events may be impacting fish populations and preventing stable colonisation of the available habitats.
- Short term impacts on fish populations resulting from independent variations in DO concentration and temperature occurring immediately prior to fish surveys.

It is likely that a combination of the above factors explains the majority of the variation.

6.4.1 Comparison against Rehabilitation Targets

There were a variety of predicted changes to fish fauna resulting from closure of the artificial channel made prior to the MPPC (Hydrosphere 2011). They are as follows:

- Reduced risk of fish kills.
- Increased Mosquitofish dominance.
- Potential for reduced freshwater eel migration to Salty Lagoon.
- A dominance of freshwater fish species, a larger fish population and reduced fish diversity.

In general, the recorded data indicates that many of the predicted changes have been realised however some have not. Predicted changes and the outcomes from the MPPC program are discussed below.

Reduced risk of fish kills.

This anticipated change has been realised. There have been no fish kill events since closure of the artificial channel and many of the conditions that were related to fish kills in the past have not eventuated or have eventuated to a lesser extent. The remaining risk of fish kills is associated with saline water ingress, algal bloom conditions, drought or deoxygenation of the water column.

Saline water ingress from Salty Creek into Salty Lagoon has occurred on a small number of occasions since the closure of the artificial channel (**Section 2**). Saline water ingress post artificial channel closure has not caused such a rapid or extreme change in the salinity of the water in Salty Lagoon that it has led to a fish kill. Saline water ingress could potentially cause a fish kill in Salty Lagoon due to a rapid and/or extreme change in the salinity of the water resulting in salinity shock.

Although BGA have only been detected in water quality samples twice since closure of the artificial channel there is a residual risk of a BGA bloom in the post-channel closure environment. Blooming BGA can lead to a fish kill because many species of BGA produce toxic alkaloids and algal blooms generally can lead to deoxygenation of the water column.

On two occasions since channel closure the water levels in Salty Lagoon have reduced to the extent that the wetlands to the west of Salty Lagoon have dried out and the area of water in Salty Lagoon has contracted. On one of these occasions the fish survey detected evidence of Salty Lagoon being used as a drought refuge (summer 2014 survey). There is an unlikely, but possible, risk of Salty Lagoon drying out completely as a result of extreme drought conditions, thereby resulting in a fish kill event.

There are a number of pathways that can lead to deoxygenation of the water column in Salty Lagoon, including decomposition of plant and animal matter, algal blooms and saltwater ingress.

Increased Mosquitofish dominance.

This perceived risk has not been realised. Across all sites the average mosquito fish capture per survey has reduced slightly since closure of the artificial channel, despite increasing at site F2 (**Figure 6.3**). However, variation in this dataset is very large and it is difficult to draw strong conclusions about the Mosquitofish population. In addition, there is some evidence of an increasing trend in mosquitofish populations at sites F1, F2 and F3 since the closure of the artificial channel (**Figure 6.4** and **Figure 6.5**).

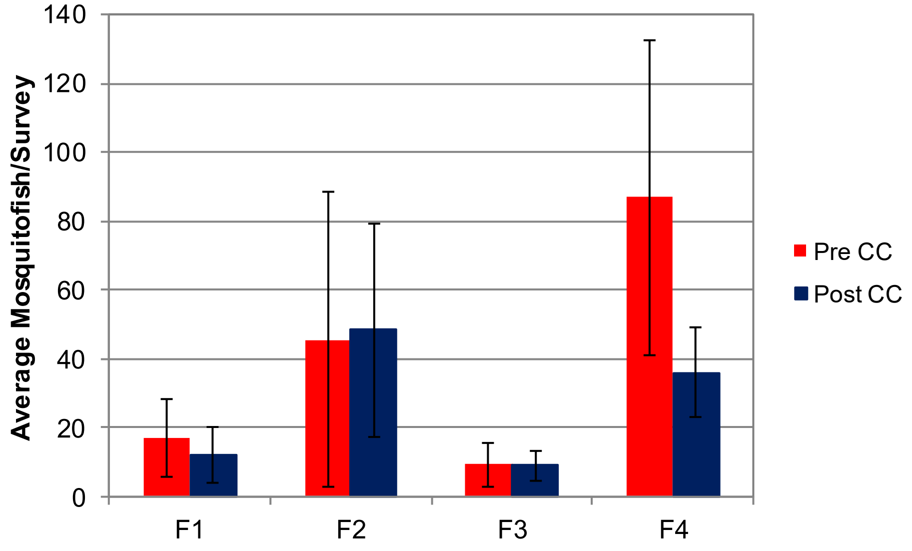


Figure 6.3 Mean ± SE Mosquitofish capture per survey at all sites in the pre and post-closure periods

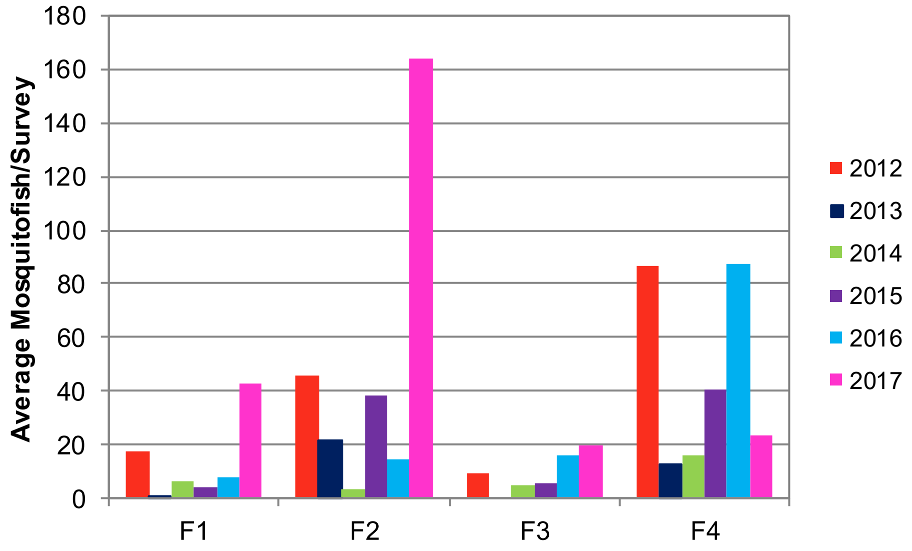


Figure 6.4 Average mosquitofish capture at all sites by annual report period

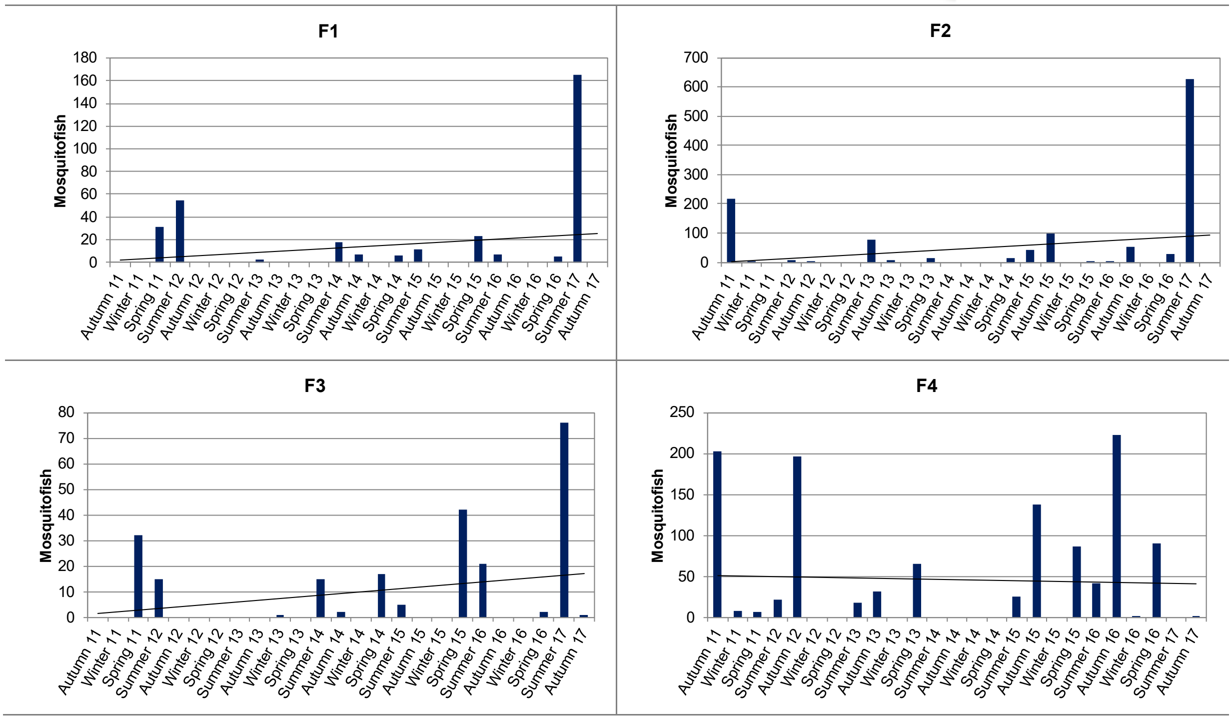


Figure 6.5 Number of mosquitofish captured per survey at all sites during the MPPC (with trendlines)

Potential for reduced freshwater eel migration to Salty Lagoon.

It is not certain whether this predicted risk has been realised or not. Freshwater eel capture has been very low throughout the MPPC. One Longfin Eel was captured in the pre-channel closure period and four were captured (in two of the surveys) in the post-channel closure period.

Large freshwater eels are regularly observed disturbing the water around Salty Lagoon. Since closure of the artificial channel the potential for upstream migration of recruiting freshwater eels into Salty Lagoon has remained good under most circumstances, with Salty Lagoon draining into Salty Creek for the majority of the time. Based on an understanding of the entrance dynamics in Salty Creek and the frequency of drainage from Salty Creek into Salty Lagoon eel migration into Salty Lagoon is more likely to be restricted by closure of the Salty Creek entrance than by closure of the artificial channel. While barriers to movement are known to impact the distribution and abundance of eels, they are renowned for their ability to overcome obstacles such as dams and weirs (Pusey *et al*. 2004) in addition to being able to traverse short distances over damp ground.

A dominance of freshwater fish species, a larger fish population and reduced fish diversity.

This anticipated change has not been consistently realised.

There is no clear trend towards dominance of freshwater fish species but there have been no Tamar River Goby (a saltwater tolerant species) captured in the post-channel closure period. The Flathead Gudgeon (a brackish water tolerant species) is the second most numerous native fish species captured and the most frequently encountered (captured in most surveys) native fish species over the course of the MPPC. There have been no clear trends in the capture of any of the native fish species at any sites during the MPPC (**Figure 6.6**, **Figure 6.7** and **Figure 6.8**).

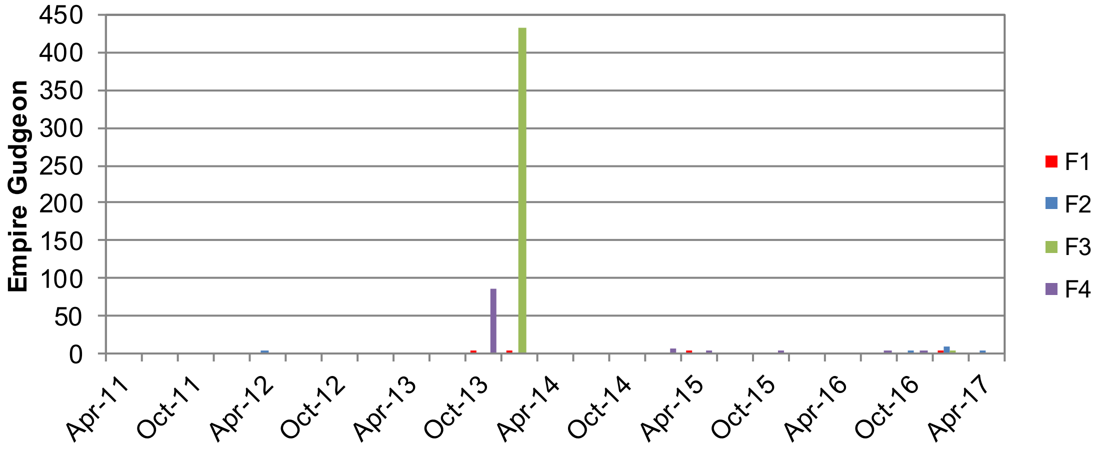


Figure 6.6 Empire Gudgeons captured at all sites during all surveys for the MPPC

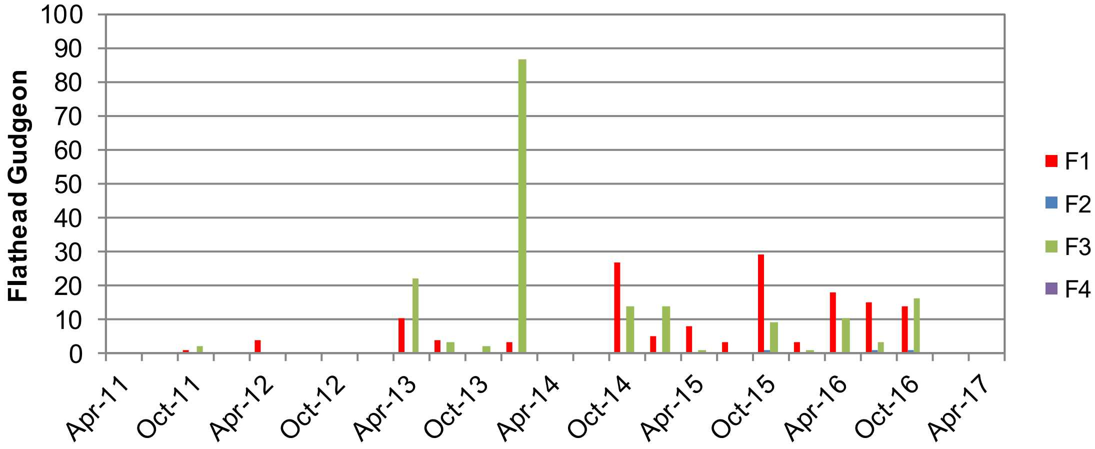


Figure 6.7 Flathead Gudgeons captured at all sites during all surveys for the MPPC

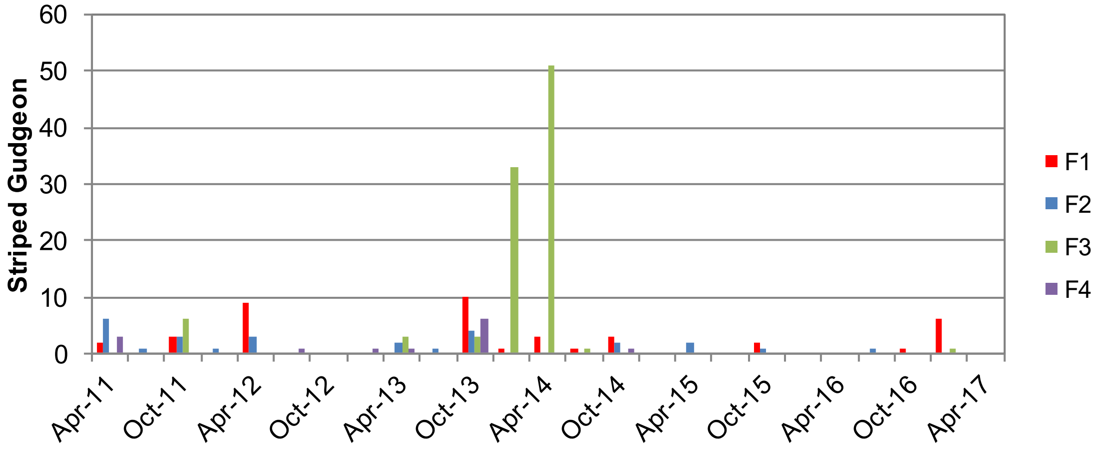


Figure 6.8 Striped Gudgeons captured at all sites during all surveys for the MPPC

There is some evidence, though not yet consistent, that fish diversity has reduced since closure of the artificial channel. Although there is not a clear trend in the overall diversity of fish species captured (**Figure 6.1**) the average number of fish species captured per survey has reduced at all sites since closure of the artificial channel. However, variation in the dataset is large, restricting the capacity to draw firm conclusions (**Figure 6.9**).

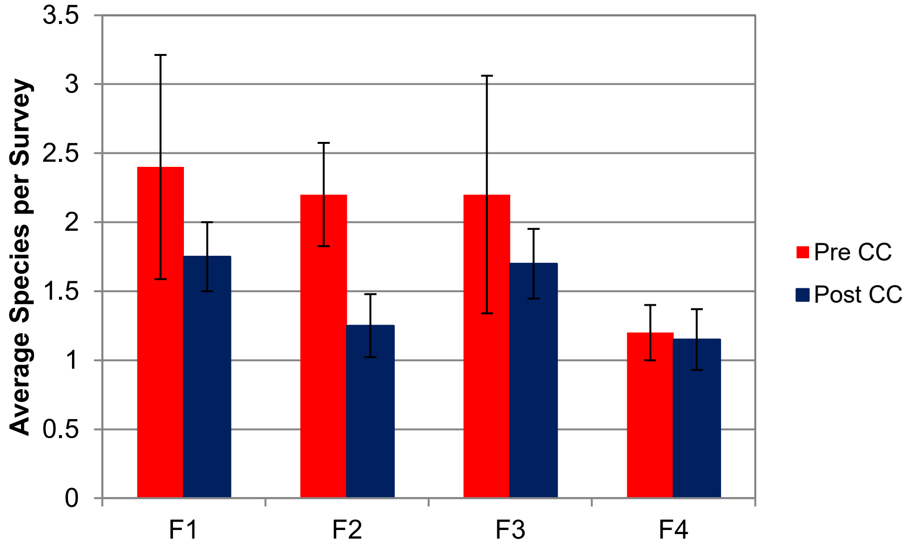


Figure 6.9 Mean ± SE fish species captured per survey at all sites in the pre and post-closure periods

There is no clear evidence of an increase or decrease in the fish population in Salty Lagoon since closure of the artificial channel. Changes in the average number of individual fish captured in the pre and post channel closure periods vary between sites (**Figure 6.10**). In addition, the variation in the dataset is high, restricting the capacity to draw firm conclusions.

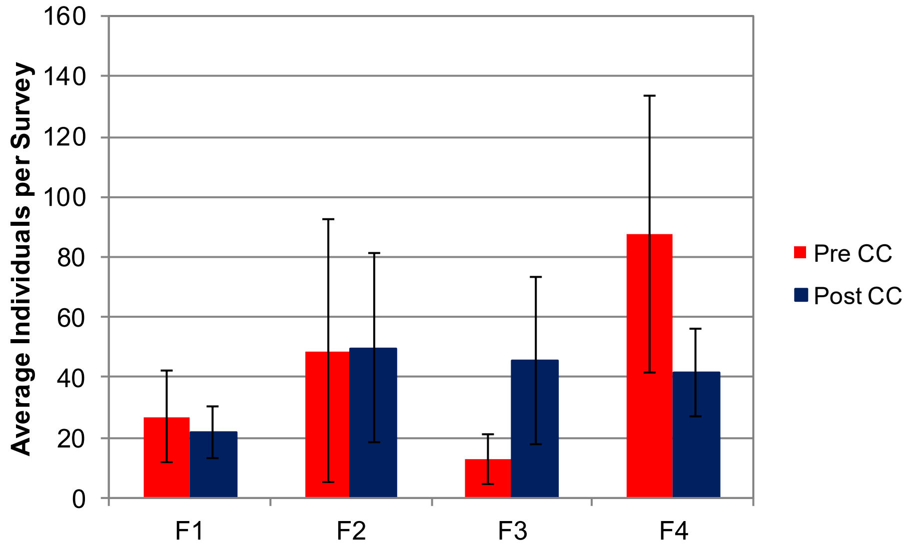


Figure 6.10 Mean ± SE fish captured per survey at all sites in the pre and post-closure periods

7. Waterfowl

7.1 Introduction

Waterbirds are an important part of wetland ecosystems. The particular range of species found in any one system depends on a range of physical and biological characteristics. Prior to the closure of the artificial channel Salty Lagoon provided a range of feeding and nesting habitats for waterfowl, waders and shorebirds, depending upon the water level. Since closure of the artificial channel, waterbird habitat diversity and variability has reduced in Salty Lagoon.

Waterbirds are included in the MPPC project because they can be monitored with relative ease and may compliment other monitoring procedures undertaken.

7.2 Methods

Water bird surveys were completed on a seasonal basis once every three months (25 monitoring events in total). Waterbird monitoring involved a foot and/or canoe based traverse of open water and fringing rushlands in Salty Lagoon over the course of one hour. All birds observed were included in the count, including non-waterbirds. However, the focus of discussion relating to changes in bird assemblages on Salty Lagoon focuses on waterbirds, waders and shorebirds. All possible efforts were made to avoid counting individual birds or flocks twice. Where flocks of >8 birds were observed, a GPS mark was taken. These are displayed in the relevant annual reports (e.g. GeoLINK 2017a).

7.3 Results

7.3.1 Conditions at the Time of Monitoring

Environmental conditions at the time of survey greatly affect the avifauna present. Water level is particularly important to habitat availability in Salty Lagoon, the most notable example being the expansion of mud flats as water levels recede and a subsequent increase in feeding habitat for wading birds. Weather patterns prior to and during surveys are also important, as is the time of survey. A detailed description of the conditions at the time of sampling can be found in the MPPC annual reports (e.g. GeoLINK 2017a)

7.3.2 Diversity

A total of 52 bird species were observed during the MPPC (see **Appendix E** for species list). The diversity of species observed in waterbird surveys undertaken during the MPPC has varied across time but not in a reliable fashion (**Figure 7.1**).

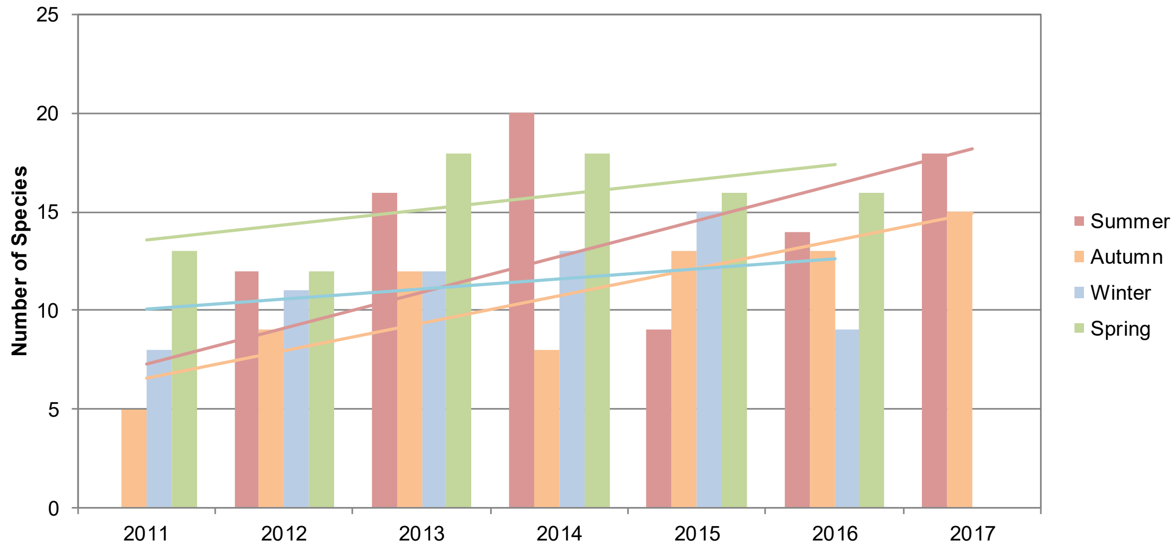


Figure 7.1 Number of bird species observed during the MPPC (with trendlines)

During the MPPC the diversity and species makeup observed in individual surveys was strongly linked to water level and, subsequently, habitat availability (GeoLINK 2017a). The effect of this was most notable on the diversity of shorebirds and waders, which depend closely on the availability of mudflats for feeding opportunities.

7.3.3 Abundance

A total of 3109 birds were observed during the MPPC surveys (see **Appendix E**). The most common bird observed was the Pacific Black Duck (*Anas superciliosa*). Overall waterbird abundance has varied throughout the MPPC since commencement in autumn 2011. There is an inconsistent trend towards increasing abundance since the closure of the artificial channel (**Figure 7.2**).

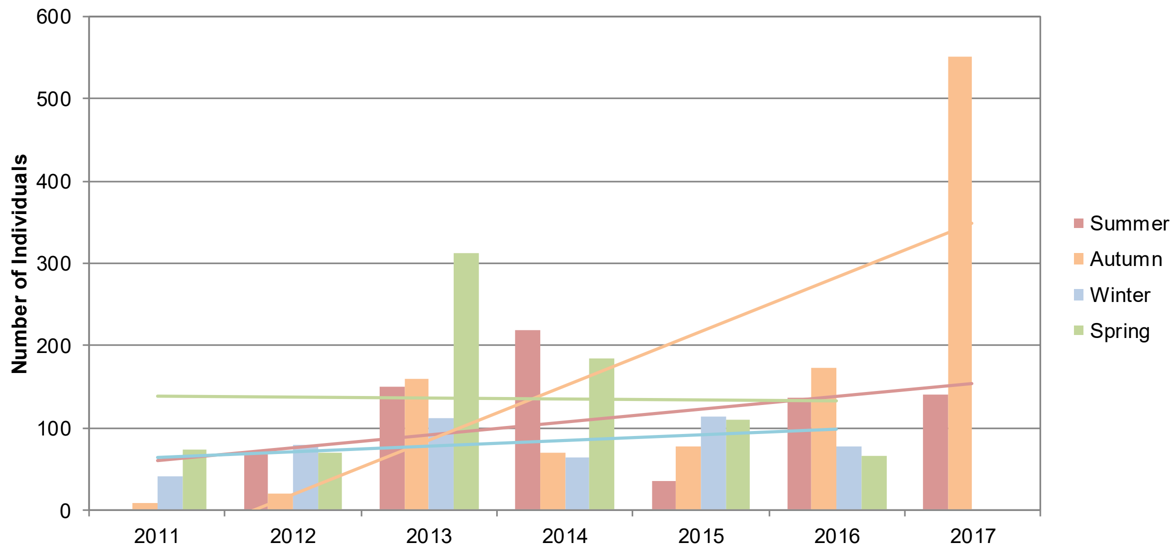


Figure 7.2 Number of individual birds observed in surveys during the MPPC (with trendlines)

In terms of individual species, the abundances of a small number of species appear to have stabilised at higher numbers or more frequent sightings since closure of the artificial channel. These species include Pacific Black Duck (*Anas superciliosa*), Hardhead (*Aythya australis*), Eurasian Coot (*Fulica atra*), Black Swan (*Cygnus atratus*) and Australasian Grebe (*Tachybaptus novaehollandiae*) (**Figure 7.3**).

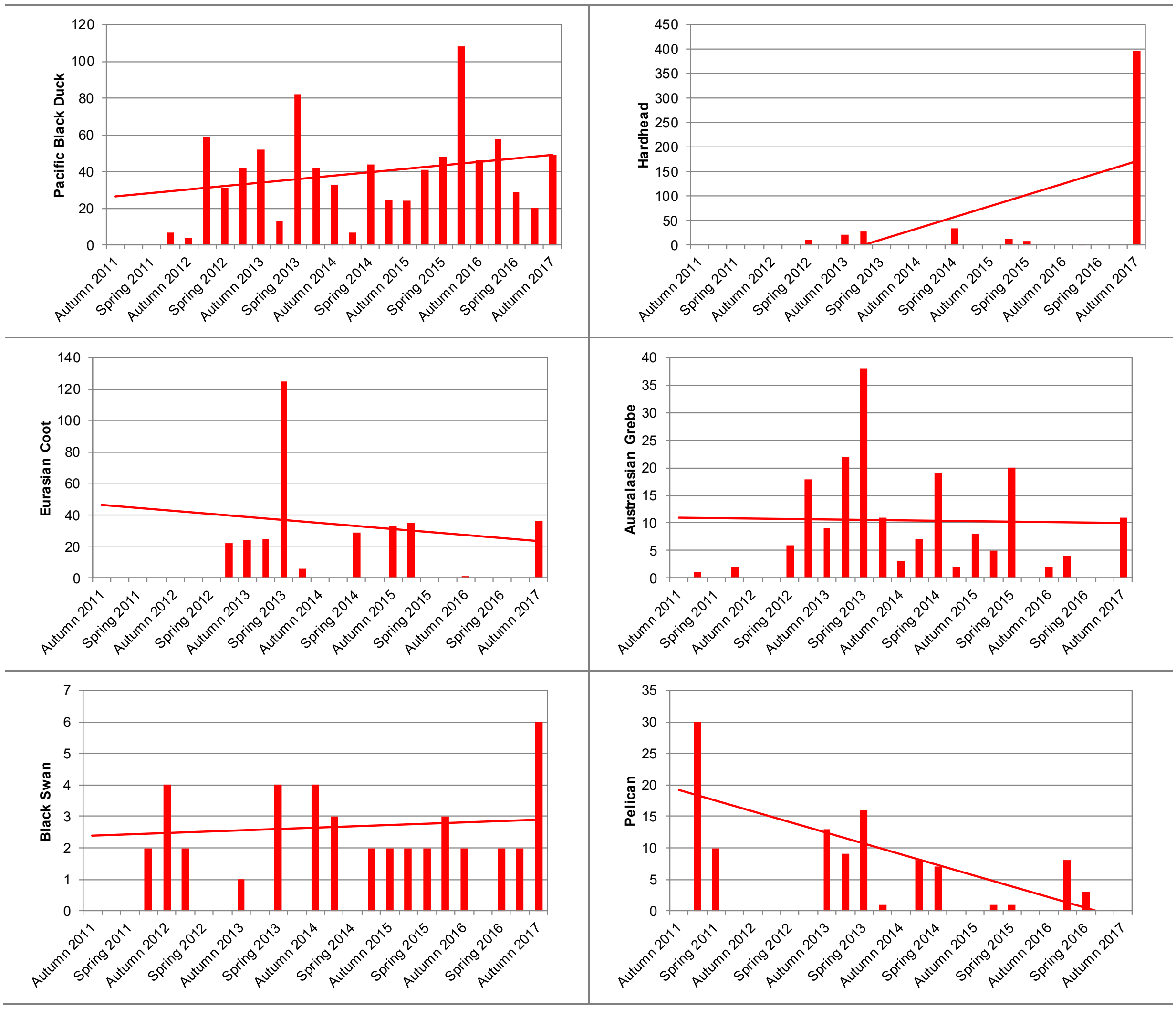


Figure 7.3 Number of individuals of waterfowl species observed per survey during the MPPC (with trendlines)

7.4 Discussion

Waterbird surveys have been a cost-effective means of assessing an important ecological aspect of the Salty Lagoon ecosystem. Waterbird abundance and diversity have both fluctuated throughout the MPPC program. The results of waterbird surveys indicate that there has been an increase in both species diversity and waterbird abundance since closure of the artificial channel. Some individual species of waterfowl, such as Pacific Black Duck and Australasian Grebe have stabilised at high numbers relative to those observed prior to channel closure. The data shows a relatively consistent increase in abundance and diversity in summer and spring when more migratory species are utilising Salty Lagoon.

7.4.1 Comparison against Rehabilitation Targets

There were two predicted changes to waterfowl usage of Salty Lagoon as a result of closure of the artificial channel made prior to the MPPC (Hydrosphere 2011). The predictions include:

- A positive impact on bird populations with an increased abundance of waterfowl but a reduction in opportunistic waders.
- Reduction in area of wading bird habitat.

In general the collected data indicates that the predicted changes with respect to waterfowl are being realised. A detailed discussion of the predicted outcomes follows.

A positive impact on bird populations with an increased abundance of waterfowl but a reduction in opportunistic waders.

This anticipated change has been realised. The average diversity and abundance of waterbirds observed during surveys has increased post-channel closure (**Figure 7.4**).

There has also been a consistent shift in the observed bird community towards a community dominated by waterfowl (families: *Anatidae*, *Anhingidae*, *Pelicanidae*, *Phalocrocoracidae*, *Podicipedidae* and *Rallidae*) (**Figure 7.5**). This trend has been relatively consistent over the years of the MPPC with the exception of a correction in 2014.

There has not been a reduction in the numbers of opportunistic waders (families: *Ardeidae*, *Ciconiidae*, *Gruidae*, *Jacanidae* and *Threskiornithidae*) or shorebirds (families: *Charadriidae*, *Haematopodidae*, *Laridae* and *Scolopacidae*) since channel closure but the variation in the dataset is large for these groups and there is no trend evident in any direction (**Figure 7.5**).

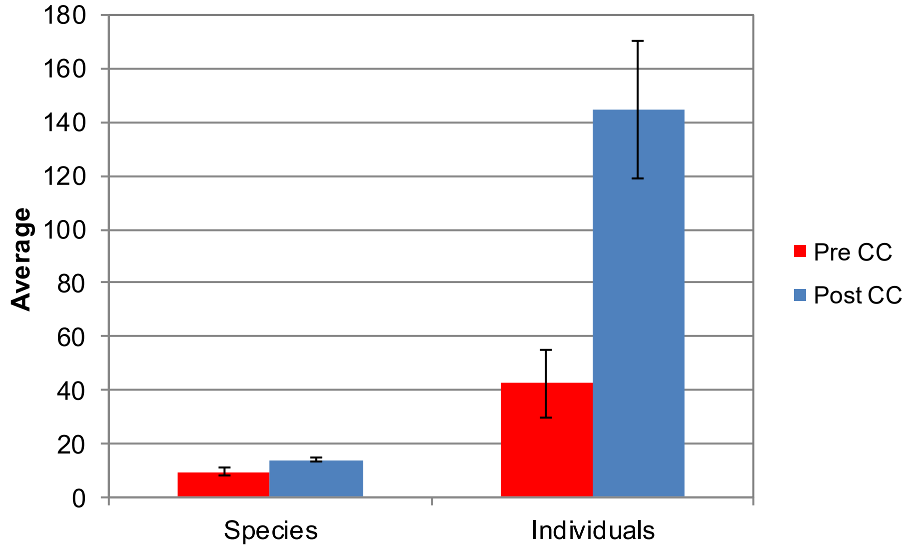


Figure 7.4 Average ± SE of bird species and individuals in surveys pre and post-channel closure

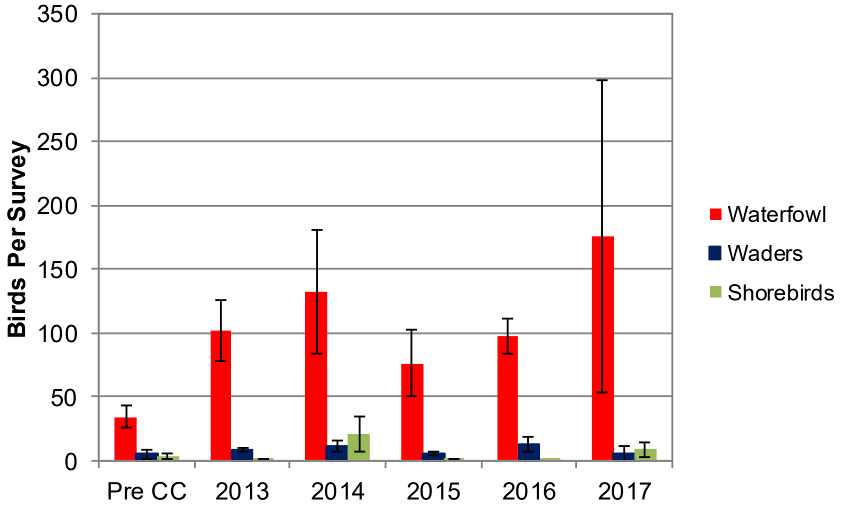


Figure 7.5 Average ± SE of waterfowl, waders and shorebirds in surveys pre and post-channel closure

Reduction in area of wading bird habitat

This anticipated change has been realised. With the exception of the low water levels in spring 2014 and summer 2015 and again in summer 2017, the area of mudflats available to wading birds has greatly reduced and the majority of habitat available in Salty Lagoon is now open water or permanently wet rushlands.

8. Frogs

8.1 Introduction

Frogs are good indicators of ecosystem health, particularly in relation to water quality (Robinson 1998). Their responsiveness to changes in water quality (including salinity and nutrient levels) and the variability of microhabitat requirements between species/ species groups known at Salty Lagoon makes them a valuable indicator of ecosystem change for the MPPC program.

It was predicted that closure of the artificial channel between Salty Creek and Salty Lagoon would lead to changes in the frog community from a number of interacting factors such as water level, salinity, pH and competition between species. In particular it was predicted that there will be an expansion of usable habitat for frogs at the site, including expansion of the area suitable for acid frog (Hydrosphere 2010a).

'Acid' (or Wallum) frogs previously recorded at Salty Lagoon include the Wallum Froglet (*Crinia tinnula*), Wallum Rocket Frog (*Litoria freycineti*) and Wallum Sedge Frog (*Litoria olongburensis*). The Wallum Froglet and Wallum Sedge Frog are listed as Vulnerable species under the *Biodiversity Conservation Act 2016* (which replaces the repealed *Threatened Species Conservation Act 1995*). The Wallum Sedge Frog is also listed as Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

8.2 Methods

Frogs were sampled using two methods:

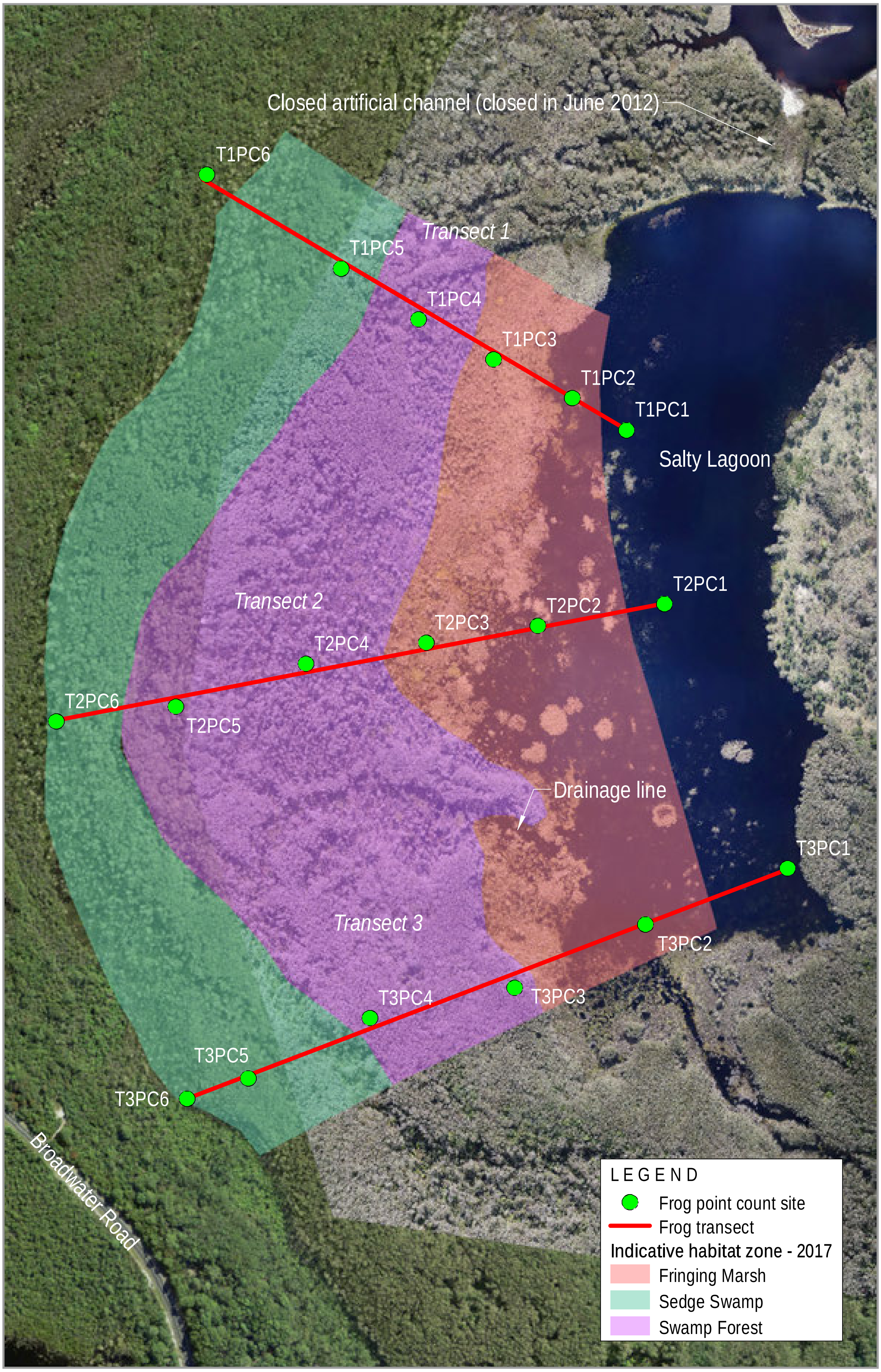
- Point counts undertaken at six fixed points along three fixed transects targeting all species. Frog species within 20 m of the point were identified and counted as 'on-site' recordings, while frogs >20 m to 50 m of the point were recorded in as 'off-site' recordings.
- Transect traverses undertaken along three fixed transects which corresponded with the point counts, targeting an 'acid' frog species (ie. Wallum Froglet) and a non-acid frog species (Dwarf Tree Frog *Litoria fallax*).

A detailed description of the survey methodology and conditions during the survey event can be found in the corresponding MPPC annual reports (eg. GeoLINK 2017a). Survey locations are shown in **Illustration 8.1**. Frog surveys were undertaken seasonally over two non-consecutive nights in late winter, spring and summer, totalling:

- Three seasonal survey events pre-artificial channel closure (baseline surveys).
- Fifteen seasonal survey events post-artificial channel closure.

Three main habitat types were initially sampled, referred to as Fringing Marsh, Swamp Forest and Sedge Swamp (refer to **Section 4** for details). Post closure of the artificial channel, as the water level within Salty Lagoon increased and stabilised, the habitat at the eastern end of the transects changed floristically and structurally. New habitats included 'Open Water' and various ecotone including Fringing Marsh/ Swamp Forest ecotone, Fringing Marsh/ Open Water ecotone; open water with emergent rushes (such as Shore Club-rush, Broadleaf Cumbungi and Common Reed).

Drawn by: GJM Checked by: RE Reviewed by: DSA Date: 13/10/2017
Source of base data: Richmond Valley Council
Information shown is for illustrative purposes only



Frog Monitoring Sites

Illustration 8.1

GeoLINK environmental management and design

Final Evaluation Report
Salty Lagoon Monitoring Program: Pre/ Post Closure of the Artificial Channel
1731-1288

8.3 Results and Discussion

8.3.1 Overall Species Diversity and Abundance

A total of 11 frog species were recorded during the MPPC program, including ten on-site recordings. This includes eight species of tree frog (Family Hylidae) and three species of burrowing frog (Family Myobatrachidae). These species are listed in **Appendix F**, along with the total number of individuals recorded on-site per species per season and year. 'Acid' frog species recorded included the Wallum Sedge Frog and Wallum Froglet.

The highest diversity of species recorded (10) was made prior to closure of the artificial channel. However there is no obvious trend in the total number of species recorded per year (range 6 to 10, mean 7.2; refer to **Figure 8.1**). Fluctuations in total species diversity per year are likely to be associated with climatic conditions during each survey event and general survey limitations (e.g. species present but not occurring or calling from within the point count footprint).

The number of individual frogs records for all species shows a general increasing trend post closure of the artificial channel (refer to **Figure 8.1**). This corresponds with an increase in the extent of available habitat within Salty Lagoon, as the system transitions to a more stable freshwater environment and vegetation colonises the areas of open water which formed post channel closure. While the highest number of individual frogs recorded was in summer, variations between seasons were not substantial (refer to **Appendix F**). This is despite some general seasonally trends for specific species which is discussed below. The low number of records during the 2013-14 reporting period (**Figure 8.1**) is attributed to dry conditions over this period.

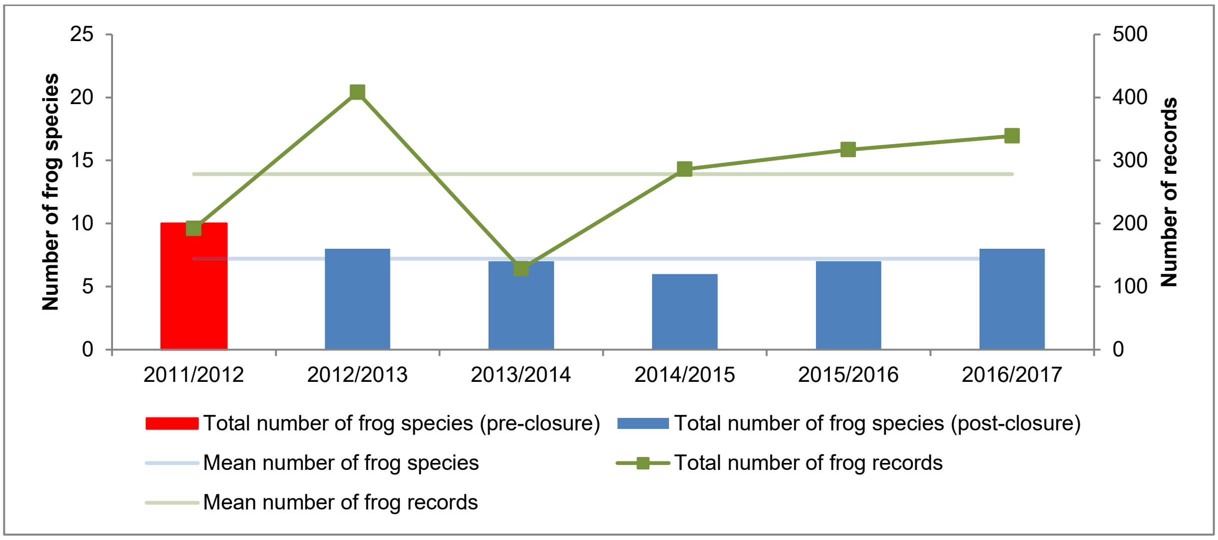


Figure 8.1 Total number of frog species and 'on-site' recordings at all sites each year during the MPPC program

The total number of on-site records per species recorded each year of the MPPC program is displayed in **Figure 8.2**. The Dwarf Tree Frog was the most abundant species recorded (807 on-site records) and was primarily recorded in the eastern portion of each transect within the open water (with emergent vegetation), Fringing Marsh and Swamp Forest habitats. The results indicate this species has been advantaged by closure of the artificial channel, with increasing numbers recorded post closure of the artificial channel. There was no trend to the total number of records made per season for this species.

Other commonly recorded species (in descending order) include:

- Rocket Frog (*Litoria nasuta* - 194 on-site records): Primarily recorded in the Fringing Marsh and Swamp Forest habitats. This species was only recorded in spring and summer, with no obvious trend in the numbers of individuals recorded each year.
- Tyler's Tree Frog (*Litoria tyleri* - 194 on-site records): Primarily recorded in the Fringing Marsh (including melaleuca dieback zone with standing dead trees) and Swamp Forest habitats. This species was recorded in similar numbers across all seasons, with the number of individuals recorded each year varying substantially.
- Wallum Froglet (159 on-site records): Primarily recorded in the Sedge Swamp and Swamp Forest habitats, with localised records in the Fringing Marsh/ Swamp Forest ecotone in the north-west of Salty Lagoon. This species was recorded in varying numbers each year. No obvious trends in the number of individuals detected per season were recorded. The highest number of individuals recorded was in the 2016/17 reporting period.
- Striped Marsh Frog (*Limnodynastes peronii* - 143 on-site records): Primarily recorded in the Fringing Marsh and Swamp Forest habitats, with the majority of records obtained during summer surveys. There were no obvious trends in the number of individuals recorded each year.
- Common Eastern Froglet (*Crinia signifera* - 109 on-site records): Primarily recorded in the Fringing Marsh and Swamp Forest habitats, with the majority of records obtained during winter surveys. There was a minor slight decreasing trend in the number of individuals recorded each year post closure of the artificial channel.

The Wallum Sedge Frog (27 on-site records) and Emerald Tree Frog (*Litoria peronii* - 35 on-site records) were less abundant. While both species show a tentative decreasing trend in the number of individuals recorded post closure of the artificial channel, this is likely to be a miss representation due to the smaller data pool. For example, the Wallum Sedge Frog was recorded off-site each year over a similar distribution (i.e. primarily the Sedge Swamp). The number of Tyler's Tree Frog individuals recorded each year ranged between 12 and 55, presenting a range larger than the highest number of records obtained for the Emerald Tree Frog (21) in a single year, both species of which occupy a similar habitat niche.

Recordings of the Bleating Tree Frog (*Litoria dentata*), Dainty Green Tree Frog (*Litoria gracilenta*) and Broad-palmed Frog (*Litoria latopalmata*) were rare (1, 0 and 1 on-site records respectively).

All species recorded in the MPPC program had previously been recorded in the broader Salty Lagoon study area in the ERMP monitoring (Sandpiper 2010), with the exception of the Broad-palmed Rocket Frog and Emerald Tree Frog. Five species recorded in the ERMP (Sandpiper 2010) were not recorded during the MPPC, including:

- Wallum Rocket Frog (*Litoria freycineti*).
- *Uperoleia spp*.
- Northern Banjo Frog (Limnodynastes terraereginae).
- Ornate Burrowing Frog (*Limnodynastes ornatus*).
- Cane Toad (*Bufo marina*).

This is primarily attributed to the ERMP covering a larger study area than the MPPC project, including additional habitat types.

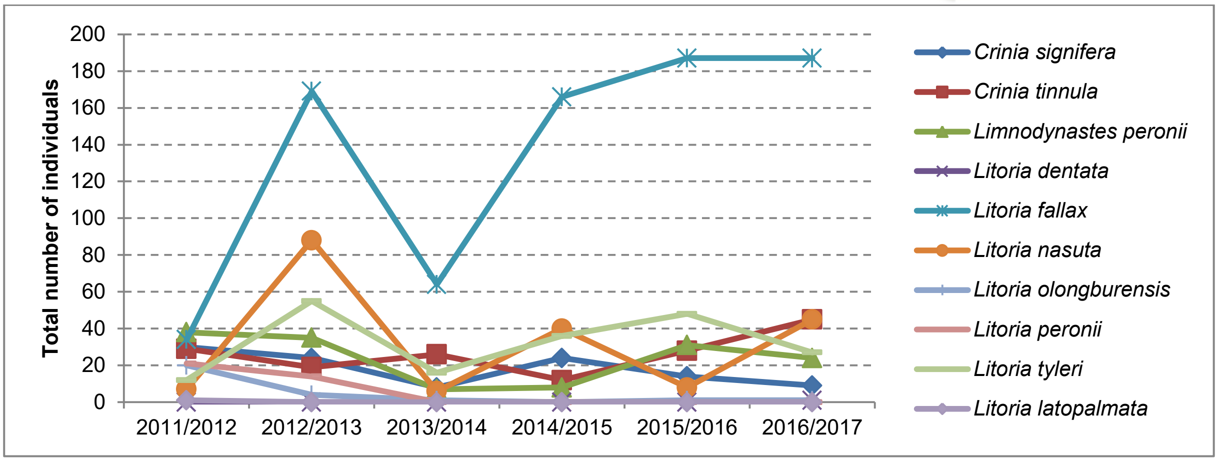


Figure 8.2 Total number of 'on-site' records per species at all sites each year during the MPPC program

8.3.2 Species Diversity by Vegetation Habitat Zone

In the Swamp Forest and Swamp Forest/ Fringing Marsh ecotone habitat:

- Eight species were recorded in the baseline (2011-2012) and 2012-2013 monitoring;
- Seven species were recorded in the 2013-2014 monitoring; and
- Six species were recorded in the 2014-2015, 2015-2016 and 2016-2017 monitoring.

In the Fringing Marsh/ open water ecotone and open water (with emergent rushes) habitats:

- Eight species were recorded in the baseline (2011-2012) and 2013-2014 monitoring;
- Seven species were recorded in the 2012-2013 monitoring;
- Five species were recorded in the 2014-2015 monitoring; and
- Four species were recorded in the 2015-2016 and 2016-2017 monitoring.

The general reduced species diversity trend over time in these habitats may be attributed to the more uniform habitat created by closure of the artificial channel. The increased water levels have resulted in reduced vegetation around the periphery of the lagoon. Fringing Marsh on the edge of the lagoon was initially converted to open water as the water level has increased in the lagoon, resulting in both a narrowing in the width of the fringing marsh habitat and a reduction in the availability of structural habitat for frogs (emergent vegetation). The colonising rushes within the open water are somewhat uniform in structure. Overall the general lower species diversity, at least in the Fringing Marsh, may be attributed to the uniform habitat within this zone, resulting in a reduced diversity of species. General variations in species detectability and calling behaviour are also likely to have contributed to this trend.

In the Sedge Swamp habitat:

- Five species were recorded in the baseline monitoring (2011-2012), 2015-2016 and 2016-2017 monitoring;
- Three species were recorded in the 2012-2013 monitoring; and
- One species was recorded in the 2013-2014 and 2014-2015 monitoring.

Variations within this habitat are likely to be associated with variability in climatic factors such as seasonal weather conditions rather than a change in salinity or water quality attributable to the closure of the artificial channel.

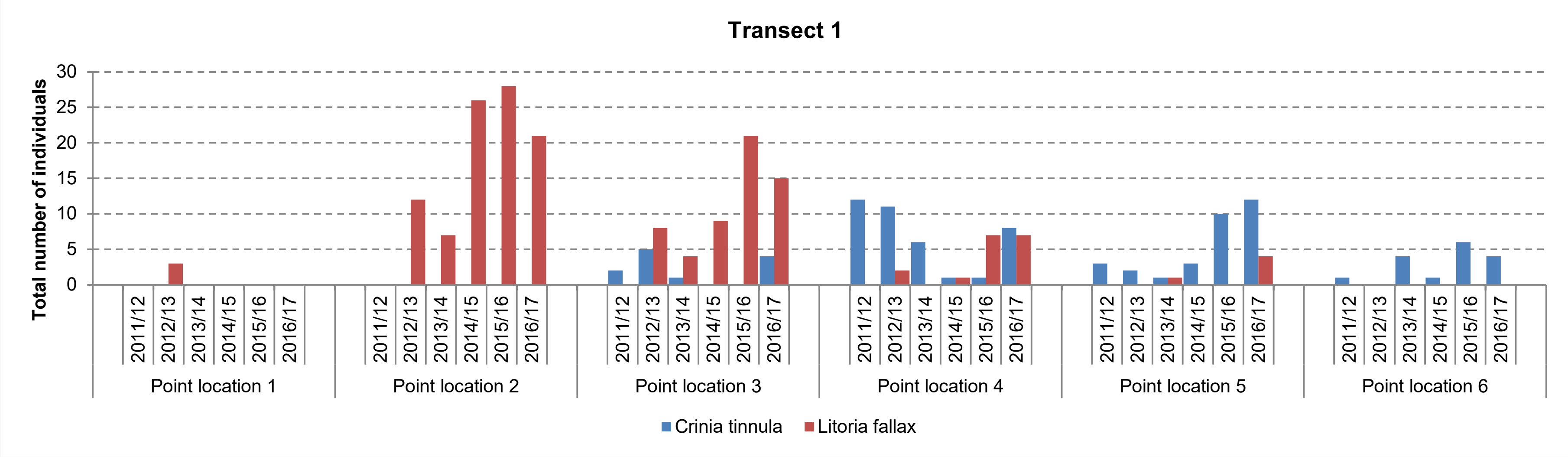
8.3.3 Habitat Segregation and Distribution Patterns

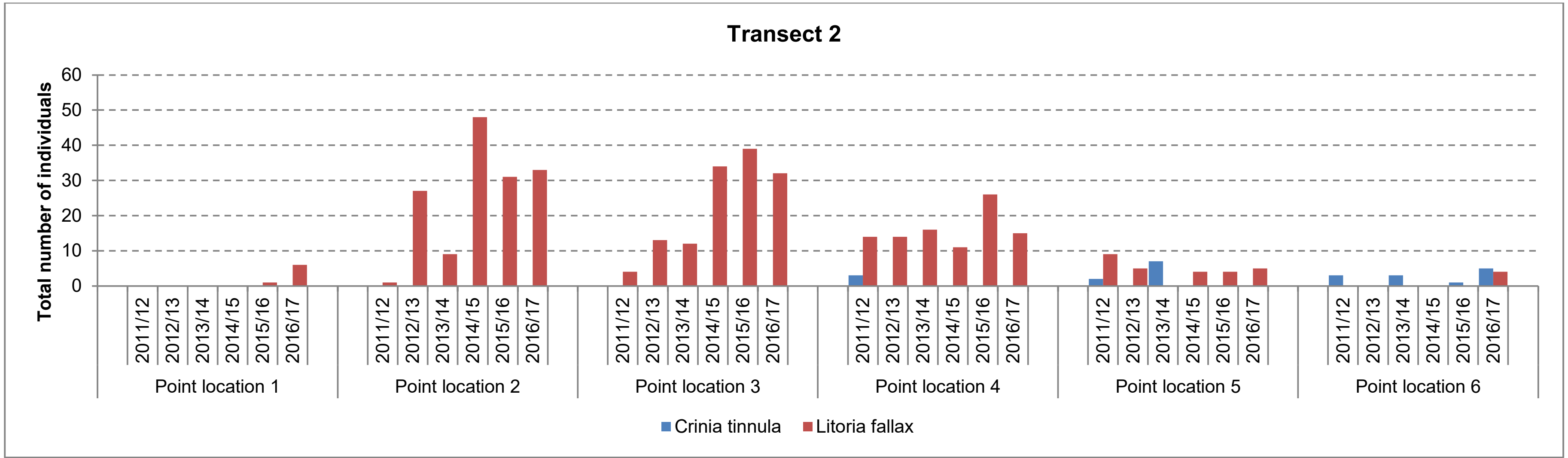
The following summary can be made relating to the distribution of the Wallum Froglet and Dwarf Tree Frog in the study area from both point count (**Figure 8.3**) and transect traverse results:

- Dwarf Tree Frogs were particularly dominant in the Fringing Marsh and Swamp Forest habitats; including the Melaleuca dieback area.
- The Wallum Froglet was dominant in the Sedge Swamp habitat.
- The Wallum Froglet was observed in Swamp Forest habitat, however Dwarf Tree Frog was the dominant species.
- Only a minor occurrence of Wallum Froglet was recorded in Fringing Marsh habitat and only a minor occurrence of Dwarf Tree Frog was recorded in Sedge Swamp habitat.
- The broadest distribution of the Wallum Froglet was recorded within habitats along Transect 1 and the narrowest distribution was along Transect 3 where this species only occurred in Sedge Swamp.
- The distribution of the Dwarf Tree Frog has fluctuated since closure of the artificial channel. Overall, however the species has been advantaged.
- The distribution of the Wallum Froglet has fluctuated since closure of the artificial channel. The species appears to have a reduced distribution in the Swamp Forest and northern Fringing Marsh area during periods when the water level is high within Salty Lagoon. However, these habitats remain at least periodically suitable and occupied by the Wallum Froglet (eg during prolonged dry periods when the water level within Salty Lagoon is low).

A primary segregating factor for the frog species at Salty Lagoon is the acid water tolerance of individual species. In general, this has the effect of limiting ‘acid’ frog species to Sedge Swamp and Swamp Forest habitats at Salty Lagoon. Although some overlap was recorded in the distribution of Wallum Froglet (acid frog) and Dwarf Tree Frog (habitat generalist), a general segregation was recorded based on habitat preference, with Wallum Froglet being most commonly recorded in those habitats furthest from the open water of Salty Lagoon and Dwarf Tree Frog being less common in these same habitats. Water quality monitoring has shown a buffering pH tendency towards neutral within the core water body of Salty Lagoon, making these areas unsuitable for the Wallum Froglet and other acid frog species. This is likely to affect the habitat quality within Swamp Forest, particularly at Transect 3 which is in proximity to the drainage channel in the south-east of the system.

In contrast to Transects 2 and 3, the monitoring has shown that the Fringing Marsh habitat bordering the Swamp Forest along Transect 1 (northern transect) provides at least periodically suitable habitat for the Wallum Froglet (see **Figure 8.3**) when environmental conditions are suitable (such as prolonged dry periods when the water level within Salty Lagoon is low).


Transect 1
Total number of individuals
30
25
20
15
10
5
0
2011/12
2012/13
2013/14
2014/15
2015/16
2016/17
Point location 1
Point location 2
Point location 3
Point location 4
Point location 5
Point location 6
Crinia tinnula
Litoria fallax


Transect 2
Total number of individuals
60
50
40
30
20
10
0
2011/12
2012/13
2013/14
2014/15
2015/16
2016/17
Point location 1
Point location 2
Point location 3
Point location 4
Point location 5
Point location 6
Crinia tinnula
Litoria fallax

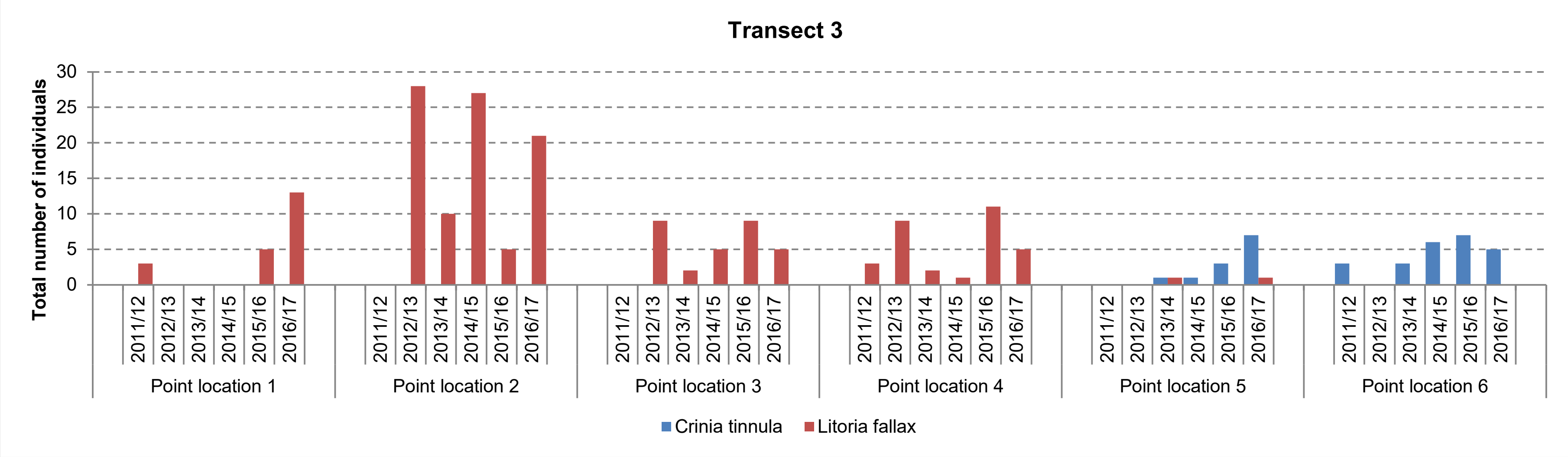


Figure 8.3 Wallum Froglet and Dwarf Tree Frog number of 'on-site' records at each point count along Transect 3 each year of the MPPC program

Note: Point location 1 to 6 along each transect extends from east to west respectively. Point 1 is closest to Salty Lagoon (Fringing Marsh or Open Water), while Point 6 is within the Sedge Swamp.

8.3.4 Comparison against Rehabilitation Targets

The ERMP data indicated that the main threat to specialist wallum species habitat (i.e. Wallum Froglet and Wallum Sedge Frog) in Salty Lagoon is from saline intrusion enabled by the artificial channel. Therefore, as the closure of the artificial channel effectively prevented large-scale salinity intrusion, it was predicted that the distribution of suitable habitat for these species might expand (Hydrosphere 2010b).

In Hydrosphere (2010b) it was predicted that:

"Changes in frog communities as a result of closure will be impacted by interacting factors, such as water level, salinity, pH and competition between species. It is likely that due to hydrological and water chemistry changes (specifically reduced saline intrusion) there will be an expansion in the usable habitat for species present at the site, including potential expansion in the area suitable for acid frogs".

Specific predicted outcomes on frogs following the closure of the artificial channel (Hydrosphere 2010b) and comparison with the findings of the MPPC frog monitoring are shown in **Table 8.1**.

Table 8.1 Predicted Frog Changes and Outcomes of the MPPC

Predicted Major Changes to the System	*MPPC Monitoring Findings*
Increase in acid frog (*Crinia tinnula, L. freycineti* and L. *olongburensis*) distribution.	Comparison of the distribution of the Wallum Froglet over the MPPC monitoring period does not support this prediction. Additionally, the core water body of Salty Lagoon has a pH unsuitable for acid frogs, also not concurring with this prediction. Wallum Froglet distribution has remained relatively stable within the Sedge Swamp and the majority of the Swamp Forest habitats, though fluctuated (reduced or similar to pre-closure) in the Swamp Forest in some areas and the northern Fringing Marsh over time. *Litoria freycineti* has not been recorded in the MPPC program. *Litoria olongburensis* has been recorded in low numbers during the MPPC program making it impossible to detect any changes in relation to these species, though the distribution within the Sedge Swamp appears stable. In contrast the habitat generalist Dwarf Tree Frog has been advantaged by closure of the artificial channel.

The results suggest that key factors determining acid frog distribution is a combination of:

- Acidic influence on water quality from water table inputs, particularly from adjacent wallum vegetation upslope.
- Higher water levels within Salty Lagoon, including water with a pH unsuitable for acid frogs within the core water body of Salty Lagoon.
- Saline intrusion into the system (predominantly pre-closure through the artificial channel and on infrequent occasions post closure of the artificial channel.

The generally higher water level within Salty Lagoon following closure of the artificial channel has effectively limited expansion of suitable acidic habitat out from the Sedge Swamp/ Swamp Forest from the west, or Swamp Forest/ Fringing Marsh from the north, towards the lagoon edge by diluting any low pH runoff or groundwater that may reach areas closer to the lagoon that have higher water levels.

8.3.5 Cane Toads

Cane Toads have not been recorded during the MPPC program. This is despite local records and recording in the broader area during the ERMP program, with the species recorded within ponds, heath and swamp forest habitats (Sandpiper 2010). While the MPPC program did not include frog monitoring on the eastern side of the lagoon (which provides better access for the Cane Toad due to the more open vegetation structure), it would be expected that breeding animals would have been heard during frog survey.

The risk of Cane Toad invasion within Salty Lagoon remains a real risk, with the post channel closure water quality of the system being within the species known foraging and successful breeding tolerance range (Wijethunga *et al*., 2015; DoEE 2015). It is noted however that prior to closure of the artificial channel, at least part of the Salty Lagoon system would have supported potential foraging for the Cane Toad, with the water quality in various areas being suitable for successful breeding at least periodically. The dense vegetation and lack of open tracks leading to the lagoon is likely to be a key factor as to why Cane Toads have not established in Salty Lagoon to date.

9. Assessment of Closure Effectiveness

9.1 Assessment of Closure Effectiveness

The primary purpose of the MPPC program is to confirm prediction that closure of the artificial channel will result in an overall improvement to the ecological and cultural values of Salty Lagoon. A summary of the predicted major changes to the Salty Lagoon system and the MPPC findings are provided in **Table 9.1**. Collectively the outcomes of the MPPC program indicate that the trial has been successful, as:

- The Salty Lagoon system has continued to move towards a predominantly freshwater lagoon system, with the monitoring recording relatively stable water quality conditions.
- Many of the predicted changes are occurring, including positive changes such as a more natural hydrology and salinity regime; reduced magnitude and rate of water level variation; less frequent saline water ingress; and reduced risk of fish kill.
- While other monitoring attributes have recorded no clear trend or negative trends, the results indicate overall improved ecological health at Salty Lagoon.

The trend towards a successful closure outcome was discussed with key stakeholders during the 2016 stakeholder meeting (which included NSW Department of Primary Industries [DPI] Fisheries, NSW Environmental Protection Agency [EPA] and RVC) based on the findings of the MPPC at that time (GeoLINK 2016). The agencies provided in-principle support of the successful closure outcome conclusion at that time. Subsequent monitoring in 2017 (GeoLINK 2017) provided similar results to other post closure monitoring years, indicating that the overall health of Salty Lagoon has improved post closure of the artificial channel. The agencies support is indicative of improvement in both the ecological and cultural values of Salty Lagoon.

Table 9.1 Predicted Major Changes to the Salty Lagoon System and Outcomes of the MPPC

Predicted Major Changes to System	*Summary of MPPC Findings*
More natural hydrology and salinity regime including higher water levels – 1.9 m AHD for approximately 63% of the time.	Positive Outcome - this prediction has been realised.
A reduced magnitude and rate of water level variation.	Positive Outcome - this prediction has been realised.
Less frequent saline water ingress.	Positive Outcome - this prediction has been realised.
Improved productivity of the benthic microalgal assemblage resulting in nutrient assimilation reduced algal blooms and reduced potential for deoxygenation.	Unclear Outcome - it is uncertain if the productivity of the benthic macroalgal assemblage has changed since the closure of the artificial channel.
Reduced water column algal biomass.	Negative Outcome - this prediction has not been realised.
Improved water quality generally with a risk of poor water quality episodes in the period immediately following the channel closure.	Variable Outcome - with respect to nutrient and microalgal concentrations there has not been an improvement in the average water quality conditions since the closure of the artificial channel. With respect to turbidity and pH there has been an improvement and stabilisation of water

Predicted Major Changes to System	Summary of MPPC Findings
	quality. The risk of poor water quality episodes in the period following the channel closure was realised during the drought conditions that persisted between October 2013 and March 2014, and January and March 2017. Poor water quality conditions resulted in algal blooms but have not resulted in a fish kill or other ecological incident.
Less temperature variability.	Positive Outcome - this prediction has been realised (with periodic exception associated with drought conditions).
Reduced average and maximum pH values.	Positive Outcome - This prediction has been realised.
Generally higher DO concentrations with a reduction in dramatic DO crashes and more predictable diurnal variation of DO.	Variable Outcome - the DO concentrations in surface waters have not increased since channel closure. While regular periods of low DO concentrations measured at the Salty Lagoon PWQMS have continued since channel closure the DO crashes that were associated with fish kill events prior to channel closure have not eventuated. Diurnal variation in DO concentrations is evident in the data from the PWQMS but when water levels are high wind driven mixing and freshwater flow are the dominant features driving DO concentrations.
Potential for low DO occurring as a result of high BOD of the marsh sediments and/or increased photo-oxidation of tannins in the warmer months.	Neutral Outcome - this prediction has been realised (minor extent).
Reduced probability of wind driven turbidity increases and no draining related turbidity spikes.	Positive Outcome - this prediction has been realised.
Reduced TP concentrations over time resulting from greater benthic microbial uptake and higher burial rates.	Negative Outcome - this prediction has not yet been realised.
Poor water quality episodes around high risk periods such as low water levels and high temperatures.	Negative Outcome - this predicted risk has been realised. During the summer months of 2013/2014 and 2016/17 water quality became very poor when water levels were at extreme lows and temperatures were very high.
Reduced TN concentrations and continued dominance of DON.	Neutral Outcome - the predicted reduced TN concentrations have not yet been realised. However, the extreme dry conditions that have characterised a large proportion of the post closure period have clearly contributed to higher average nitrogen concentrations. The predicted continued dominance of DON as the major form of nitrogen in samples has continued although at open water sample sites (S1 and S3) the proportion of TN as DIN has increased slightly in the post closure period.
Reduced severity of Salty Creek drawdown during draining events.	Positive Outcome - this prediction has been realised.
Less protracted entrance opening of Salty Creek.	Neutral Outcome - This anticipated change has not been consistently realised. Although it is difficult to assess the change due to differences in the conditions that cause entrance opening and closing there appears to have been a change in the dynamics of the entrance and the trends of opening and closing. Since channel closure the entrance to Salty Creek has more often been very shallow and narrow and only very slowly draining. Prior to channel closure the entrance was more likely to close

Predicted Major Changes to System	Summary of MPPC Findings
	completely but when open the entrance was more likely to be deeper and/or wider.
Macroinvertebrates: Change to freshwater dominated, more diverse, more robust aquatic ecology.	Positive Outcome - this prediction has been realised (to an extent).
Change of saltmarsh community to freshwater macrophyte/ macroalgae in Salty Lagoon with change to freshwater.	Positive Outcome - this prediction has been realised.
Melaleuca re-colonisation and reduction in area of dieback.	Neutral Outcome - this prediction has not been realised yet. There is neither little evidence of recolonisiation of Broad-leaved Paperbark nor any further dieback occurring. The overall health of the trees continues to be good, with thick foliage throughout and no signs of stress detected on any trees within the dieback zone.
Potential for aquatic weed growth in early stages with change to freshwater.	Positive Outcome - the risk of aquatic weed invasion has not been realised.
Reduced risk of fish kills.	Positive Outcome - this anticipated change has been realised. There have been no fish kill events since closure of the artificial channel and many of the conditions that were related to fish kills in the past have not eventuated or have eventuated to a lesser extent.
Increased Mosquitofish dominance.	Positive Outcome - this perceived risk has not been realised. The average mosquito fish capture per survey has reduced slightly since the closure of the artificial channel, despite an increase at one site. However, variation in this dataset is very large and it is difficult to draw strong conclusions about a reduction in the Mosquitofish population.
Potential for reduced freshwater eel migration to Salty Lagoon.	Unclear Outcome - it is not certain whether this predicted risk has been realised or not.
A dominance of freshwater fish species, a larger fish population and reduced fish diversity.	Neutral Outcome - this anticipated change has not been consistently realised.
A positive impact on bird populations with an increased abundance of waterfowl but a reduction in opportunistic waders.	Neutral Outcome - this anticipated change has been realised.
Reduction in area of wading bird habitat	Neutral Outcome - This anticipated change has also been realised.
Increase in acid frog (*Crinia tinnula, L. freycineti* and L. *olongburensis*) distribution.	Negative Outcome - this prediction has not been realised.

9.2 Emerging Trends and Issues

The erosive headcut to the east of the old artificial channel continues to present a threat to the project. Adaptive monitoring as part of the MPPC has observed continued advancement of the headcut. The position and continued advance of the headcut could potentially lead to a new channel between Salty Lagoon and Salty Creek supporting flow in both directions and return Salty Lagoon to the pre-closure state.

10. Considerations and Recommendations

10.1 MPPC Findings and Management Considerations

The *Salty Lagoon Rehabilitation Plan: Part B Options Assessment* (Hydrosphere 2009b) assessed management options to address the key issues at Salty Lagoon and provided the following key recommendations:

- Pursue the option to temporarily close the artificial channel connecting Salty Lagoon to Salty Creek for a nominal 5 year trial period.
- Maintain STP discharges to Salty Lagoon in the medium term (5 to 20 years), depending on environmental outcomes during the artificial channel closure trial.
- Continue to investigate long-term options for alternative disposal/ reuse of the effluent from the Evans Head STP. Progression of any of these options should consider the risks of effluent reduction to both the Drainage Channel and Salty Lagoon environments and appropriate management of these risks.
- Continue to monitor environmental condition and processes within the Salty Lagoon environment in order to document the anticipated long-term improvement due to the upgrade of the STP and the ecological response to artificial channel closure.
- Continue to liaise with regulatory agencies, Aboriginal stakeholders and other members of the community regarding future management of Salty Lagoon.

The primary management outcome of a successful (positive) trial based on the MPPC results is for the channel closure to be a permanent component of the Salty Lagoon rehabilitation strategy (Hydrosphere 2010a). Other key findings from the MPPC in relation to Evans Head STP discharge relevant to future management at Salty Lagoon are discussed in **Section 2.3.4** and summarised as follows:

- The discharge from the Evans Head STP does not appear to increase the water levels in Salty Lagoon. In effect, Evans Head STP discharge is not enough to maintain water levels and water losses to evaporation and groundwater are larger than the input from the STP.
- It is unlikely that discharged effluent from the Evans Head STP is contributing significantly to faecal coliform measurements in Salty Lagoon.
- The majority of the nitrogen in discharged effluent appears to be processed by the ecosystems occurring along the drainage channel upstream of Salty Lagoon. It is also likely that dilution with unpolluted water from around the catchment contributes to this effect. It is possible that elevated nitrogen concentrations around Salty Lagoon may be partially maintained in the long term by the input from the Evans Head STP.
- It is not likely that current phosphorus concentrations in discharged effluent are sufficient to maintain the phosphorus concentrations in the waters of Salty Lagoon. Hydrosphere (2010b) found an increasing trend of TP concentration along the drainage channel from the STP to Salty Lagoon and linked it to the release of phosphorus stored in sediments after years of effluent discharge rather than a lack of ecosystem processing of phosphorus released from the STP along

the drainage channel. It is likely that this is still the case and that it will continue for some time into the future.

The MPPC program has found that, at current levels, continued discharge from the Evans Head STP has a minimal effect on bioavailable nutrient concentrations within Salty Lagoon. Residual nutrients from historic pollution are currently the primary contributor of nutrients causing periodic poor water quality episodes in the system, and continued discharge from the Evans Head STP is unlikely to adversely affect the overall health of the system.

10.2 Ongoing Management of Salty Lagoon

Based on the MPPC findings and the Salty Lagoon Rehabilitation Plan recommendations (Hydrosphere 2009b, 2011), RVC propose to:

- Maintain permanent closure of the artificial channel between Salty Lagoon and Salty Creek.
- Continuing discharge of treated water from the Evans Head STP into the creek upstream (known as the 'Drainage Channel') of Salty Lagoon for the medium term (i.e. next 15 years).

With this the following recommendations are provided:

- Develop a long-term (>15 year) plan for the Evans Head STP, including a clear discharge strategy.
- Continue to liaise with regulatory agencies, Aboriginal stakeholders and other members of the community regarding future management of Salty Lagoon.
- Continue environmental monitoring at Salty Lagoon for the next 5 years (years 6 to 10 post closure of the artificial channel), with a review at completion of monitoring in 2021/2022.
- Continue to monitor and assess impacts of the head cut and work with stakeholders in regards to managing this as appropriate.

These recommendations are in line with Salty Lagoon Salty Lagoon Rehabilitation Plan recommendations (Hydrosphere 2009b; 2011).

10.2.1 Ongoing (Years 6 to 10 Post Closure of the Artificial Channel) Salty Lagoon Monitoring

It is recommended that environmental monitoring at Salty Lagoon continues, with the objective of:

- Monitoring the health of Salty Lagoon and confirming that Evans Head STP discharge is not adversely impacting water quality and ecology at Salty Lagoon.
- Monitoring water quality and the ecological attributes of the MPPC where predicted trends have not been confirmed and risks to the ecosystem health remain.
- Observing medium to long term changes in the Salty Lagoon system in response to channel closure.
- Informing future management decision making for Salty Lagoon and the Evans Head STP.

To determine a suitable monitoring program, the artificial channel closure risk assessments (Appendix 1 of the MPPC; Hydrosphere 2010a) were reviewed based on the MPPC monitoring findings (refer to **Appendix H**). Key findings of post closure risks to be monitored and managed include:

- The risk of fish kills and aquatic weed invasion has been reduced in comparison to the MPPC risk assessment for (one to five year period post-closure) based on the MPPC monitoring results.
- The potential for poor water quality episodes and aquatic plant and/or algal blooms remains as a moderate risk to ecosystem health in the 6-10 year period post-closure. The main factors in this risk rating are: the existing nutrient load in Salty Lagoon; and the unknown time required for the establishment of a freshwater ecosystem capable of efficiently assimilating the accumulated nutrient load. Ongoing monitoring of these risks is recommended.
- Widespread Cane Toad invasion remains a moderate risk, however is not recommended for ongoing monitoring as this risk is somewhat independent of ongoing discharge into Salty Lagoon.
- Low-risk impacts predicted in the 6-10 year period post-closure and recommended for continued regular monitoring include: weed invasion, health impacts from poor water quality and unsightly algal blooms affecting amenity.

The proposed monitoring will effectively continue and duplicate the existing MPPC program to allow for long-term data comparisons, though with reduced monitoring frequency and/or discontinuation of some monitoring activities. In addition, monitoring of the active headcut will be incorporated into the monitoring program.

The proposed ongoing monitoring program is based on five years of monitoring (2017/2018 to 2021/2022), with a review at completion of Year 5 (2021/2022). An outline monitoring plan is provided in **Appendix I**. A revised incident response protocol (titled *Post Closure Environmental Response Protocol – October 2017* in **Appendix J**) has been developed to accompany the ongoing monitoring and provide procedures to be followed during a response to a potential environmental incident in the Salty Lagoon system.

11. Conclusion

11.1 Conclusion

The *Salty Lagoon Monitoring Program: Pre-Post Closure of Artificial Channel* was undertaken between March 2011 and June 2017. Collectively the outcomes of the MPPC program indicate that the 5 year trial closure of the artificial channel between Salty Lagoon and Salty Creek has been successful, as:

- The Salty Lagoon system has continued to move towards a predominantly freshwater lagoon system, with the monitoring recording relatively stable water quality conditions.
- Many of the predicted changes of the MPPC (Hydrosphere 2010a) are occurring, including positive changes such as a more natural hydrology and salinity regime; reduced magnitude and rate of water level variation; less frequent saline water ingress; and reduced risk of fish kill.
- While other monitoring attributes have recorded no clear trend or negative trends, the results indicate overall improved ecological health at Salty Lagoon.

The primary management outcome of a successful (positive) trial is for the channel closure to be a permanent component of the Salty Lagoon rehabilitation strategy. With this the following recommendations are provided:

- Develop a long-term (>15 year) plan for the Evans Head STP, including a clear discharge strategy.
- Continue to liaise with regulatory agencies, Aboriginal stakeholders and other members of the community regarding future management of Salty Lagoon.
- Continue environmental monitoring at Salty Lagoon for the next 5 years (years 6 to 10 post closure of the artificial channel), with a review at completion of monitoring in 2021/2022.
- Continue to monitor and assess impacts of the head cut and work with stakeholders in regards to managing this as appropriate.

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Appendix A

Sample of Fixed Photo Point Results

Appendix A Fixed Photo Points Results Sample

Sites 1-5 correspond with discrete water quality monitoring sites, with sites 1-4 located within Salty Lagoon and site 5 located within Salty Creek (refer to **Section 2.2.2** for specific site location details). Site 6 is located at the infilled artificial channel.

	
Site 1 North August 2011	**Site 1 North May 2012**
	
Site 1 North November 2013	**Site 1 North January 2015**
	
Site 1 North March 2016	**Site 1 North April 2017**

	
Site 2 South August 2011	**Site 2 South May 2012**
	
Site 2 South November 2013	**Site 2 South January 2015**
	
Site 2 South March 2016	**Site 2 South April 2017**

Site 3 East August 2011

Site 3 East May 2012

Site 3 East November 2013

Site 3 East December 2014

Site 3 East March 2016

Site 3 East February 2017

Site 4 East August 2011

Site 4 East May 2012

Site 4 East November 2013

Site 4 East December 2014

Site 4 East March 2016

Site 4 East April 2017

Site 5 East August 2011

Site 5 East May 2012

Site 5 East November 2013

Site 5 East January 2015

Site 5 East February 2016

Site 5 East February 2017

Site 6 South November 2012

Site 6 South November 2013

Site 6 South January 2015

Site 6 South February 2016

Site 6 South April 2017

Appendix B

PWQMS Results

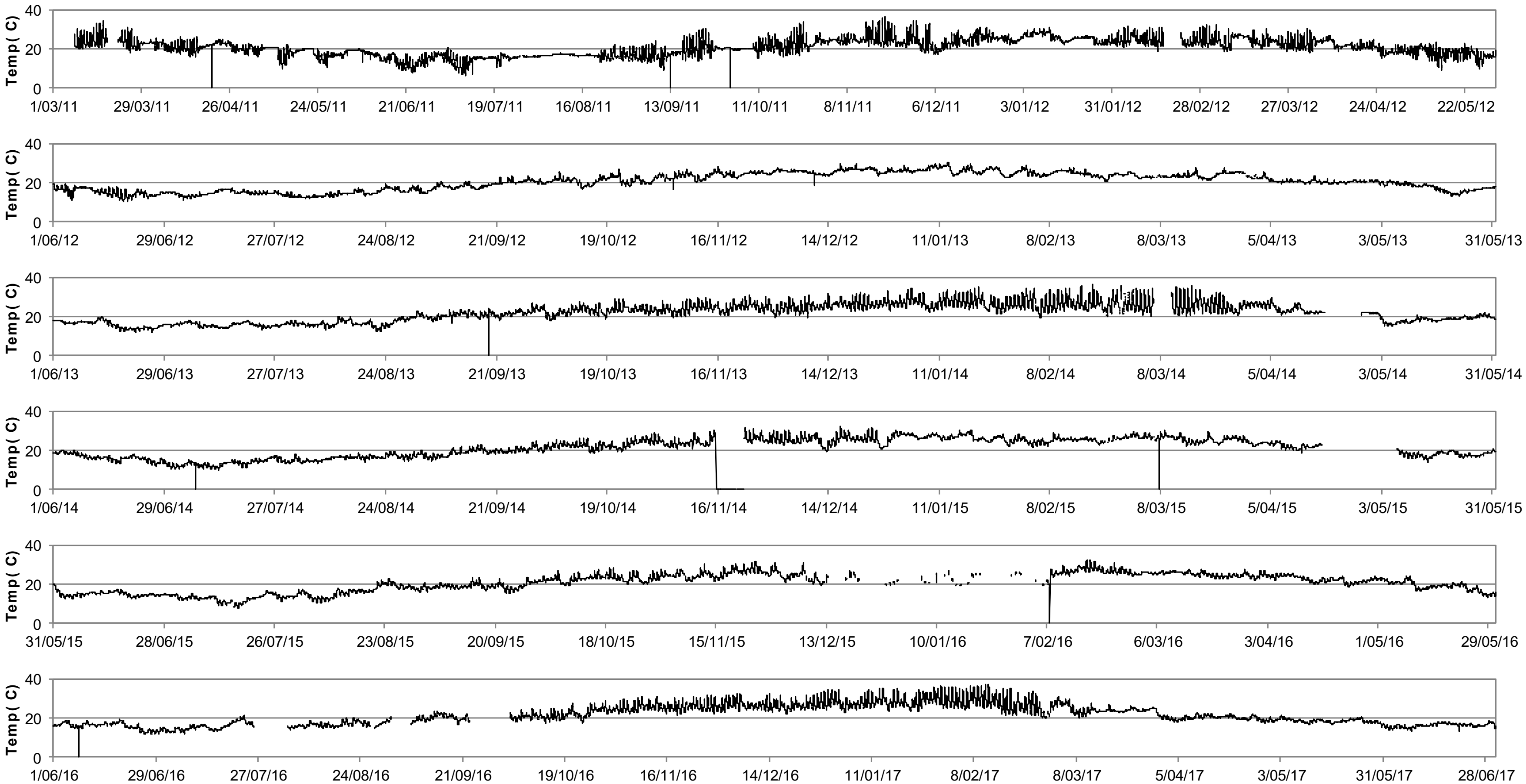


Figure B1 Temperature measurements from the Salty Lagoon PWQMS for the duration of the MPPC

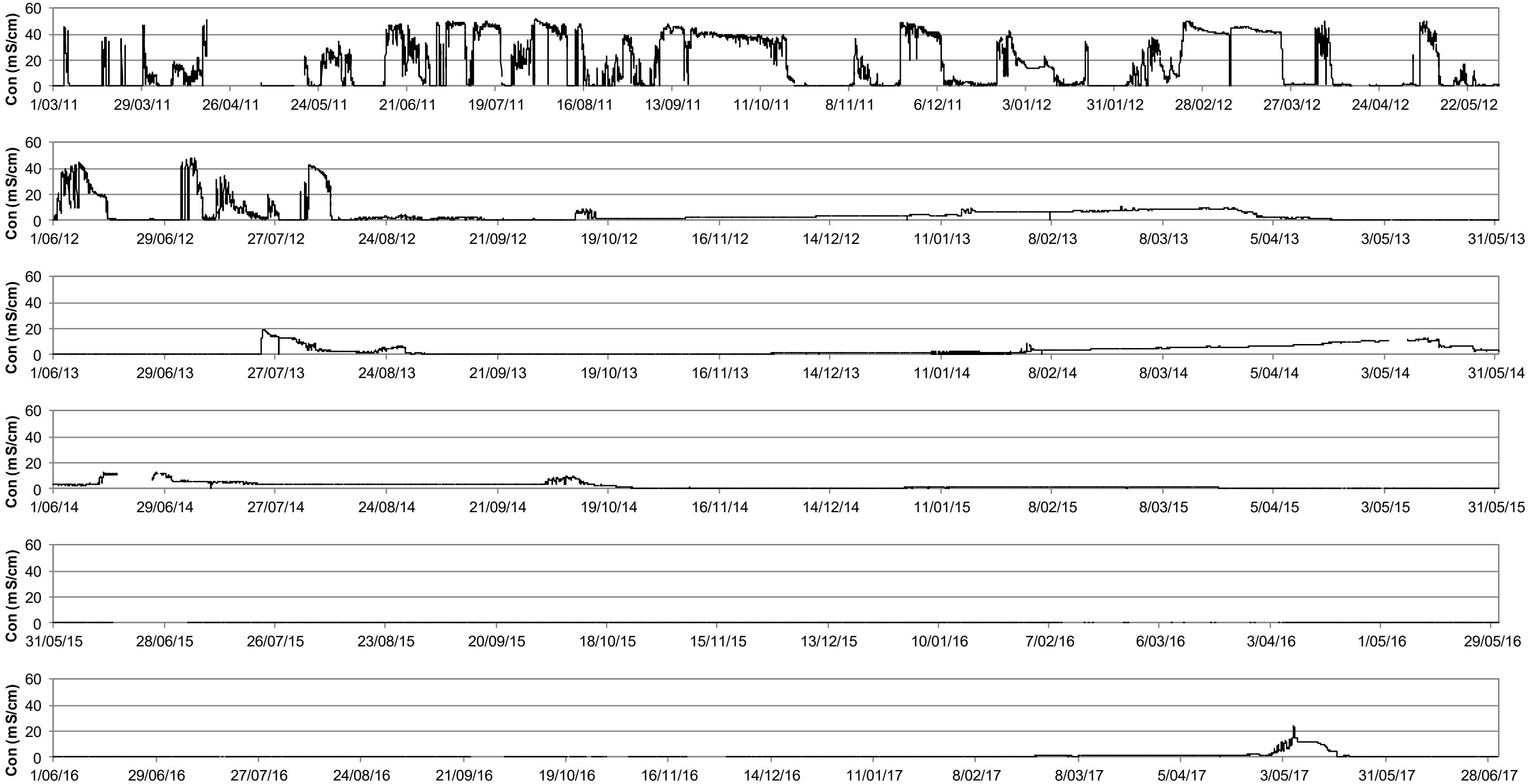


Figure B2 Conductivity measurements from the Salty Lagoon PWQMS for the duration of the MPPC

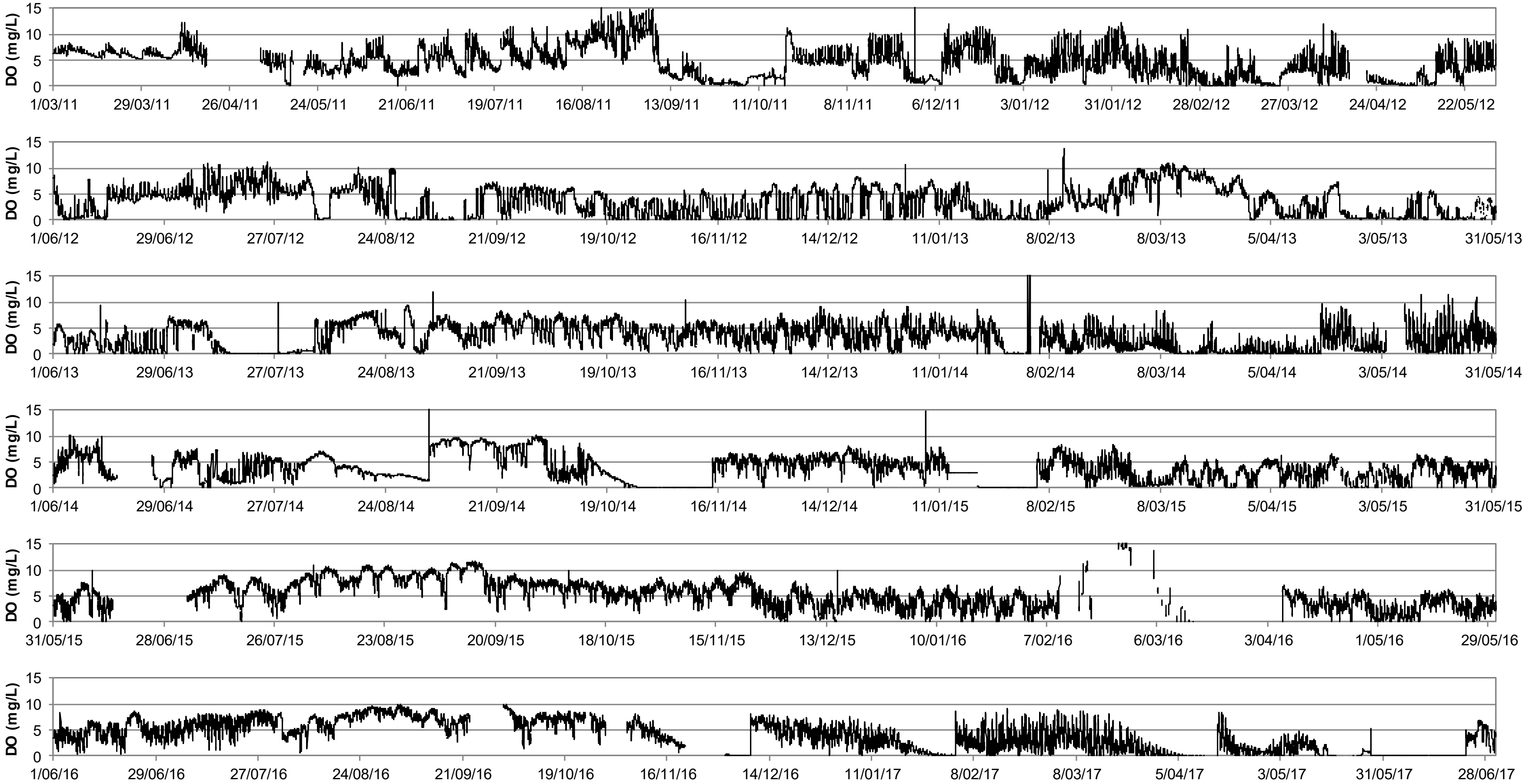


Figure B3 DO measurements from the Salty Lagoon PWQMS for the duration of the MPPC

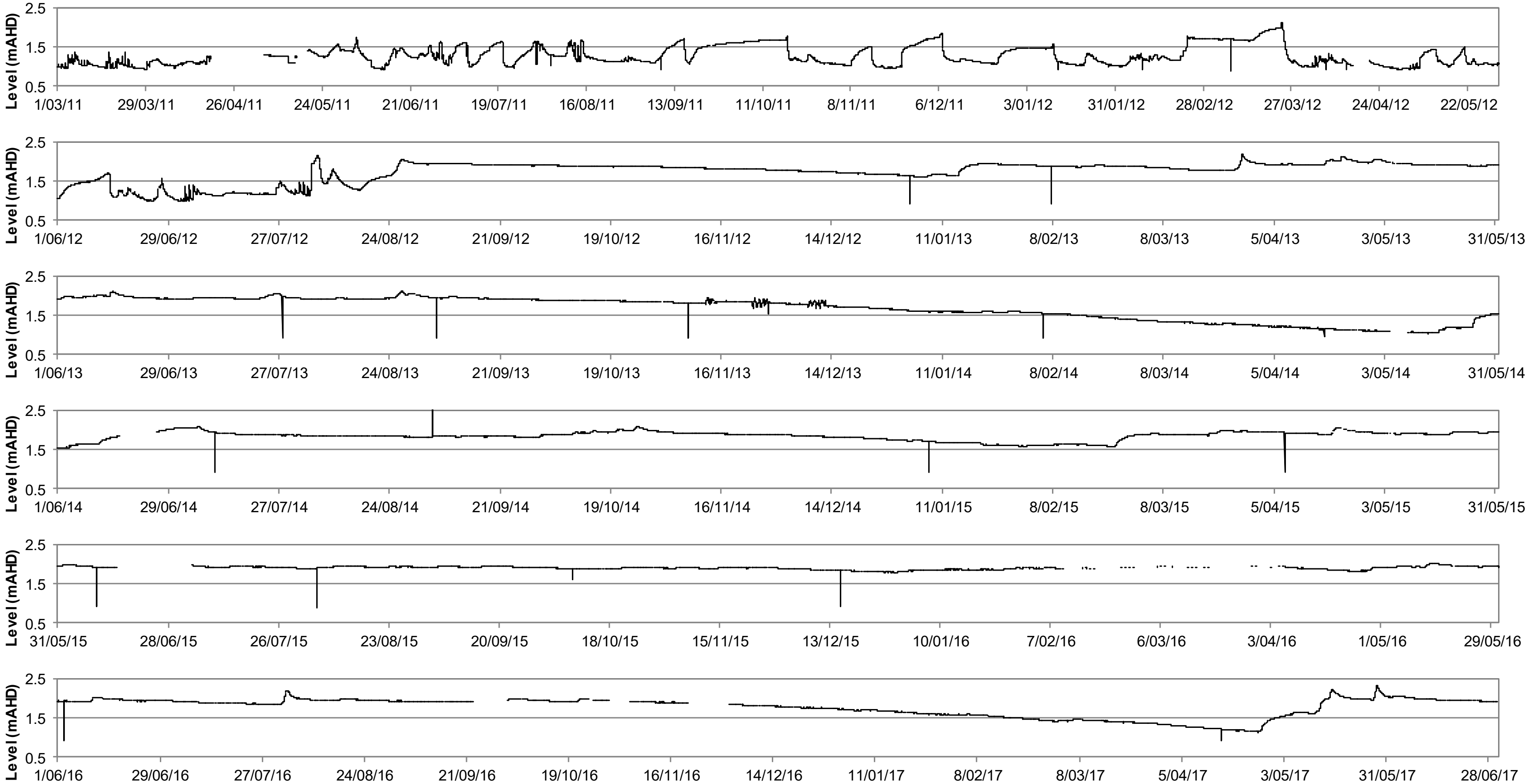


Figure B4 Level measurements from the Salty Lagoon PWQMS for the duration of the MPPC

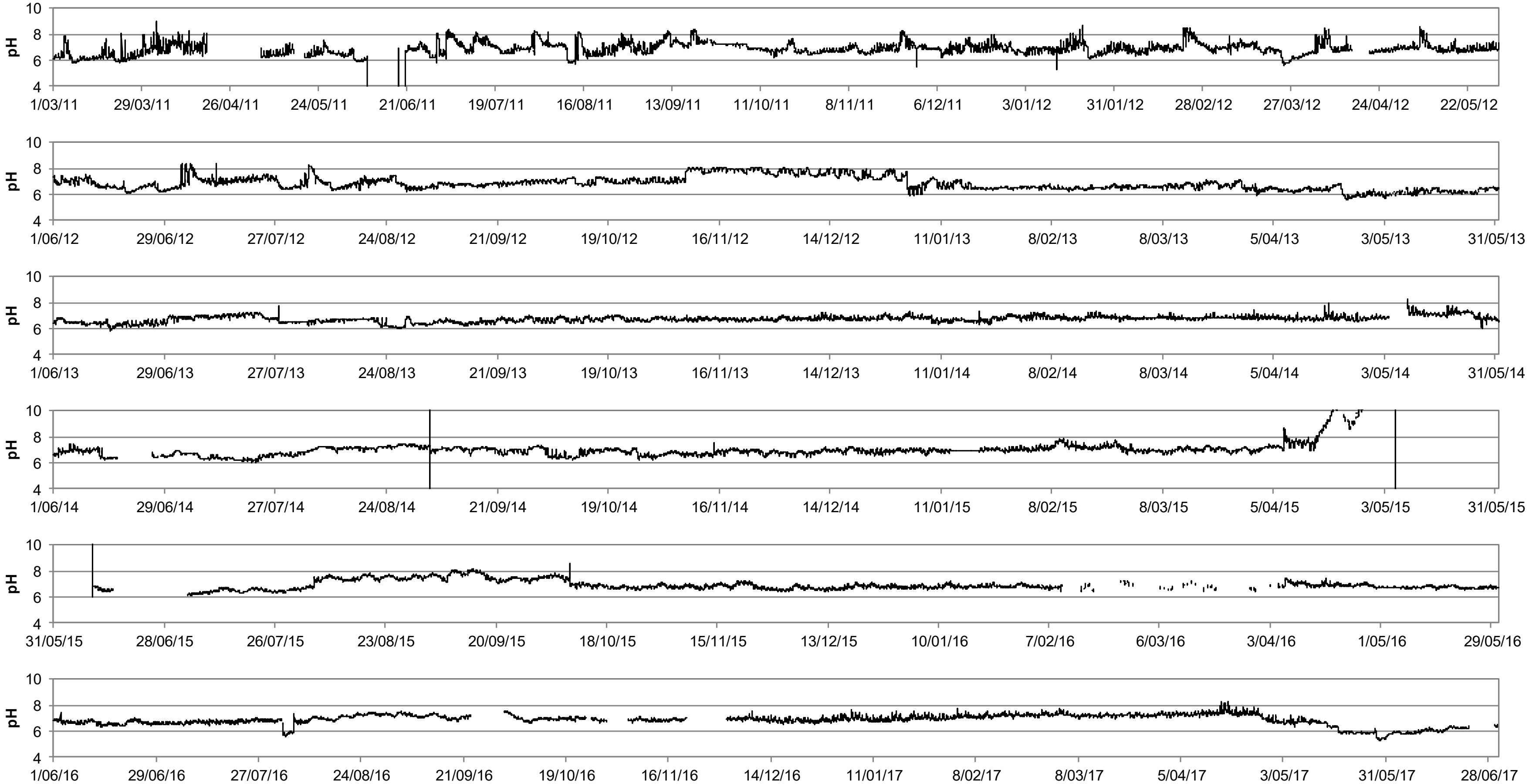


Figure B5 pH measurements from the Salty Lagoon PWQMS for the duration of the MPPC

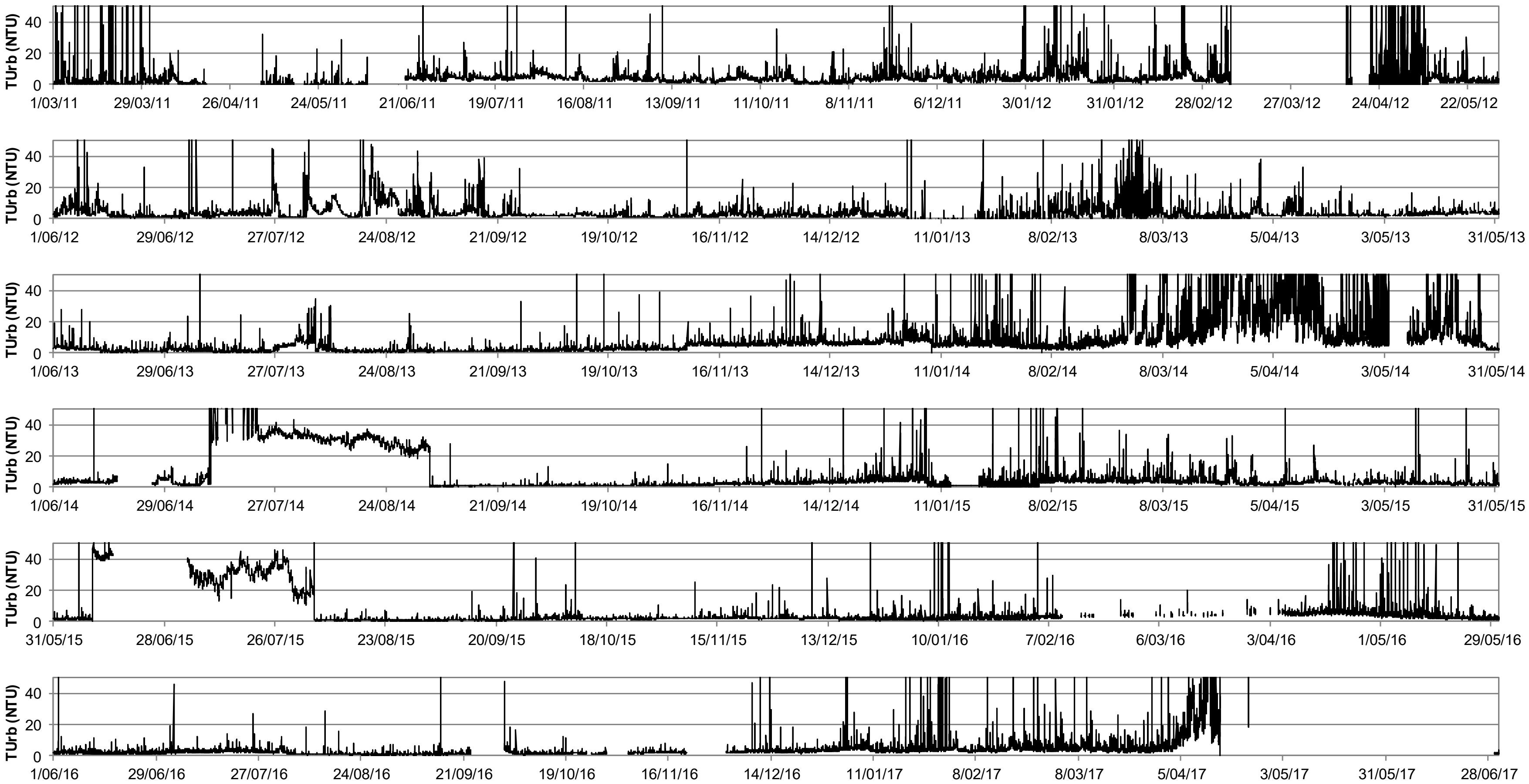


Figure B6 Turbidity measurements from the Salty Lagoon PWQMS for the duration of the MPPC

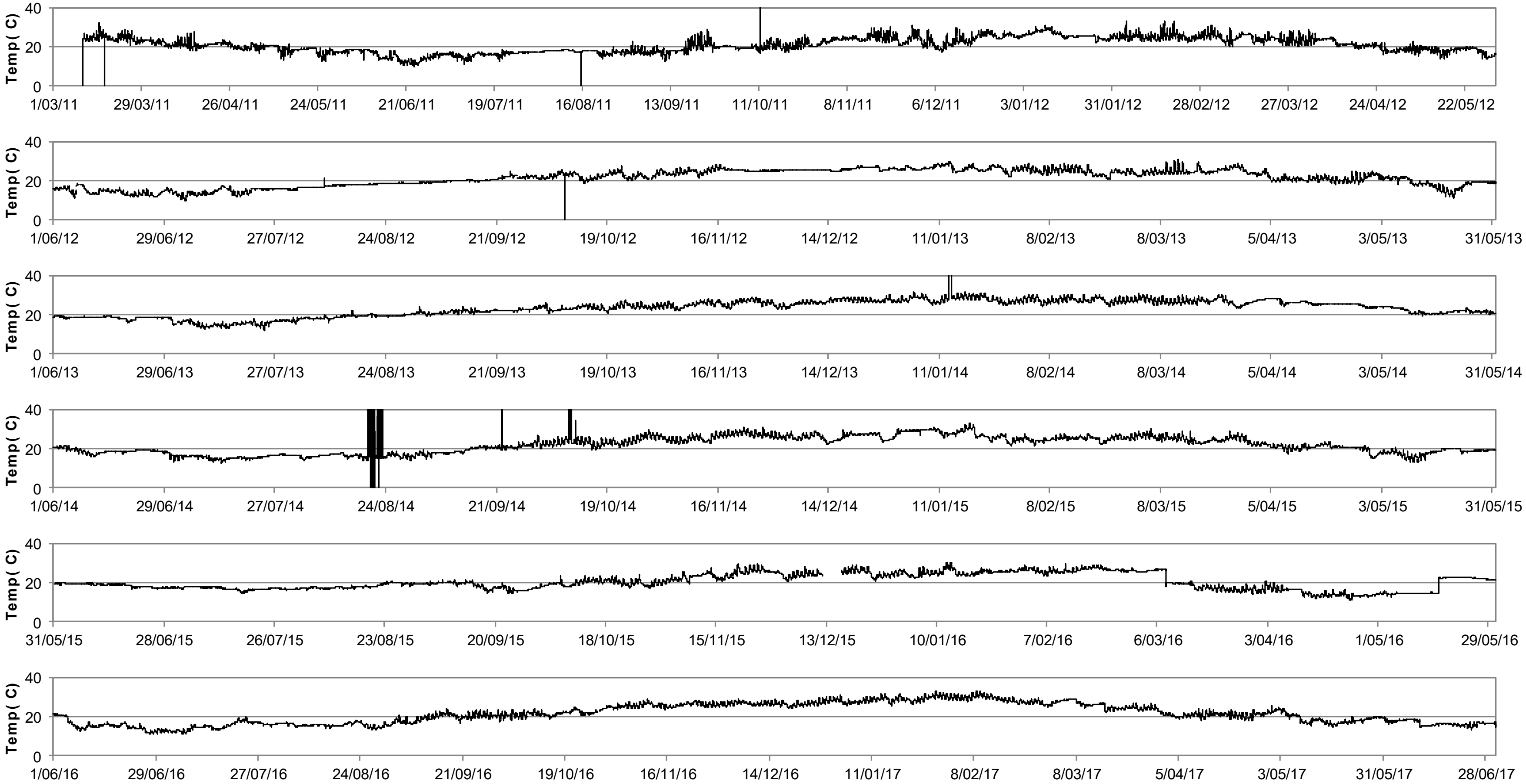


Figure B7 Temperature measurements from the Salty Creek PWQMS for the duration of the MPPC

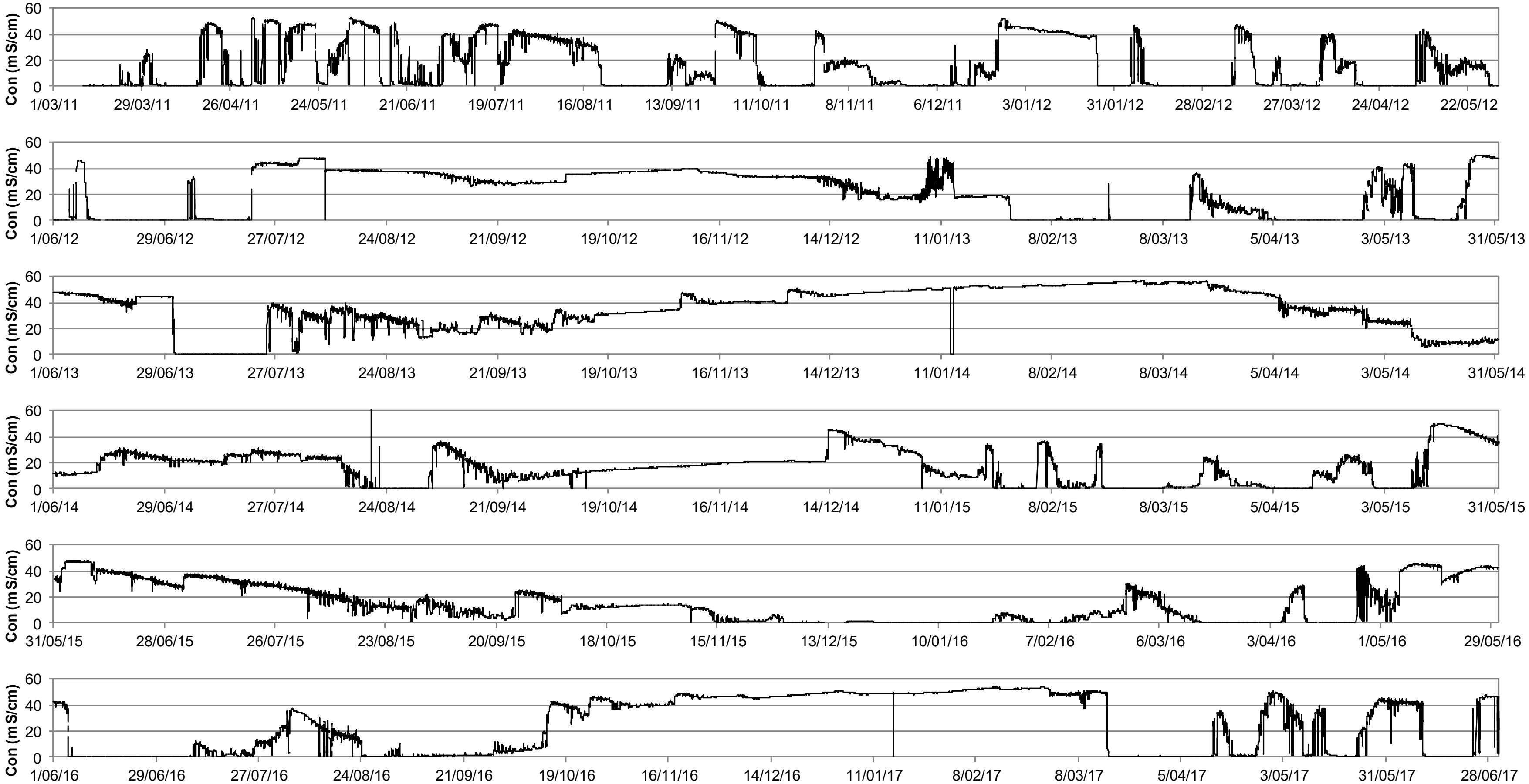


Figure B8 Conductivity measurements from the Salty Creek PWQMS for the duration of the MPPC

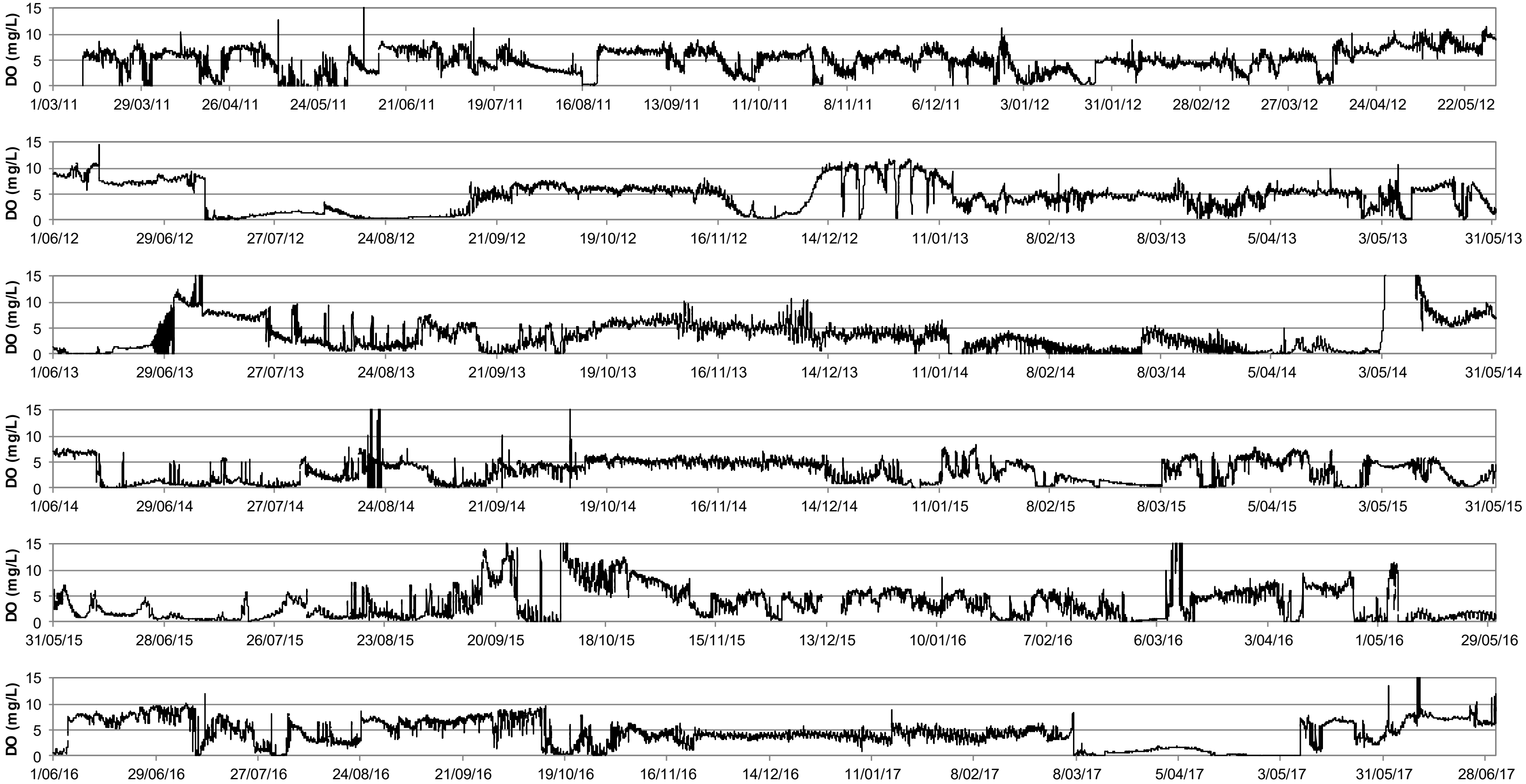


Figure B9 DO measurements from the Salty Creek PWQMS for the duration of the MPPC

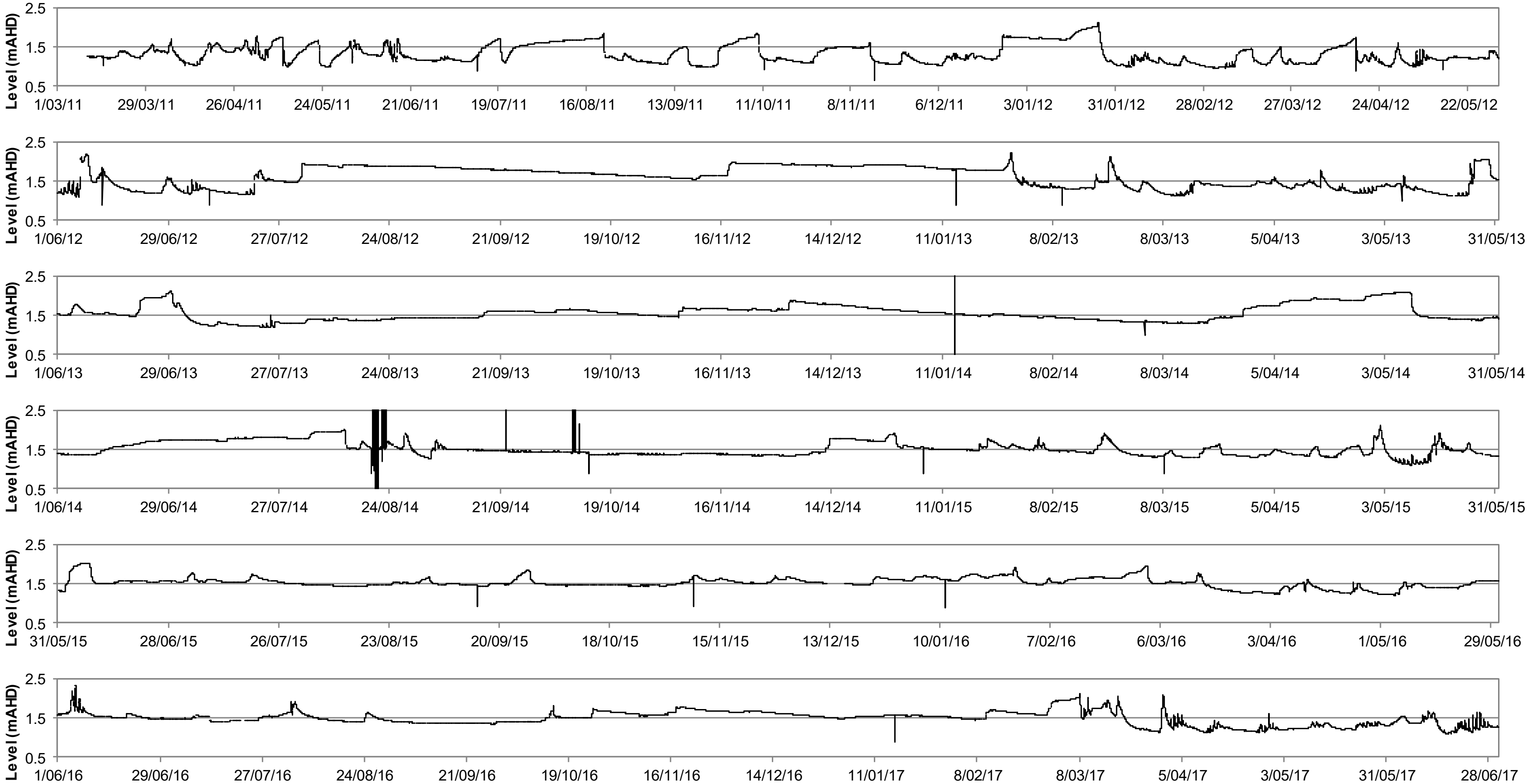


Figure B10 Level measurements from the Salty Creek PWQMS for the duration of the MPPC

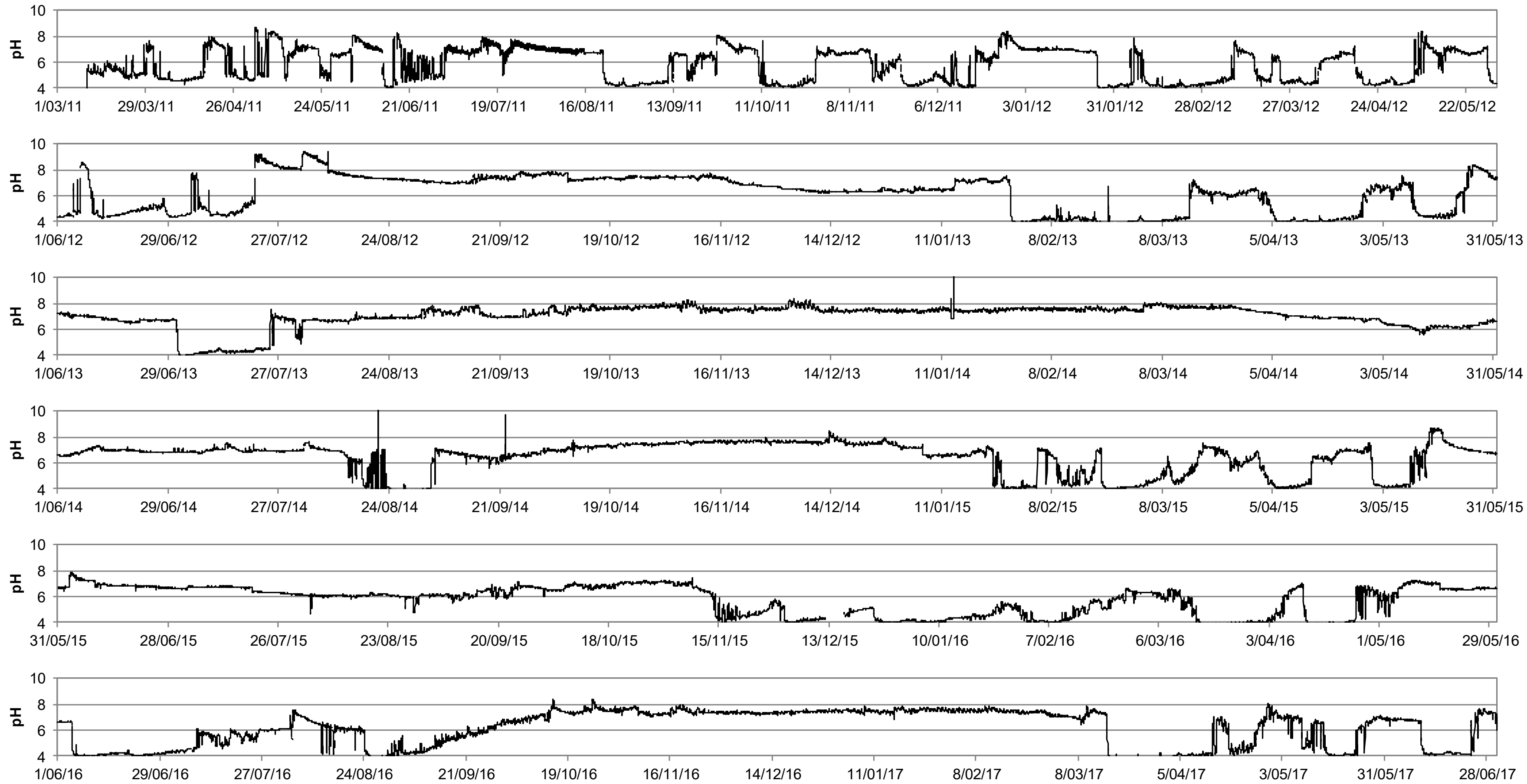


Figure B11 pH measurements from the Salty Creek PWQMS for the duration of the MPPC

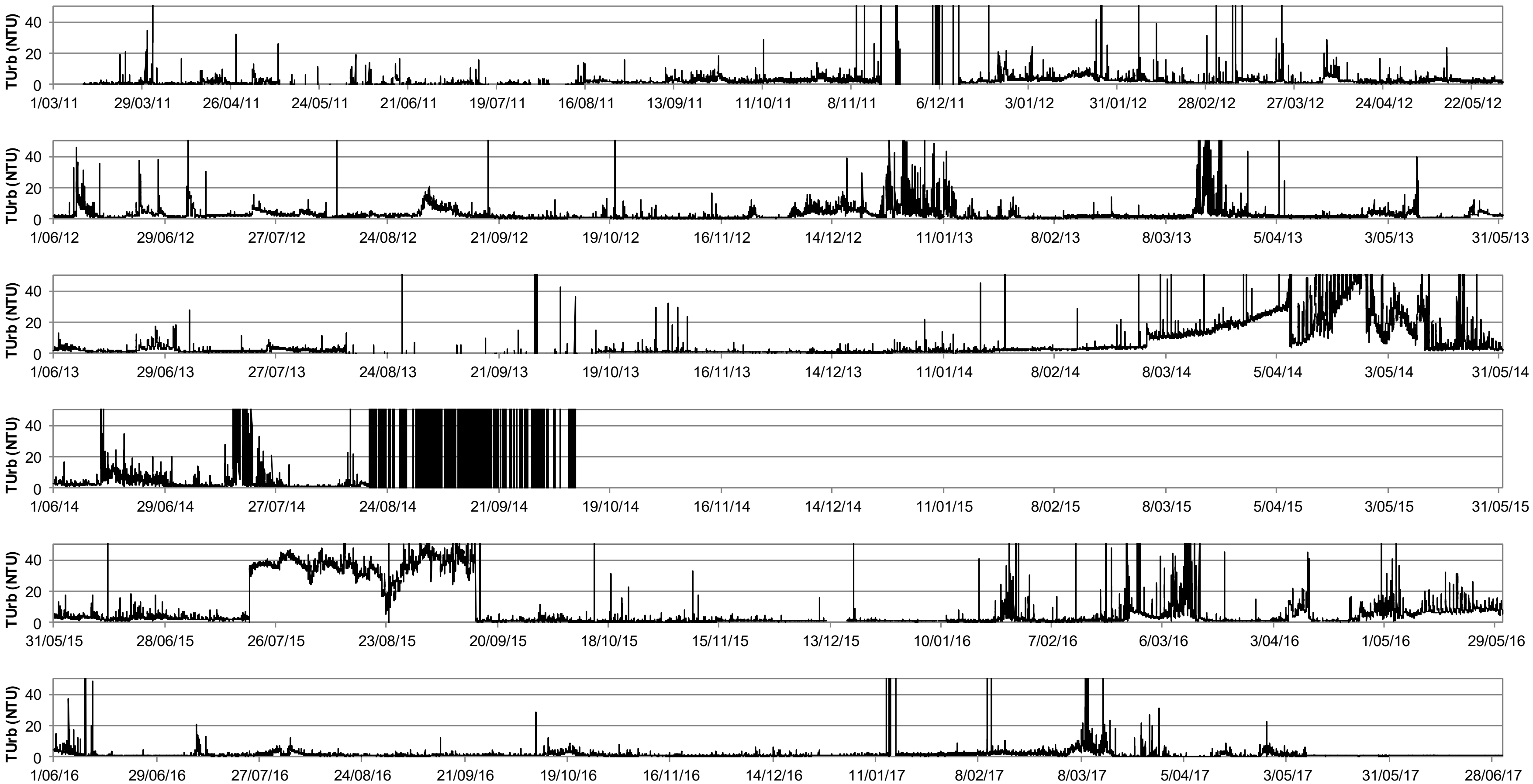


Figure B12 Turbidity measurements from the Salty Creek PWQMS for the duration of the MPPC

Appendix C

Macroinvertebrate Results

Table C1 Annual Totals of Benthic Macroinvertebrate Taxa at BM1 and BM2

Taxa	*Common Name*	*BM1*						*BM2*					
		2012	*2013*	*2014*	*2015*	*2016*	*2017*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*
Chironominae	Non biting midge	19	7	318	13	37	257	98	137	43	51	156	650
Tanypodinae	Non biting midge	0	0	0	3	16	10	0	0	0	0	2	2
Ceratopogonidae	Biting midge	10	1	0	2	0	3	0	2	2	0	3	4
Chaoboridae	Phantom midges	0	0	0	0	0	0	0	0	0	0	0	0
Sialidae	Alderfly	0	0	0	0	0	0	0	0	0	0	0	0
Libellulidae	Dragonfly	0	0	0	0	0	0	5	4	0	0	0	3
Hemiphlebidae	Damselfly	1	0	0	0	0	0	0	0	0	0	0	0
Ecnomidae	A Caddis Fly	0	0	0	0	0	4	0	0	0	0	0	0
Leptoceridae	Stick Caddis	0	0	0	1	27	16	0	0	0	0	2	0
Pyralidae	Aquatic Caterpillar	0	0	0	1	0	0	0	1	0	1	0	0
Hygrobiidae	Screech Beetle	0	0	0	0	0	0	0	0	0	0	0	0
Hydrophiidae	Water Scavenger Beetle	0	0	1	1	0	0	0	0	5	0	0	0
Dytiscidae	Diving Beetle	0	0	0	0	0	0	0	0	1	0	1	4
Belastomatidae	Giant Water Bug	0	0	0	0	0	1	0	0	0	0	0	1
Corixidae	Water Boatmen	0	0	20	2	0	2	0	0	0	0	0	0
Veliidae	Small Water Strider	0	0	0	0	0	0	0	0	0	1	0	0
	Springtail	2	7	2	1	3	0	1	0	4	2	2	2
Capitellidae	Polychaete	5	2	4	5	2	5	0	0	0	0	0	0
Spionidae	Polychaete	92	8	11	1	0	0	1	0	0	0	0	0
Mytilidae	Mussel	1	85	4	1	0	0	1	0	0	0	0	0
Hydrobiidae	Snail	3	4	31	22	1	0	3	20	0	0	0	0
Planorbidae	Snail	0	0	0	0	0	0	0	1	0	1	2	10
Sphaeromatidae	Isopod	0	4	5	0	0	0	3	1	0	0	0	0
Hymenosomatidae		0	0	0	0	0	0	0	0	0	0	0	0
	Copepod	0	0	0	0	0	0	0	0	0	0	0	0
	Cladoceran	0	0	0	0	3	5	0	0	0	0	0	0
Total animals		**133**	**118**	**396**	**53**	**86**	**303**	**112**	**166**	**55**	**56**	**168**	**676**
Total taxa		**8**	**8**	**9**	**12**	**7**	**9**	**7**	**7**	**5**	**5**	**7**	**8**

Table C2 Annual Totals of Benthic Macroinvertebrate Taxa at BM3 and BM4

Taxa	Common Name	BM3						BM4					
		2012	2013	2014	2015	2016	2017	2012	2013	2014	2015	2016	2017
Chironominae	Non biting midge	23	23	197	38	82	423	2	3	12	28	276	99
Tanypodinae	Non biting midge	0	0	0	0	4	10	2	1	3	0	5	4
Ceratopogonidae	Biting midge	0	1	1	1	2	13	3	0	0	0	8	15
Chaoboridae	Phantom midges	0	0	0	0	0	0	0	0	0	1	0	0
Sialidae	Alderfly	0	0	0	0	0	0	1	0	0	0	0	0
Libellulidae	Dragonfly	0	0	0	0	0	1	2	0	1	0	0	2
Hemiphlebidae	Damselfly	0	0	0	0	0	2	0	0	0	0	0	0
Ecnomidae	A Caddis Fly	0	0	0	0	1	1	0	0	0	0	0	8
Leptoceridae	Stick Caddis	0	0	0	5	23	29	0	0	0	1	0	2
Pyralidae	Aquatic Caterpillar	0	0	0	0	0	0	0	0	0	0	0	0
Hygrobiidae	Screech Beetle	0	0	0	0	0	0	1	0	0	0	0	0
Hydrophiidae	Water Scavenger Beetle	0	0	0	0	0	1	0	1	1	2	0	4
Dytiscidae	Diving Beetle	0	0	0	0	0	0	0	1	0	0	0	0
Corixidae	Water Boatmen	0	0	40	1	0	0	0	0	4	2	11	0
Veliidae	Small Water Strider	0	0	0	0	0	2	0	0	0	0	0	1
	Springtail	1	1	0	0	1	0	0	3	3	3	3	0
Capitellidae	Polychaete	42	14	17	25	7	0	0	0	0	0	0	1
Spionidae	Polychaete	11	91	26	1	0	5	2	0	0	0	0	0
Mytilidae	Mussel	3	172	56	2	0	3	0	0	0	0	0	0
Hydrobiidae	Snail	0	6	66	58	14	1	54	1	5	0	0	0
Planorbidae	Snail	0	0	0	2	0	0	0	0	4	1	1	0
Sphaeromatidae	Isopod	1	5	16	2	0	0	9	3	0	0	0	1
Hymenosomatidae		1	0	0	0	0	0	0	0	0	0	0	0
	Copepod	0	0	0	0	1	0	0	0	0	0	0	0
	Cladoceran	0	0	0	0	0	0	0	0	0	0	0	0
Total animals		**82**	**313**	**419**	**135**	**134**	**492**	**76**	**13**	**33**	**38**	**304**	**137**
Total taxa		**7**	**8**	**8**	**10**	**9**	**13**	**9**	**7**	**8**	**7**	**6**	**10**

Appendix D

Fish Survey Results

Table D1 Fish Species Captured at Site F1 During MPPC Fish Surveys

Family Species	*Common Name*	*04/ 11*	*07/ 11*	*10/ 11*	*01/ 12*	*04/ 12*	*07/ 12*	*10/ 12*	*01/ 13*	*04/ 13*	*07/ 13*	*10/ 13*	*01/ 14*	*04/ 14*	*07/ 14*	*10/ 14*	*01/ 15*	*04/ 15*	*07/ 15*	*10/ 15*	*01/ 16*	*04/ 16*	*07/ 16*	*10/ 16*	*01/ 17*	*05/ 17*
Anguilla reinhardtii	Longfin Eel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gobiomorphus australis	Striped Gudgeon	2	0	3	0	9	0	0	0	0	0	10	1	3	1	3	0	0	0	2	0	0	0	1	6	0
Hypseleotris compressa	Empire Gudgeon	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypseleotris galii	Firetail Gudgeon	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	1	0	0	0	0	0	0	2	0
Philypnodon grandiceps	Flathead Gudgeon	0	0	0	20	2	0	0	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Philypnodon macrostomas	Dwarf Flathead Gudgeon	0	0	1	0	4	0	0	0	10	4	0	3	0	0	27	5	8	3	29	3	18	15	14	0	0
Afurcagobius tamarensis	Tamar River Goby	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gambusia holbrooki	Mosquito Fish^	0	0	31	55	0	0	0	2	0	0	0	18	7	0	6	11	0	0	23	7	0	0	5	165	0

^ *Introduced Species*

Table D2 Fish Species Captured at Site F2 During Fish Surveys

Family Species	Common Name	04/11	07/11	10/11	01/12	04/12	07/12	10/12	01/13	04/13	07/13	10/13	01/14	04/14	07/14	10/14	01/15	04/15	07/15	10/15	01/16	04/16	07/16	10/16	01/17	05/17
Anguilla reinhardtii	Longfin Eel	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Gobiomorphus australis	Striped Gudgeon	6	1	3	1	3	0	0	0	2	1	4	0	0	0	2	0	2	0	1	0	0	1	0	0	0
Hypseleotris compressa	Empire Gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypseleotris galii	Firetail Gudgeon	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	1
Philypnodon grandiceps	Flathead Gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Philypnodon macrostomas	Dwarf Flathead Gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
Afurcagobius tamarensis	Tamar River Goby	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gambusia holbrooki	Mosquito Fish^	217	1	0	8	2	0	0	79	6	0	14	0	0	0	15	41	97	0	1	5	53	0	28	628	0

^ *Introduced Species*

Table D3 Fish Species Captured at Site F3 During MPPC Fish Surveys

Family Species	Common Name	04/11	07/11	10/11	01/12	04/12	07/12	10/12	01/13	04/13	07/13	10/13	01/14	04/14	07/14	10/14	01/15	04/15	07/15	10/15	01/16	04/16	07/16	10/16	01/17	05/17
Anguilla reinhardtii	Longfin Eel	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gobiomorphus australis	Striped Gudgeon	0	0	6	0	0	0	0	0	3	0	3	33	51	1	0	0	0	0	0	0	0	0	0	1	0
Hypseleotris compressa	Empire Gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypseleotris galii	Firetail Gudgeon	0	0	0	0	0	0	0	0	0	0	0	434	0	0	0	0	0	0	0	0	0	0	0	3	0
Philypnodon grandiceps	Flathead Gudgeon	1	0	3	1	2	0	0	9	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Philypnodon macrostomas	Dwarf Flathead Gudgeon	0	0	2	0	0	0	0	0	22	3	2	87	0	0	14	14	1	0	9	1	10	3	16	0	0
Afurcagobius tamarensis	Tamar River Goby	0	0	1	0	1	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gambusia holbrooki	Mosquito Fish^	0	0	32	15	0	0	0	0	0	1	0	15	2	0	17	5	0	0	42	21	0	0	2	76	1

^ *Introduced Species*

Table D4 Fish Species Captured at Site F4 During MPPC Fish Surveys

Family Species	*Common Name*	*04/ 11*	*07/ 11*	*10/ 11*	*01/ 12*	*04/ 12*	*07/ 12*	*10/ 12*	*01/ 13*	*04/ 13*	*07/ 13*	*10/ 13*	*01/ 14*	*04/ 14*	*07/ 14*	*10/ 14*	*01/ 15*	*04/ 15*	*07/ 15*	*10/ 15*	*01/ 16*	*04/ 16*	*07/ 16*	*10/ 16*	*01/ 17*	*05/ 17*
Anguilla reinhardtii	Longfin Eel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Gobiomorphus australis	Striped Gudgeon	3	0	0	0	0	1	0	1	1	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Hypseleotris compressa	Empire Gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypseleotris galii	Firetail Gudgeon	0	0	0	0	0	0	0	0	0	0	87	0	0	0	0	7	2	0	1	0	0	3	1	0	0
Philypnodon grandiceps	Flathead Gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Philypnodon macrostomas	Dwarf Flathead Gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Afurcagobius tamarensis	Tamar River Goby	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gambusia holbrooki	Mosquito Fish^	202	8	7	22	196	0	0	18	31	0	65	0	0	0	0	25	138	0	87	41	222	1	90	0	2

^ *Introduced Species*

Appendix E

Waterbird Survey Results

Table E1 Results of Waterbird Surveys

Common Name	04/ 11	07/ 11	10/ 11	01/ 12	04/ 12	07/ 12	10/ 12	01/ 13	04/ 13	07/ 13	10/ 13	01/ 14	04/ 14	07/ 14	10/ 14	01/ 15	04/ 15	07/ 15	10/ 15	01/ 16	04/ 16	07/ 16	10/ 16	01/ 17	05/ 17
Little Black Cormorant			4	3			2	4	8	2	1	3			4	2	2		7	4	1		4		
Little Pied Cormorant	2	1		1		1				1		2			2				3	1		1		7	
Pied Cormorant				9	2	1		1		1			1		4		1	2		6			2		4
Great Cormorant						1			1	2	4		1	1	6	1				1			1		
Darter				1	1	1	1	2							1		1	1	2	1	1		3		2
Pelican		30	10						13	9	16	1		8	7			1	1			8	3		
Australasian Grebe		1		2			6	18	9	22	38	11	3	7	19	2	8	5	20		2	4			11
Grey Teal	1	3	29	23				16	20	5		28			2					2	5	2	3	10	35
Pacific Black Duck				7	4	59	31	42	52	13	82	42	33	7	44	25	24	41	48	108	46	58	29	20	49
Chestnut Teal			1				6			2		14						2	7						
Australasian Shoveler														25				7							
Hardhead							11		20	28					33			12	7			1			397
Musk Duck																		1							
Black Swan				2	4	2			1		4		4	3		2	2	2	2	3	2		2	2	6
Dusky Moorhen																					1				1
Australian Spotted Crake															1										
Purple Swamphen								33														2			
Eurasian Coot								22	24	25	125	6			29		33	35			1				36
Comb-crested Jacana*								3									1			1	1				
White-faced Heron	1	2	5		2	6	2	1	9		2	1	4	7	3		1		1		2			7	1
Black Bittern*			1																						
White-necked Heron			2					1			4			1				1	1						

Common Name	04/ 11	07/ 11	10/ 11	01/ 12	04/ 12	07/ 12	10/ 12	01/ 13	04/ 13	07/ 13	10/ 13	01/ 14	04/ 14	07/ 14	10/ 14	01/ 15	04/ 15	07/ 15	10/ 15	01/ 16	04/ 16	07/ 16	10/ 16	01/ 17	05/ 17
Little Egret			1																					1	
Intermediate Egret							1	1			1	1		1	1	1		1	1				1		1
Great Egret			3	1	1	1	4	2	1		4	2	1	1	1		2	1	2		30	1	5		
White Ibis			2				1				7	12			2				2					1	
Royal Spoonbill											5			1					5						
Black-necked Stork*												2								1				2	
Brolga*											2													1	
Whimbrel								1																	
Lathams Snipe																								2	
Sharp-tailed Sandpiper												44												2	
Black-winged Stilt	3				2						11	13													
Pied Oystercatcher*																							5		
Masked Lapwing		2	2								2	3			3								1	4	
Pacific Golden Plover												12													
Black-fronted Dotterel			7																					20	
Common Tern																				1				1	
Crested Tern																1							1		
Rainbow Bee Eater				3																1					
Forest Kingfisher																					1	1			2
Welcome Swallow			7		3	3	3				3	3			22					4					
Tree Martin																								50	
White-throated Needletail				15								17	22								80				

Common Name	04/11	07/11	10/11	01/12	04/12	07/12	10/12	01/13	04/13	07/13	10/13	01/14	04/14	07/14	10/14	01/15	04/15	07/15	10/15	01/16	04/16	07/16	10/16	01/17	05/17
Raven				1																				6	
Eastern Osprey*									1							1									
White-Bellied Sea-Eagle*	2	1			1	1				1				1		1	1		1	2					
Wedge-tailed Eagle							1	1															3	2	4
Black Kite											1						1	2						2	
Brahminy Kite																	1						1		
Whistling Kite		1				4		2				1		1											1
Red Goshawk^																							1		
Total No. Species	**5**	**8**	**13**	**12**	**9**	**11**	**12**	**16**	**12**	**12**	**18**	**20**	**8**	**13**	**18**	**9**	**13**	**15**	**16**	**14**	**13**	**9**	**16**	**18**	**15**
Total No. Individuals	**9**	**41**	**74**	**68**	**20**	**80**	**69**	**150**	**159**	**111**	**312**	**218**	**69**	**64**	**184**	**36**	**78**	**114**	**110**	**136**	**173**	**78**	**65**	**140**	**551**

** Species listed as vulnerable under the Biodiversity Conservation Act 2016*

Red text – waterfowl; Blue text – waders; Green text – shorebirds

^ Tentative recordings only. The Red Goshawk is listed as Critically Endangered under the BC Act and Vulnerable under the Environment Protection and Biodiversity Conservation Act 1999

Appendix F

Frog Survey Results

Table F1 Frog Diversity and Abundance at Point Counts During the MPPC Program

Common Name	Scientific Name	2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		Total (All Seasons)	Winter Total	Spring Total	Summer Total
		Point Count (No.)	Offsite	Point Count (No.)	Offsite	Point Count (No.)	Offsite	Point Count (No.)	Offsite	Point Count (No.)	Offsite	Point Count (No.)	Offsite				
Common Eastern Froglet	*Crinia signifera*	30	Yes	24	Yes	8	Yes	24	Yes	14	Yes	9	Yes	**109**	**93**	**2**	**14**
Wallum Froglet*	***Crinia tinnula***	29	Yes	19	Yes	26	Yes	12	Yes	28	Yes	45	Yes	**159**	**51**	**44**	**64**
Striped Marsh Frog	*Limnodynastes peroni*	38	Yes	35	Yes	7	Yes	8	Yes	31	Yes	24	Yes	**143**	**31**	**31**	**81**
Bleating Tree Frog	*Litoria dentata*	0	Yes	0	No	0	No	0	No	0	No	1	Yes	**1**	**0**	**0**	**1**
Dwarf Tree Frog	*Litoria fallax*	34	Yes	169	Yes	64	Yes	166	Yes	187	Yes	187	Yes	**807**	**259**	**251**	**297**
Dainty Green Tree Frog	*Litoria gracilenta*	0	No	0	No	0	Yes	0	No	0	No	0	No	**0**	**0**	**0**	**0**
Rocket Frog	*Litoria nasuta*	7	Yes	88	Yes	6	Yes	40	Yes	8	Yes	45	Yes	**194**	**0**	**117**	**77**
Wallum Sedge Frog*^	***Litoria olongburensis***	20	Yes	4	Yes	1	Yes	0	Yes	1	Yes	1	Yes	**27**	**2**	**6**	**19**
Emerald Tree Frog	*Litoria peronii*	21	Yes	14	Yes	0	No	0	Yes	0	Yes	0	No	**35**	**14**	**20**	**1**
Tyler's Tree Frog	*Litoria tyleri*	12	Yes	55	Yes	16	Yes	36	Yes	48	Yes	27	Yes	**194**	**83**	**49**	**62**
Broad-palmed Frog	*Litoria latopalmata*	1	Yes	0	No	0	No	0	No	0	No	0	No	**1**	**0**	**0**	**1**
Total	**-**	**192**	**-**	**408**	**-**	**128**	**-**	**286**	**-**	**317**	**-**	**339**	**-**	**1670**	**533**	**520**	**617**

* denotes threatened species listed under the *Biodiversity Conservation Act 2016*

^ denotes threatened species listed under the *Environment Protection and Biodiversity Conservation Act 1999*

Bold denotes 'acid' frog species

Appendix G

Representative Sample of Fixed Photo Point Results at Vegetation Monitoring Sites

Representative Fixed Photo Point Results Over Time

2011

2013

2015

2017

Plate G1 Transect 3 quadrat A1 (Sedge Swamp – far south-western portion of Salty Lagoon)

2011 2013

2015 2017

Plate G2 Transcect 1 quadrat B1 (Swamp Forest – central north-western portion of Salty Lagoon)

2011 2013

2015 2017

Plate G3 Transect 1 quadrat C2 (Fringing Marsh – north-western portion of Salty Lagoon)

2011 **2013**

2015 **2017**

Plate G4 Transect 3 quadrat C2 (Fringing Marsh – south-western portion of Salty Lagoon)

2011 2013

2015 2017

Plate G5 Transect 4 quadrat A1 (Sedge Swamp/Open Water – drainage channel in south-east of Salty Lagoon)

2011 2013

2015 2017

Plate G6 Transect 5 quadrat A1 (Fringing Marsh/ Open Water – south-eastern edge of Salty Lagoon)

2011 **2013**

2015 **2017**

Plate G7 Transect 6 quadrat B1 (Fringing Marsh/ Open Water – south-eastern edge of Salty Lagoon)

2011 **2013**

2015 **2017**

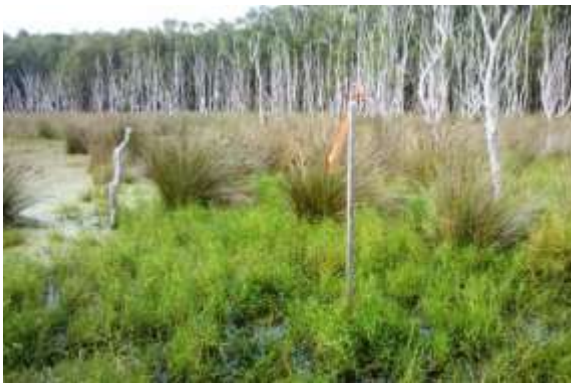
Plate G8 Melaleuca Dieback Transect 1 quadrat D (Swamp Forest – central north-west of Salty Lagoon)

2011 2013

2015 2017

Plate G9 Melaleuca Dieback Transect 2 quadrat E (Fringing Marsh/Swamp Forest– central eastern portion of Salty Lagoon)

2011 2013



2015 2017

Plate G10 Melaleuca Dieback Transect 3 quadrat C (Fringing Marsh – central south-west of Salty Lagoon

Appendix H

Post Closure Environmental Risk Assessment

Post Closure Environmental Risks to be Monitored and Managed (Years 6-10 Post Closure)

Updated risk assessments from Appendix A of the MPPC (Hydrosphere 2010a) are provided below, based on the results of the MPPC project. The risk assessments have been undertaken to assist decision making with regards to management and ongoing monitoring at Salty Lagoon. Refer to Appendix A of the MPPC (Hydrosphere 2010a) for the risk assessment matrix used.

Table H1 Post Closure Environmental Risks to be Monitored and Managed (Years 6-10 Post Closure - Updates Based on MPPC Results)

Aspect	Impact	Method/ Indicators	Likelihood	Consequence	Risk	Prevention/Avoidance measure	Likelihood	Consequence	Risk	Response Measure	Comment Based on MPPC Results
Fauna	Fish Kills	Water quality loggers (DO, pH, turbidity), health assessment	**D**	2	**Low**	Water exchange between lagoon and creek if water quality indicates declining conditions	**D**	2	**Low**	Clean up of any dead aquatic organisms to prevent further impacts (i.e. bird kills) Event/Incident Reporting	**No fish kills were recorded during the MPPC monitoring, despite periods of poor water quality.** **Management response remains valid.**
	Gambusia become more dominant	Fish monitoring	D	2	Low	-	D	2	Low	-	**This is an existing risk which is unlikely to be increased from STP discharge.** **Continued seasonal monitoring not required.**
	Widespread Cane Toad invasion	Frog monitoring	E	3	Moderate	**Minimising openings or tracks leading to Salty Lagoon (i.e. tracks established from monitoring or maintenance activities) may also reduce the potential for Cane Toad accessing Salty Lagoon.**	E	3	Moderate	**Plantings of dense vegetation (e.g. Matrush) and/or temporary barriers (e.g. frog fence) to be installed at any openings or tracks established that lead to Salty Lagoon.**	**Cane Toads have not been recorded during the MPPC. The risk of invasion remains though, and is an existing risk independent of STP discharge.** **Monitoring for Cane Toads may form part of NPWS general monitoring in Broadwater National Park.** **The MPPC monitoring does not include frog monitoring on the eastern side of the lagoon, where Cane Toads are more likely to be able to access due to the more open vegetation condition.** **Continued seasonal monitoring not required.**
Vegetation	Lack of colonisation by aquatic plants	Vegetation surveys/mapping/ monthly health assessment and photo points	**E**	2	Low	-	**E**	2	Low	Consider planting of Melaleucas if no colonisation is observed and nutrient levels remain high	**Aquatic vegetation colonisation has been observed and no management actions have been required or are likely to be triggered. The exception being no Melaleuca colonisation has been observed and is expected to take longer to capture this change.** **Vegetation monitoring recommended (with modified frequency).**
	Aquatic weed invasion	Weed surveys/monthly health assessment and photo points	**D**	2	**Low**	Weed control program involving monitoring and subsequent control if recommended	D	2	Low	Follow up weed surveys and control if required	**Aquatic weed invasion remains a risk, though has not eventuated to any significant extent during the MPPC.** **Ongoing monitoring recommended**

Aspect	Impact	Method/ Indicators	Likelihood	Consequence	Risk	Prevention/Avoidance measure	Likelihood	Consequence	Risk	Response Measure	Comment Based on MPPC Results
	Water-logging impacts on fringing flora	Vegetation surveys/mapping/ monthly health assessment and photo points	**E**	1	Low	No measures planned as impacts are predicted to be negligible	**E**	1	Low	Follow up monitoring	**MPPC monitoring is consistent with prediction (i.e. observed water logging impacts is minor). Vegetation monitoring recommended (with modified frequency).**
Water quality	Algal blooms	Chl a, monthly health assessment and photo points	**D**	2	Moderate	Water exchange	**D**	2	Moderate	Continued water quality monitoring	**Continued water quality monitoring recommended**
	Low DO events	Water quality loggers, grab samples and depth profiles (DO, temp, EC)	C	2	Moderate	Water exchange	C	2	Moderate	Continued water quality monitoring	**Continued water quality monitoring recommended**
Public safety and amenity	Health impacts from poor water quality	Faecal Coliform and or Blue Green Algae levels above recreational guidelines	D	2	Low	Recreational strategy including water quality monitoring and assessment against triggers, signage and warnings etc.	E	2	Low	Continued water quality monitoring	**Continued water quality monitoring recommended**
	Unsightly algal blooms and surface scums	Monthly health assessment and photo points Water quality grab samples (Chl a, screening for BG algae)	D	2	Low	Water exchange	**E**	2	Low	Continued water quality monitoring	**Continued water quality monitoring recommended**

Note: **Bold** text shows changes from MPPC (Hydrosphere 2010a) risk assessment

Conclusions:

- The risk of fish kills and aquatic weed invasion have been reduced in comparison to the MPPC risk assessment for (one to five year period post-closure) based on the MPPC monitoring results.
- The potential for poor water quality episodes and aquatic plant and/or algal blooms remains as a moderate risk to ecosystem health in the 6-10 year period post-closure. The main factors in this risk rating are: the existing nutrient load in Salty Lagoon; and the unknown time required for the establishment of a freshwater ecosystem capable of efficiently assimilating the accumulated nutrient load. Ongoing monitoring of these risks is recommended.
- Widespread Cane Toad invasion remains a moderate risk, however is not recommended for ongoing monitoring as this risk is somewhat independent of ongoing discharge into Salty Lagoon.
- Low-risk impacts predicted in the 6-10 year period post-closure and recommended for continued regular monitoring include: weed invasion, health impacts from poor water quality and unsightly algal blooms affecting amenity.

Table H2 **Pre vs. Post Artificial Channel Closure Risk Assessment (Assessing the Long-term Risk >5yrs After Closure – Updates Based on MPPC Results)**

Aspect	***Impact***	***PRE – Artificial Channel Closure (current) (Source: Hydrosphere 2011)***			***POST – Artificial Channel Closure (long- term) (Source: Hydrosphere 2011)***			***POST – Artificial Channel Closure (6-10 years post closure)***		
		Likelihood	***Consequence***	***Risk***	***Likelihood***	***Consequence***	***Risk***	***Likelihood***	***Consequence***	***Risk***
Aquatic Fauna	Fish Kills	C	3	High	E	2	Low	D	2	Low
	Reduction in area of wading bird habitat	E	1	Low	C	1	Low	C	1	Low
	Gambusia become more dominant	D	2	Low	D	2	Low	D	2	Low
	Widespread Cane Toad invasion	E	3	Moderate	E	3	Moderate	E	3	Moderate
Aquatic Vegetation	Saltmarsh die-off	E	1	Low	A	1	High	B	1	High
	Lack of colonisation by native freshwater plants	B	3	High	D	2	Low	E	2	Low
	Aquatic weed invasion	C	2	Moderate	D	1	Low	D	2	Low
Water Quality	Algal blooms (including blue green algae)	C	2	Moderate	D	2	Low	D	2	Low
	High turbidity events	C	3	High	E	2	Low	E	2	Low
	Low DO causing aquatic organism stress	B	3	High	D	2	Low	D	2	Low
Public Safety, Amenity and Human Health	Faecal Coliform levels above recreational guidelines	E	2	Low	E	2	Low	E	2	Low
	Blooms of toxic blue-green algae (levels above recreational guidelines)	E	2	Low	E	2	Low	E	2	Low
	Unsightly algal blooms, surface scums etc.	C	2	Moderate	D	1	Low	D	1	Low
Hydrology	Water – logging impacts on fringing fauna and flora	D	1	Low	C	1	Low	E	1	Low
	Flooding risk upstream of lagoon affecting roads, infrastructure and property	E	2	Low	E	2	Low	E	1	Low

Appendix I

Post Closure (Year 6-10) Monitoring Program

Post Closure (Year 6-10) Monitoring Program

Ongoing Salty Lagoon Monitoring

It is understood that RVC plan on continuing discharge of treated water from the Evans Head Sewerage Treatment Plant (STP) into the creek upstream (also known as the 'Drainage Channel') of Salty Lagoon in the medium term (i.e. next 15 years). The results of the MPPC program have found that, at current levels, continued discharge from the Evans Head STP has a minimal effect on bioavailable nutrient concentrations within Salty Lagoon. Residual nutrients from historic pollution are currently the primary contributor of nutrients causing occasional poor water quality episodes in the system, and continued discharge from the Evans Head STP is unlikely to adversely affect the overall health of the system.

It is recommended that environmental monitoring at Salty Lagoon continues, with the objective of:

- Monitoring the health of Salty Lagoon and confirming that Evans Head STP discharge is not adversely impacting water quality and ecology at Salty Lagoon.
- Monitoring water quality and the ecological attributes of the MPPC where predicted trends have not been confirmed and risks to the ecosystem health remain.
- Observing medium to long term changes in the Salty Lagoon system in response to channel closure.
- Informing future management decision making for Salty Lagoon and the Evans Head STP.

To determine a suitable monitoring program, the following tasks were undertaken:

- Review of the MPPC predicted changes and monitoring outcomes.
- Update the closure risk assessments (Appendix 1 of the MPPC) based on the MPPC program findings (**Appendix H**).

The proposed monitoring will effectively continue and duplicate the existing MPPC monitoring to allow for long-term data comparisons, though with reduced monitoring frequency and/or discontinuation of some monitoring activities. The proposed ongoing monitoring program is based on five years of monitoring (2017/2018 to 2021/2022), with a review at completion of Year 5. An outline monitoring plan is provided in **Table I1** and summarised below.

Water Quality Monitoring

Generally as per Section 3.1 of the MPPC (Hydrosphere 2010a), including the following key components and revisions:

- Continued water quality sensors and loggers at currently deployed sites in Salty Lagoon (SL1) and Salty Creek (SL2) with new water quality systems (existing infrastructure is aging). Loggers are to measure water level, temperature, pH, conductivity, turbidity and dissolved oxygen (DO) concentrations. Timing would be continuous (15 minute intervals) with data downloaded directly during bimonthly site visits (no telemetry alarm system is proposed).
- Bimonthly (every two months) water quality sampling and depth profile measurements at five existing sites (no change from MPPC methodology).

- Bimonthly (every two months) health assessments for Salty Lagoon and Salty Creek including photo point record at all water quality sites (no change from MPPC methodology).
- STP discharge monitoring (no change from MPPC methodology).

Hydrology

As per Section 3.2 of the MPPC (Hydrosphere 2010a).

Vegetation

Generally as per Section 3.3.1 of the MPPC (Hydrosphere 2010a), including the following key revisions:

- Timing reduced to five yearly (i.e. the next event is 2021/22).
- Inclusion of a belt transect along the Melaleuca dieback transect and extending a further 50 m east into the fringing marsh (150 m in total). At each fixed 10 m point along the transect, record the following data based on a two metre radius of that point:
  - Vegetation type.
  - Presence or absence of dead Melaleucas.
  - Presence or absence of live Melaleucas.
  - Where Melaleucas are present, record:
  - Tree health (presence of necrotic spots on leaves, galls on small branches):
    - Presence or absence of trees (DBH>10 cm), small trees (DBH <10 cm to >5 cm), saplings (DBH <5 cm; height >0.5 m) and seedlings (height <0.5 m), including tree height within each category.
    - Condition of trees (DBH>10 cm) and small trees (DBH <10 cm to >5 cm) using the following categories: unaffected/ full recovery; resprouting; and dying.

The inclusion of the belt transect data is to capture changes in Melaleuca condition which has not been well captured by the methodology in the MPPC. Melaleuca dieback belt transect data would need to be collected in 2017/2018 to enable for comparison in 2021/22.

Weed Monitoring

As per Section 3.3.2 of the MPPC (Hydrosphere 2010a).

Erosional Areas Identification and Monitoring

The active headcut that has formed on the eastern side of the original channel at Salty Lagoon post closure of the artificial channel has been identified as a significant risk to the Salty Lagoon rehabilitation project (GeoLINK 2016). Active management of the headcut is recommended before the headcut extends and compromises current rehabilitation efforts associated with the artificial channel closure. Monitoring tasks proposed include:

- Survey (walk) the edge of Salty Creek, along the stretch that is adjacent the lagoon to identify scour points that may have been impacted by the closure of the artificial channel and which may migrate towards the lagoon over time.

- Establish monitoring points and pegs, including control sites (i.e. not impacted by drainage from Salty Lagoon). The erosional points west of the old channel appear to be caused by a combination of water running over them (from the lagoon and immediate area runoff) and wave action from Salty Creek. Outputs include headcut reference points (pegs) to allow for subsequent measurement of headcut movement (upstream progression and width) and photo monitoring points.
- Undertake bimonthly monitoring of the headcut east of the old channel and identified additional scours/ headcuts west of the old channel. Outputs include measurements of headcut movement (upstream progression and width) and photo points, identifying changes in headcut progression.

Provisional Ongoing Salty Lagoon Monitoring

Macroinvertebrate, fish, waterbird and frog monitoring have been removed from the recommended ongoing Salty Lagoon monitoring program based on the results of the MPPC and/or low risk associated with measured attribute from the continued STP discharge. Ongoing monitoring of these features are provided on a provisional basis, with the intent of observing medium to long term changes in the Salty Lagoon system in response to channel closure. This would build upon the existing extensive datasets for the project.

Macroinvertebrates: Generally as per Section 3.4 of the MPPC (Hydrosphere 2010a), including the following key revision:

- Timing reduced to five yearly (i.e. the next event is Winter, Spring, Summer and Autumn in 2021/22).

Fish: Generally as per Section 3.4 of the MPPC (Hydrosphere 2010a), including the following key revision:

- Timing reduced to five yearly (i.e. the next event is Winter, Spring, Summer and Autumn in 2021/22).

Waterbirds: Generally as per Section 3.6 of the MPPC (Hydrosphere 2010a), including the following key revision:

- Timing reduced to five yearly (i.e. the next event is Winter, Spring, Summer and Autumn in 2021/22).

Frogs: Generally as per Section 3.7 of the MPPC (Hydrosphere 2010a), including the following key revision:

- Timing reduced to five yearly (i.e. the next event is Winter, Spring, Summer and Autumn in 2021/22).

Reporting

The following reporting is recommended:

- Bimonthly ecosystem health reporting (as per MPPC).
- Annual data compilation and analysis reporting (as per MPPC).
- Evaluation report at completion of the five year monitoring.

Key outputs from the reporting include:

- Monitoring results and ecosystem health status.
- Environmental risk and adaptive management requirements.
- Comparison of results against MPPC predicted trends (annual report only).

Table I1 Outline Monitoring Plan Year 6-10

Task Number	*Key Activity*	*Methodology (see Hydrosphere 2010 for further details)*	*Replications (see Hydrosphere 2010 for further details)*	*Number of Events*	*Timing*	*Milestones*	*Comments*
1	**Water quality loggers – maintenance/ calibration**	As per Section 3.1 in Hydrosphere 2010. Includes: ▪ monitoring of water temperature, DO, pH, EC, turbidity and water level. ▪ sonde cleaning and basic maintenance, calibration and replacement of spare sensor set; and ▪ liaison with Council if repairs are needed.	Two existing sites (one at Salty Lagoon and one at Salty Creek).	30 maintenance/ calibration events in total throughout project (July 2017 to June 2022).	Bimonthly (30 in total from July 2017 to June 2022).	Completion of bimonthly monitoring in June 2022.	Undertaken at the same time as Task 2 and 3 to maximise efficiency.
2	**Water quality sampling**	As per Section 3.1 in Hydrosphere 2010. Includes: ▪ sampling and depth profiling of pH, temperature, DO, EC, turbidity (all using an Horiba U-52 multimeter), Secchi depth. ▪ Also includes TN, NH3-N, NO2-N, NO3-N, TKN, TP, ortho-P, Chl-a, Ent and faecal coliforms, BGA taken by grab sample at fixed locations.	Five sites (four at Salty Lagoon and one at Salty Creek). One randomly selected quality assurance grab sample replicate per sampling event.	30 monitoring events in total throughout project (six per year from July 2017 to June 2022).	Bimonthly (30 in total from July 2017 to June 2022).	Completion of bimonthly monitoring in June 2022.	Undertaken at the same time as Task 1 and 3 to maximise efficiency.
3	**Health assessment: visual inspection**	As per Section 3.1 in Hydrosphere 2010. Includes: ▪ visual inspection of water quality and visibility of surface films, algal blooms, weed encroachment, revegetation establishment and debris; and ▪ obtaining photo point records.	six target sites (water quality monitoring sites - four at Salty Lagoon and one at Salty Creek, and channel infill site); opportunistic elsewhere while undertaking general monitoring activities.	30 monitoring events in total throughout project (six per year from July 2017 to June 2022).	Bimonthly (30 in total from July 2017 to June 2022).	Completion of bimonthly monitoring in June 2022.	Undertaken at the same time as Task 1 and 2 to maximise efficiency.
4	**Bimonthly ecosystem health assessment reports**	As per Section 4 in Hydrosphere 2010. Includes: ▪ compilation of bimonthly water quality data from Task 1, 2 and 3, continuously recorded data loggers, and relevant hydrological data (e.g. STP discharge data from Council; and rainfall data from Council and Bureau of Meteorology); ▪ documenting all environmental risk and adaptive management responses; ▪ documenting recent seasonal monitoring events (where appropriate); and ▪ documenting ecosystem heath, status and a risk assessment.	N/A	30 monitoring events in total throughout project (six per year from July 2017 to June 2022).	Bimonthly (30 in total from July 2017 to June 2022).	Submission of bimonthly report. Completion of bimonthly monitoring in June 2022.	
5	**Vegetation monitoring and assessment**	As per Section 3.3.1 Hydrosphere 2010. Includes field sampling and assessment to: ▪ document floristic diversity, cover, health and changes overtime as a result of the artificial channel closure; ▪ map changes in vegetation community boundaries; ▪ identify and monitor weed diversity, distribution and abundance; ▪ assess vegetation; and ▪ develop photo point records. Data recorded along transects include: ▪ vegetation boundaries changes; ▪ weed species, distribution and abundance; and ▪ Melaleuca dieback locations. Data recorded at quadrat sites includes: ▪ description of vegetation by stratum (height and total % cover); ▪ floristic composition with cover abundance for each species; ▪ DBH (diameter at breast height) for each stem greater than 10 cm DBH; ▪ condition for each Melaleuca stem (unaffected/full recovery, partial recovery, dead); and ▪ photo points taken from eastern end of each quadrat looking west. Additional melaleuca belt transect along the Melaleuca dieback transect and extending a further 50 m east into the fringing marsh (150 m in total).	Five transects with 20 quadrats including: ▪ Three approximately 400 to 600 m long transects on the western side of the lagoon. Six (10 x 10 m) quadrats are located along each transect (two quadrats would be located in each vegetation zone); and ▪ Two approximately 20 m long transects on the eastern side of the lagoon, each with one (10 x 10 m) quadrat. ▪ Three melaleuca dieback belt transects.	One event establishing melaleuca dieback belt transects (winter 2017). One complete event March 2022.	Winter 2017 and March 2022.	Completion of monitoring in 2022.	-

Task Number	*Key Activity*	*Methodology (see Hydrosphere 2010 for further details)*	*Replications (see Hydrosphere 2010 for further details)*	*Number of Events*	*Timing*	*Milestones*	*Comments*
		At each fixed 10 m point along the transect, record the following data based on a two metre radius of that point: Vegetation type; Presence or absence of dead melaleucas and Presence or absence of alive melaleucas. Where melaleucas are present, record: ▪ Tree health (presence of necrotic spots on leaves, galls on small branches); ▪ Presence or absence of trees (DBH>10cm), small trees (DBH <10cm to >5cm), saplings (DBH <5cm; height >0.5m) and seedlings (height <0.5 m), including tree height within each category; ▪ Condition of trees (DBH>10cm) and small trees (DBH <10cm to >5cm) using the following categories: unaffected/ full recovery; resprouting; and dying.					
6	**Aquatic weed survey and assessment**	As per Section 3.3.2 Hydrosphere 2010. Includes seasonal targeted and opportunistic (during bimonthly water monitoring) surveying, as follows: ▪ meander transects throughout Salty Lagoon system, specifically targeting lagoon perimeter and any disturbed areas; ▪ weed identification; ▪ GPS and map locations of infestations; and ▪ report results in relevant bimonthly and annual report where appropriate (eg. after seasonal monitoring). ▪ apply adaptive management responses where necessary.	Single targeted meander monitoring event undertaken every Spring, Summer and Autumn throughout project across the lagoon (15 surveys in total). Opportunistic aquatic weed monitoring events undertaken bimonthly during Tasks 1, 2 and 3.	15 targeted monitoring events in total. Opportunistic aquatic weed monitoring events undertaken bimonthly during Task 1, 2 and 3.	15 targeted meander surveys, undertaken every Autumn, Spring and Summer post artificial channel closure. 30 opportunistic aquatic weed monitoring events undertaken bimonthly during Tasks 1, 2 and 3.	Completion of monitoring in Autumn 2022.	Undertaken at the same time as Tasks 1, 2 and 3 to maximise efficiency.
7	**Erosional areas identification and monitoring**	Monitoring tasks proposed include: ▪ Survey (walk) the edge of Salty Creek, along the stretch that is adjacent the lagoon to identify scour points that may have been impacted by the closure of the artificial channel and which may migrate towards the lagoon over time. ▪ Establish monitoring points and pegs, including control sites (i.e. not impacted by drainage from Salty Lagoon). The erosional points west of the old channel appear to be caused by a combination of water running over them (from the lagoon and immediate area runoff) and wave action from Salty Creek. Outputs include headcut reference points (pegs) to allow for subsequent measurement of headcut movement (upstream progression and width) and photo monitoring points. ▪ Undertake bimonthly monitoring of the headcut east of the old channel and identified additional scours/ headcuts west of the old channel. Outputs include measurements of headcut movement (upstream progression and width) and photo points, identifying changes in headcut progression.	TBC	One establishment event. 30 monitoring events in total throughout project (six per year from July 2017 to June 2022).	Bimonthly (30 in total from July 2017 to June 2022).	Completion of bimonthly monitoring in June 2022.	Undertaken at the same time as Task 1, 2 and 3 to maximise efficiency.
8	**Annual ecosystem health assessment report**	Collaborate monitoring data and develop comprehensive report on environmental condition of the Salty Lagoon Ecosystem. To include a review of the usefulness and validity of collected data and future monitoring recommendations.	N/A	Five annual reports in total	Five reports provided annually from 2018 to 2022. Document provided in August each year.	Submission of each annual report. Completion of annual monitoring documentation in August 2022.	
9	**Final evaluation reports**	Collaborate monitoring data and annual reports to develop evaluation report to assist decision makers in determining further management directions for Salty Lagoon.	N/A	1	One report due August 2022	Completion of project and submit evaluation report.	

Task Number	Key Activity	Methodology (see Hydrosphere 2010 for further details)	Replications (see Hydrosphere 2010 for further details)	Number of Events	Timing	Milestones	Comments
10	**Project management**	Includes: ▪ background information review (including results from previous monitoring events); ▪ coordination of field monitoring; ▪ coordination and submission of reporting; ▪ general Council liaison; ▪ laboratory sample delivery and analysis co-ordination.	-	Ongoing	Ongoing	Project delivery at relevant stages.	
PROVISIONAL ITEMS							
11	**Macroinvertebrate monitoring**	As per Section 3.4 of Hydrosphere 2010. Includes: ▪ grab/core benthic sediment samples collected and sieved to 1 mm in the field then fixed in ethanol; ▪ samples processed and sorted in the laboratory; ▪ invertebrates identified to family level and counted; and ▪ results reported in relevant annual report.	Three replicates at each of the four fixed sample sites, all within Salty Lagoon.	Four monitoring events in the last year of the project	Seasonally in winter, spring, summer and autumn 2021-22	Completion of the project in 2022.	
12	**Fish monitoring**	As per Section 3.5 of Hydrosphere 2010. Includes: ▪ overnight bait trapping at selected sites to monitor species composition, distribution and abundance; ▪ fish identified counted and released in the field; ▪ site inspections as per adaptive management and fish kill response protocols; and ▪ results reported in relevant annual report.	20 bait traps at four fixed sample sites, all located within Salty Lagoon.	Four monitoring events in the last year of the project	Seasonally in winter, spring, summer and autumn 2021-22	Completion of the project in 2022.	
13	**Waterfowl monitoring**	As per Section 3.6 of Hydrosphere 2010. Includes: ▪ foot or canoe based traverse around the edge of the lagoon to record waterfowl species diversity, abundance and distribution over an one hour period; and ▪ map groups >8 individuals. Monitoring undertaken either in the early morning. Transportation method would depend on the status of the system.	One sample per monitoring event.	Four monitoring events in the last year of the project	Seasonally in winter, spring, summer and autumn 2021-22	Completion of the project in 2022.	
14	**Frog monitoring**	As per Section 3.7 of Hydrosphere 2010. Includes: ▪ Three transects recording dominant indicator species and their distribution (using GPS) and habitat associations; ▪ Six point counts along the three transects. Point counts surveys involve a two minute settling period followed by a five minute recording period during which the number of calling frogs within a 20 m radius, recorded independently by two observers. After five minutes counts would be discussed between observers and a consensus reached on abundance and diversity. Other frog calls within 50 m of point count sites would also be recorded; ▪ recording opportunistic recordings; and ▪ recording weather conditions during monitoring events.	Three transects each with six frog point count points, located on the western side of the lagoon.	Undertaken in late Winter, Spring and Summer commencing late Winter 2021 and finishing in Summer 2021/22. Monitoring undertaken on 2 non consecutive days/ nights during appropriate weather conditions. Six seasonal sampling events in total.	Seasonally in winter, spring and summer 2021-22	Completion of the project in 2022.	-

Appendix J

Post Closure Environmental Response Protocol – October 2017

Environmental Response Protocol - October 2017

Salty Lagoon Monitoring: Post Closure of Artificial Channel

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environmental management and design

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Prepared for: Richmond Valley Council

UPR	Description	Date Issued	Issued By
1731-1281	First issue	13/10/2017	David Andrighetto
1731-1290	Second issue	25/10/2017	David Andrighetto

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1. Introduction

1.1 Aim

The principal aim of this protocol is to document the procedures resulting in, and followed during, a response to a potential environmental incident in the Salty Lagoon system. The most relevant environmental incident that may require a response is an episode of poor water quality in Salty Lagoon with the potential to cause a fish kill. The key water quality variable in Salty Lagoon with the potential to cause a fish kill is a critically low dissolved oxygen concentration.

1.2 Background

Since 2008 water quality and other environmental variables have been monitored in Salty Lagoon, first as part of the Salty Lagoon Ecosystem Recovery Monitoring Program (ERMP) and subsequently as part of the Salty Lagoon Monitoring Pre/ Post Channel Closure (MPPC) program. Following on from this monitoring, an additional five-year Post Closure Monitoring Program (PCMP) has been implemented. The ERMP was implemented to monitor the response of the system to an upgrade of the Evans Head Sewage Treatment Plant (STP) and the MPPC was implemented to monitor the response of the system to closure of the artificial channel connecting Salty Lagoon and Salty Creek.

The additional five-year PCMP has been implemented with three main objectives:

1. Monitoring the health of Salty Lagoon and confirming that Evans Head STP discharge is not adversely impacting water quality and ecology at Salty Lagoon.
2. Monitoring water quality and attributes of the previous MPPC program where predicted trends have not been confirmed and risks to the ecosystem health still remain.
3. Observing medium to long term changes in the Salty Lagoon system in response to channel closure.

The primary outcome of this revised monitoring program is to inform decision makers in the future of the effect, if any, of continued long-term discharges of the Evans Head STP effluent into the Salty Lagoon system. One of the main variations in monitoring is associated with the removal of automated alarms from the system, given the reduction in alarms and adaptive management trips following the closure of the artificial channel.

Historically, the risk of a fish kill occurring in the Salty Lagoon system led to the introduction of a risk monitoring and event response protocol (Hydrosphere 2009) during the ERMP. Whilst not preventing fish kills, the protocol was valuable in the sense that information gathered during the event responses gave a detailed picture of the major risk factors occurring prior to a fish kill and the processes leading to a fish kill. For this reason, the key elements of the risk monitoring and event response protocol were maintained when the MPPC began.

The key factors that contributed to fish kills observed in Salty Lagoon following implementation of the event response protocol were:

- sustained periods of high salinity and high water levels;
- low dissolved oxygen concentrations;
- high temperatures; and
- rapid draining of the water from Salty Lagoon.

1.3 Current Context

The artificial channel connecting Salty Creek and Salty Lagoon was filled in by works that occurred from May to July 2012. Since the infill of the artificial channel the risk of some of the factors listed above has been reduced markedly. Although there is still some risk of seawater penetration into the Salty Lagoon system, the risk of it leading to very high concentrations of salt has been greatly reduced by the increased capacity for storage of fresh water and the subsequent likelihood of dilution. The risk of high temperatures has also been reduced because of the increased storage capacity and reduced light penetration to the bottom of the water column. The risk of rapid draining of the water from Salty Lagoon has been removed entirely. It is noted that an eroding head cut progressing between the creek and the lagoon, without suitable monitoring and management, may reinstate the connection between the two water bodies, hence returning the site to pre channel fill state. Generally speaking, the triggers that were developed during the ERMP are no longer relevant.

There are some new risks associated with the infill of the artificial channel and the changes to the Salty Lagoon ecosystem. These are:

- Potential deoxygenation of the water column resulting from:
  - a rapid increase in nutrient concentrations and biological processing of nutrients (primarily sourced from the decomposition of plant matter); and
  - the changeover period between a degraded brackish system with fluctuating water levels to a freshwater system with stable water levels (primarily relating to the decomposition of plant matter).
- Potential for salinity increases resulting from saltwater intrusion via Salty Creek.
- Risks associated with high temperatures (although the possibility is low).

In addition to the above information, continued monitoring of the data collected from Salty Lagoon and application of the adaptive management response protocol since the closure of the artificial channel have indicated that most of the time the DO concentrations at the bottom of the water column, where the permanently installed loggers are located, are low to very low (**Figure 1.1**). However, the percentage of low dissolved oxygen concentrations has reduced in the years since the channel was closed and the dissolved oxygen concentrations at the surface (and the majority of the water column) have been shown to be relatively stable and adequate for supporting biota in the main body of Salty Lagoon.

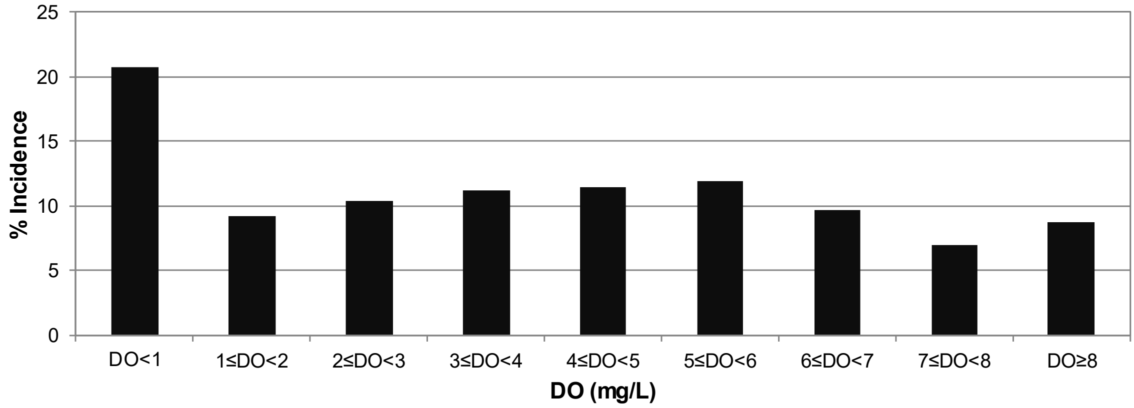

Figure 1.1 Percentage incidences of DO concentration brackets at the bottom of the water column since July 2012

With respect to DO concentrations, since closure of the artificial channel the water column in the main body of Salty Lagoon is sometimes stratified into a moderately well oxygenated surface layer (**Figure 1.2**) and an anoxic, occasionally hypoxic bottom layer. There are several factors that contribute to low DO concentrations at the bottom of the water column, including:

- Decomposing plant material resulting from the changeover from a degraded brackish to a freshwater system.
- Low background DO concentrations.
- Low benthic productivity due to poor light penetration.
- High DO consumption among benthic sediments resulting from elevated nutrient and organic matter processing.

It is uncertain how long these conditions will persist.

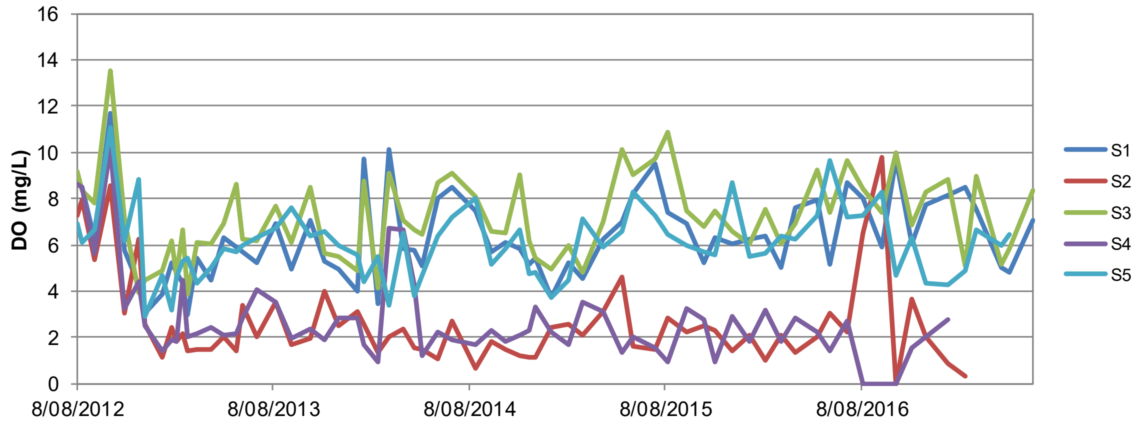

Figure 1.2 Surface DO concentrations at all sites since August 2012

In summary, the key factors that influence overall DO concentrations in Salty Lagoon can include:

- Diffusion of air into the surface waters, leading to higher surface water DO concentrations.
- Concentration of Microalgae, with photosynthesis (day) and respiration (night) producing and consuming oxygen respectively.
- Light availability influencing photosyntehese of microalgae (Turbidity).
- Wind and flow driven mixing, with more mixing leading to a well oxygenated water column.
- Water Level, with an effect on the impact of wind driven mixing and light availability to the entire water column.
- Salinity which can result in severe deoxygenation of the water column.

2. Event Response

2.1 Risk Monitoring

2.1.1 Monitoring Pre/ Post Channel Closure

Permanent water quality monitoring stations (PWQMS) were installed in Salty Lagoon and Salty Creek in May 2008. The PWQMS recorded and transmitted water quality and water level data at 15 minute intervals. This information formed the basis of ongoing risk monitoring. The data from the PWQMS was monitored on at least a weekly basis with email alerts sent to GeoLINK staff under particular circumstances. The triggers for email alerts have been revised over the course of the MPPC.

Triggers were revised and set at levels that reflected some environmental risk and intended to strike a balance between too many alerts and facilitating a rapid response when an event occurs (Hydrosphere 2009):

- Dissolved oxygen concentration < 1 mg/L – average over one hour.
- Dissolved oxygen concentration < 1 mg/L – average over three hours.
- Water temperature > 30˚C.
- Water level change (up or down) > 0.05 m in one hour.
- Water level change (up or down) > 0.4 m in 24 hrs.

Given that a variety of environmental scenarios have been observed (e.g. heavy rainfall, extended dry conditions, saline water ingress, etc.) over the course of the monitoring program, revised parameters were developed in 2013. The subsequently revised trigger levels for the Salty Lagoon PWQMS were as follows:

- Dissolved oxygen concentration < 1 mg/L – average over 12 hours.
- Conductivity > 3 mS/cm.
- Water temperature > 30˚C.

Typical responses to the receipt of alarms were based upon an assessment of risk that was dependent upon other supporting information and the understanding of the state of the system. Since the beginning of the MPPC a large number of alarms resulted in further response, i.e. a site inspection. This was particularly true in the early phase immediately following the closure of the artificial channel.

The changes to the alert triggers were based on the likelihood of differing scenarios following the closure of the artificial channel. The modified dissolved oxygen trigger was an acknowledgement of the increased likelihood of low dissolved oxygen at the base of the water column resulting from the greater water depths experienced in Salty Lagoon following the closure of the artificial channel. The introduction of a conductivity trigger was in response to the risk of saltwater penetration from Salty Creek. Although this is a natural feature of the system, it was still considered important to have immediate knowledge of such an occurrence via an alarm. The removal of the alarm for a change in water level was an acknowledgement that water level change was no longer related to a specific environmental risk in Salty Lagoon.

In moving beyond the MPPC, it has been acknowledged that the PWQMS have surpassed their useful life, and as such have been replaced with new water quality sondes and probes. Since the channel closure in 2012, there has been a clear reduction over time in alerts and subsequent adaptive management field trips with the risk of instantaneous events leading to fish kills reduced with the stabilisation of the Salty Lagoon ecosystem. Given this, the newly deployed water quality monitoring infrastructure will not be telemetered for alarm purposes however will still provide important water quality data at bimonthly intervals used to monitor ecosystem health.

2.2 Alarm Response

2.2.1 Previous Application

Since the beginning of the MPPC, upon receipt of an alarm, the current responses were either Level 1 or Level 2 (Hydrosphere 2010). A Level 1 response resulted in an increased frequency of checking data on the Richmond Valley Council (RVC) server. A Level 2 response resulted in a site inspection and extra round of water quality sampling. The site inspection was based upon a check of the banks of Salty Creek and Salty Lagoon for any sign of ecosystem disturbance such as a fish kill, algal bloom or impacts upon aquatic vegetation. Water quality sampling undertaken as part of an event response replicated the routine monthly discrete water quality sampling. Details of the previous alarm triggers and their allocated response level follow:

- DO < 1 mg/L – average over one hour – **Level 1 response**.
- DO < 1 mg/L – average over three hours – **Level 2 response**.
- Temp > 30°C – **Level 1 response**.
- Water level change (up or down) > 0.05 m in one hour – **Level 1 response**.
- Water level change (up or down) > 0.4 m in 24 hours – **Level 1 response**.

2.2.2 Revised Response

The revised response adopted in 2013 was based upon **Figure 2.1**.

2.2.3 Further Monitoring and Response

As addressed above, there were 13 adaptive management visits based upon alarms prior to channel closure and 10 adaptive management visits in the first 30 months following channel closure. There have been no adaptive management visits based on alarms since November 2014. Given the reduction in alerts and subsequent adaptive management field trips, the newly deployed water quality monitoring infrastructure will not be telemetered for alarm purposes. This results in a new pathway in regards to incident response and management. Because the risk of instantaneous events leading to fish kills has reduced with the stabilisation of the Salty Lagoon ecosystem, it is expected that the bimonthly monitoring will enable the determination of potential negative trends over the course of the program. Evans Head STP discharge data would continue to be assessed, with the notification provided for any Environmental Protection Licence (EPL) discharge exceedances.

Adaptive management will be undertaken in conjunction between Aquatic Science and management, GeoLINK and RVC, as part of the ongoing management of Salty Lagoon. The experience gained amongst the Project team will enable them to monitor external conditions which have led to previous adaptive management trips. The revised response will be based upon **Figure 2.2**.

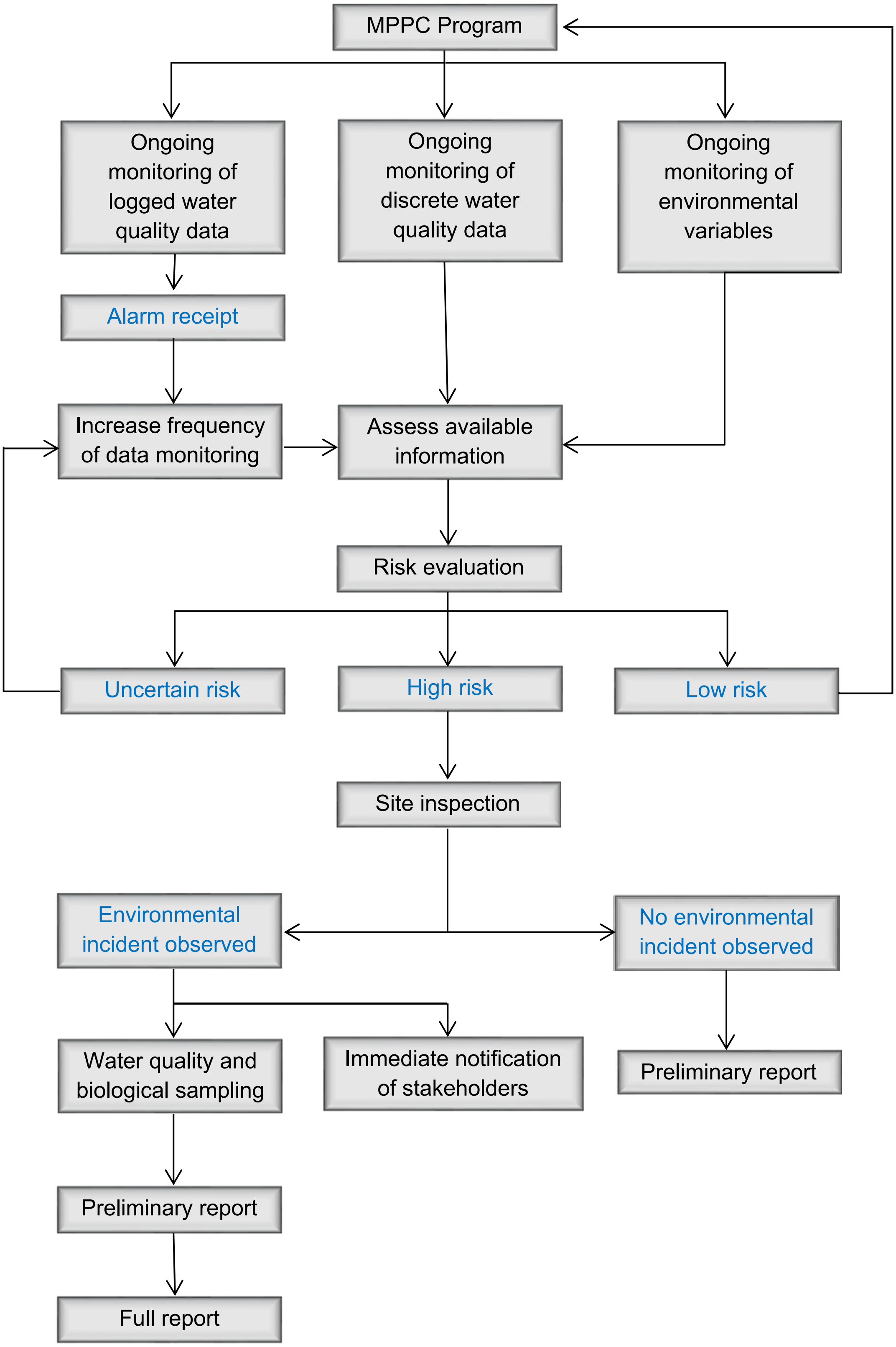

Figure 2.1 Salty Lagoon Response Protocol (adopted 2013)

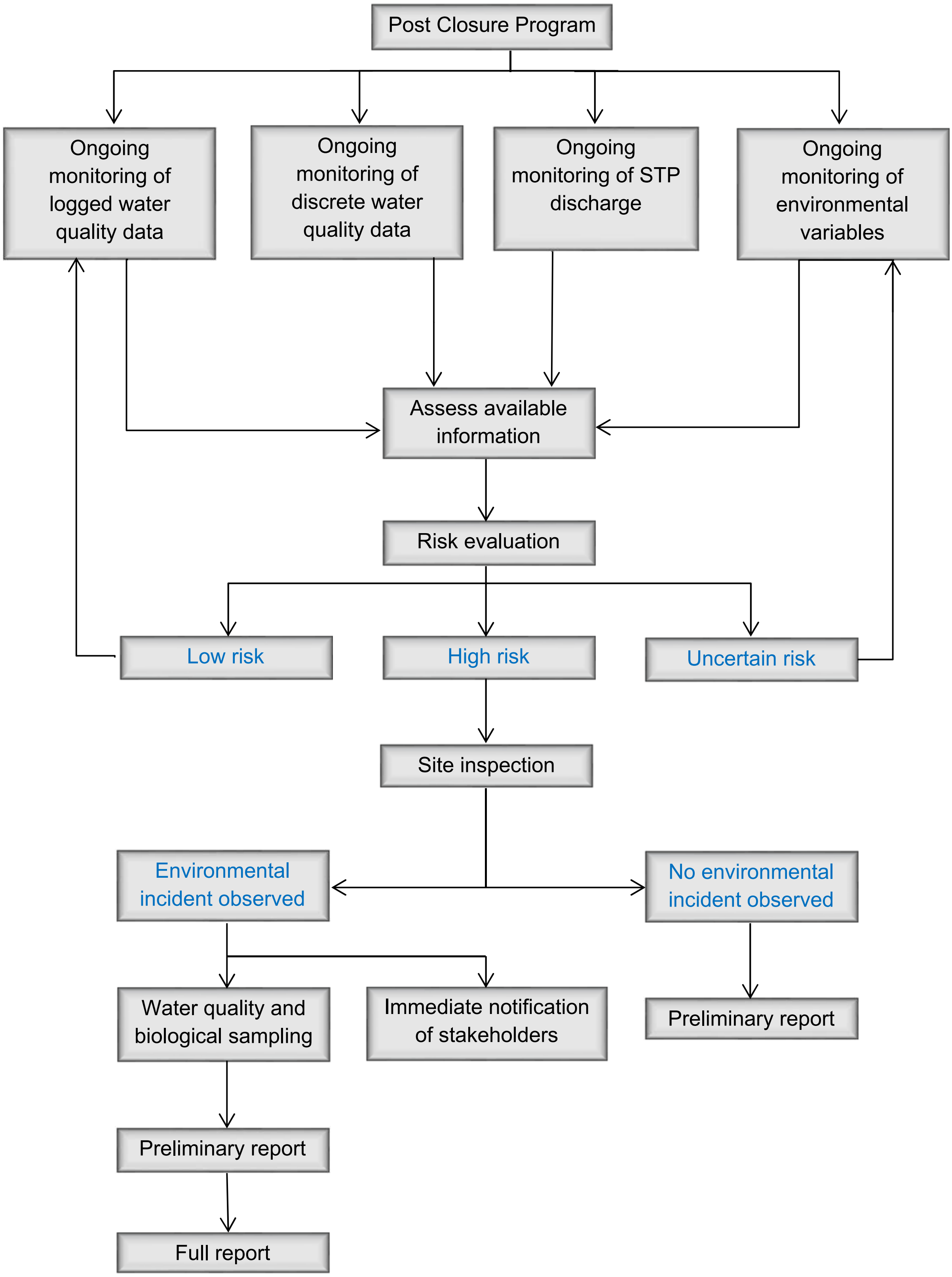

Figure 2.2 Salty Lagoon Revised Response Protocol (2017)

2.2.4 Detailed Response Protocol

The details of the environmental incident response protocol are displayed in **Table 2.1**.

Table 2.1 Details of Steps in the Revised Environmental Incident Protocol for Salty Lagoon

Task	*Description*	*Responsibility*
Post closure program ongoing monitoring of water quality data and environmental variables	Ongoing monitoring involves bimonthly checking of the logged water quality data, bimonthly measurements of surface water quality including physico-chemical, chemical and biological measurements, and surveys of aquatic weeds.	GeoLINK, Aquatic Science and Management
Ongoing monitoring of Evans Head STP discharge	Ongoing fortnightly monitoring of Evans Head STP discharge, including discharge quality and faecal coliform, Total Nitrogen (TN) and Total Phosphorus (TP) concentrations. The data collected from the Evans Head STP is used to contextualise results collected during ongoing monitoring and inform any pollution incidents that may occur.	Richmond Valley Council
Risk evaluation	Use all available data to evaluate the risk of the circumstances leading to environmental incidents. The key data include all recent water quality data and recent observations of environmental variables such as vegetation decay, tidal information potentially affecting the status of the entrance to Salty Creek and data from the Evans Head STP. Risk is classified as either **high**, **low** or **uncertain**. Risk remains as **uncertain** until classified as **high** or **low.** Classification of **low** risk is by consensus among representatives of RVC, GeoLINK and Aquatic Science and Management. If the perceived risk is thought to be **high** by a representative of RVC, GeoLINK or Aquatic Science and Management, a site inspection is required and all other parties are to be notified immediately by phone and email. In the case that the conditions resulting in a risk evaluation persist, risk will be re-evaluated on a weekly basis.	Richmond Valley Council, GeoLINK, Aquatic Science and Management
Site inspection	A site inspection will be conducted within 24 hours of a high risk classification. A site inspection involves: ▪ Physico-chemical water quality measurements at least five sites using a hand held probe. ▪ Checking the open water, banks and surrounding vegetation for evidence of fish kill or other loss of fauna. ▪ Checking for signs of abnormal vegetation	GeoLINK, Aquatic Science and Management

Task	Description	Responsibility
	or algal growth or death.	
Water quality and biological sampling	In the case that an abnormal environmental incident is noted during the site inspection water quality and biological sampling will proceed. Water quality monitoring will replicate the routine bimonthly water quality sampling in addition to any other samples/ analyses deemed necessary. RVC will be notified of any variation to the normal monthly monitoring prior to laboratory analysis. Biological sampling may include sampling fish, plant material or algal material dependent upon the nature of the incident.	GeoLINK, Aquatic Science and Management
Immediate notification of stakeholders	In the case of an environmental incident, representatives of DPI (Fisheries), OEH (EPA) and NPWS will be notified immediately by phone. In the case of a fish kill, the protocol for reporting a fish kill will be implemented.	Richmond Valley Council, GeoLINK, Aquatic Science and Management
Preliminary report	Within two working days of any site inspection a preliminary report will be delivered to RVC. The preliminary report will describe: ▪ a summary of the conditions in the lead-up to the site inspection and the factors that resulted in a high risk classification; ▪ the results of physico-chemical water quality monitoring; and ▪ the results of the site inspection, i.e., environmental incident detected/ no environmental incident detected.	GeoLINK, Aquatic Science and Management
Full report	In the case that an abnormal environmental incident is detected during a site visit and water quality and biological sampling proceed, a full report will be delivered to RVC within seven days of receiving results of the analyses of water quality and biological samples. A full report will describe: ▪ a summary of conditions leading up to the site inspection and the factors that resulted in a high risk classification; ▪ the nature of the environmental incident detected; ▪ charts of logged water quality data in the lead up to and immediately after the site inspection; ▪ the results of physico-chemical water quality monitoring; ▪ the results of water quality and biological sample analyses undertaken in response to the environmental incident; and ▪ follow-up required.	GeoLINK, Aquatic Science and Management

References

Hydrosphere Consulting (2009). *Salty Lagoon Ecosystem Recovery Monitoring Program – Environmental Incident Response Protocol*. Report to Richmond Valley Council.

Hydrosphere Consulting (2010). *Salty Lagoon Monitoring Program Pre/Post Closure of the Artificial Channel*. Report to Richmond Valley Council.

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Appendix A

Responsibilities and Contact Details

Responsibility	***Name/ Position***	***Role***	***Contact Details***
Representative – Richmond Valley Council	Craig Connolly (Water and Sewer Support Engineer)	■ Management of ERMP ■ DECC and DPI notification ■ Event response as required	craig.connolly@richmondvalley.nsw.gov.au Phone: 6660 0247 Mobile: 0457 505 625
	Johan Schoonwinkel (Water and Sewer Engineer)	■ Alternative RVC contact	johan.schoonwinkel@richmondvalley.nsw.gov.au Phone: 6660 0248 Mobile: 0414 395 706
Salty Lagoon Ecosystem Recovery Monitoring Program – GeoLINK Consulting	David Andrighetto (Project Manager / Ecologist) Duncan Thomson (Environmental Engineer/ Director) Mathew Birch (Aquatic Ecologist)	■ Data collection and monitoring ■ Risk Assessment ■ Alarm evaluation ■ RVC, NPWS, DPI notification as required ■ On-site assessment ■ Reporting	dandrighetto@geolink.net.au Phone: 6687 7666 Mobile: 0468 997 449 dthomson@geolink.net.au Phone: 6687 7666 Mobile: 0419 237 075 matbirch@iinet.net.au Phone: 6655 2140 Mobile: 0410 470 204
Representative – Broadwater National Park National Parks and Wildlife Service (NPWS)	Brian McLachlan (Ranger Richmond River Area)	■ Event response as required	brian.mclachlan@environment.nsw.gov.au Phone: 6627 0203
	Mark Pittavino (Area Manager, Richmond River Area)	■ Alternative NPWS contact	mark.pittavino@environment.nsw.gov.au Phone: 6627 0220
Representative – Fisheries Department of Primary Industries	Patrick Plunkett (District Fisheries Officer)	■ Event response as required in accordance with DPI Protocol for Investigating and Reporting Fish Kills (Appendix A)	patrick.plunkett@dpi.nsw.gov.au Phone: 6618 1800 Mobile: 0417 692 608
	Pat Dwyer (Fisheries Conservation Manager North)	■ Alternative DPI contact	patrick.dwyer@dpi.nsw.gov.au Phone: 6626 1397
Representative – Office of Environment and Heritage (OEH) – Environmental Protection Agency (EPA) branch	EPA Environment Hotline	■ Reporting of environmental incidents (24-hour)	Phone: 131 555
	Janelle Bancroft (Senior Operations Officer - North Coast)	■ Event response as required	Janelle.bancroft@epa.nsw.gov.au Phone: 6640 2513 Mobile: 0447 139 638

Appendix B

DPI Protocol for Reporting and Investigating Fish Kills

PROTOCOL FOR REPORTING AND INVESTIGATING FISH KILLS

Information on fish kills is available at: www.dpi.nsw.gov.au/fisheries/habitat/threats/fish-kills

Notification

When a report of a fish kill is received all information is to be recorded on the ***Fish Kill Notification & Investigation Report [Part A]***. Officers of the Department of Primary Industries (DPI) who receive this information must notify the Environmental Protection Agency (EPA) on 131 555 office and vice versa. Local offices of the Local Land Service and the relevant local council should also be notified.

Email the completed Part A form to ahp.central@dpi.nsw.gov.au and the relevant Regional Offices of DPI and EPA (see contact list) for their information. Each agency is responsible for information exchange within their respective departments.

Initial assessment

The officer receiving notification of the fish kill will decide whether a field investigation is warranted. This decision will be made following discussions with other staff (e.g. DPI and EPA) on the basis of: size of kill, sensitivity of waterway, potential cause (including likelihood of a disease agent), species affected, potential public interest, etc. If a field investigation is warranted, and DPI or EPA officers are not available, the department with primary responsibility for the investigation (see below) will endeavour to arrange an inspection by the local council or another government authority, whichever is most appropriate.

Field investigation

Generally, DPI officers will investigate fish kills in non-metropolitan areas while EPA officers will investigate fish kills in Sydney, Newcastle and Wollongong metropolitan areas. In many cases a joint inspection will be appropriate. Regardless of the location, EPA officers will be responsible for detailed investigation of kills which appear to be related to pollution events, hazardous chemical incidents or discharges from commercial or industrial premises.

Please note that all DPI Fisheries Officers in NSW have fish kill response kits available with required fish and water sampling and water quality testing equipment.

Investigating officers will inspect the site and complete the ***Notification & Investigation Report [Part B]***. If officers from a local council or a department other than EPA or DPI investigate a fish kill, the investigating officer should discuss the fish kill with their regional DPI Aquatic Ecosystem Fisheries Manager at the earliest opportunity (see contact list). The completed Part B form and other information such as photos or information about local media articles should be emailed to ahp.central@dpi.nsw.gov.au .

Media contact

Fish kills can generate significant media interest. All media requests for comment should be directed to the **DPI Media Unit** on **(02) 6391 3686**. Prior to any response to the media, a common view should be established between EPA and DPI officers, including any other relevant parties. The Program Leader - Aquatic Ecosystems is the DPI co-ordinator for media contact (phone 6626 1370 or 0419 253 819). Alternatively, DPI Senior Fisheries Managers can provide a regional response (see contact list). Any EPA related media queries should be directed to the relevant EPA regional office (refer to Contacts below).

Collection and analysis of samples

Water quality - on-site water quality measurements should be undertaken where possible. Regional DPI Aquatic Ecosystem - Fisheries Managers, EPA officers and local councils generally have digital meters available to undertake such assessments (see list of contacts). Water samples should be taken if a pollutant, algae or disease is possible, particularly during or immediately following an event where fish are still dying or recently dead. Water samples should be taken from the affected area and if possible from a nearby unaffected area for comparison. Water samples should be kept cold, but not frozen. Specialist advice should be sought regarding relevant water sampling procedures if a disease is suspected please call Program Leader - Aquatic Biosecurity and Risk Management (ph 4916 3911) or EPA officers for pollutants or algae (see list of contacts for specialist advice). Water samples will need to be logged with an appropriate NATA laboratory for testing as soon as possible, and again, advice from the appropriate specialists should be sought.

Fish samples for a possible disease - a disease agent may be possible when only a single species has been affected or the fish have visible lesions, fungus, and/or sick fish are visible and continue to die over a period, rather than in a sudden incident. Fish samples should be obtained but only after consultation with the Program Leader - Aquatic Biosecurity and Risk Management (ph 4916 3911). All fish samples are to be lodged with the DPI Elizabeth Macarthur Agriculture Institute laboratory for analysis. All appropriate information is to be included, including time, date, and exact location. Transport of live fish is ideal, but if not feasible, approximately six, dying (not yet dead) individuals of each species affected should be placed in separate plastic bags and placed on ice, **NOT FROZEN**. Dead fish should not be submitted for disease diagnosis as any deterioration in the condition of the fish post death will confound the results. The final report on the samples will be received and reviewed by the Aquatic Biosecurity and Risk Management before being forwarded to the reporting officer to assist with interpretation of results and advice on appropriate course of action to take if results for disease are positive. Results will generally be provided within two weeks of submission.

Fish samples where another agent, other than disease is possible – another set of fish samples should also be obtained where poor water quality, pollution, algal bloom or other agent is possible. Approximately six recently dead or dying individuals of each species affected should be placed in separate plastic bags and placed on ice. If immediate delivery is not possible fish samples should be frozen. Fish samples should only be lodged with an EPA laboratory in consultation with the DPI Program Leader or regional Fisheries Managers in Aquatic Ecosystems (see contact list).

Reporting of laboratory analysis

The officer responsible for organising transportation and analysis of water and fish samples will be responsible for reporting results of the analysis to all organisations previously involved with the fish kill.

Database, lodging completed forms

All completed **Notification and Investigation Report** forms and results of analyses are to be forwarded to ahp.central@dpi.nsw.gov.au please make the email subject reads: 'FISH KILL: [state the location of kill]'. The NSW DPI Fish Kill Database Coordinator will include the details in the state-wide fish kill database. Information from the database is available on request (see contact details provided on the forms).

FISH KILL Form Part A: Notification Report

NAME OF WATERBODY: ……………………………...…………………………………………………………

CATCHMENT: ……………………………………………………………………………..……………………..………
(e.g. Murray River, Sydney Harbour, Tuggerah Lakes)

PRECISE LOCATION WITHIN WATERBODY: ………………..……………………………….…………………………

(Place a pin on a Google Earth map and email with the KMZ or KML file attached)

HABITAT DESCRIPTION: (circle/highlight as appropriate)

(A) Freshwater / estuarine / marine

(B) stream / river / anabranch / lake / billabong / swamp / drain / channel / impoundment / bay / lagoon / farm dam / beach / open ocean / other:……………...……………………………………………………

REPORTED BY: ....……………………………………………………………….……..………………………………
(Name, address, phone)

TIME / DATE REPORTED ……………….……….. TIME / DATE KILL FIRST OBSERVED…..……………………

WEATHER CONDITIONS PRIOR TO OBSERVATION OF KILL: ..…………………………………....……………

……………………………………………………………………………………………………..……………………..…

TIDAL STATE/WATER LEVEL AT TIME OF KILL (if applicable):………………..……………….………………..

NUMBERS OF FISH AFFECTED (circle): less than 10 / 10 to 100 / 100s / 1000s / 10,000s / 100,000s / millions

CONDITION OF FISH (circle): dying / freshly dead / few hours old / few days old / decomposed

SIZE OF FISH (circle): all similar size (..…..…cm) / range of size classes (…..…. to ..…….cm)

SPECIES OF FISH AFFECTED (circle): one species only / few species / many different species

Please list if known: ………………………………………………………………………………………………………

LOCATION OF FISH (circle): floating in water / on bottom / along waters edge / onshore

EXTENT OF KILL (area (ha) or length (m) of area affected): ……………………..……………………………

(Create a polygon or line on a Google Earth map and email through the KMZ or KML file)

GENERAL OBSERVATIONS OF REPORTING PERSON: …………...………………………….………………………

……………………………………………………………..…………………………………………………………….…..

……………………………………………………………..……………………………………………………………..….

OTHER FORMS OF WILDLIFE AFFECTED? (specify): ……………………………………………….………………

WHAT IS THE SUSPECTED CAUSE? ………………………………………..………………………………………

OTHER INDIVIDUALS & AUTHORITIES NOTIFIED

INDIVIDUAL	DEPARTMENT	LOCATION	COMMENTS

REPORTED TO : ....POSITION: ....LOCATION...............……

ORGANISATION : ....…. DATE: ....…. PHONE………………......

REMINDER. Send copies of Parts A and B to:

NSW DPI Fish Kill Database Coordinator
1243 Bruxner Hwy WOLLONGBAR NSW 2477
ahp.central@dpi.nsw.gov.au

FISH KILL Form Part B: Investigation Report

TIME/DATE KILL INVESTIGATED: ....

HABITAT DESCRIPTION: (circle as appropriate)

(A) Freshwater / estuarine / marine

(B) stream / river / anabranch / lake / billabong / swamp / drain / channel / impoundment / bay / lagoon / farm dam / beach / open ocean / other:……………………….....……………………………………………….

ADJACENT LAND USES (specify): ……………………………………………………………………………

PHYSICAL EVIDENCE OF POLLUTION (OR ALGAL BLOOMS) OBSERVED:..

ON-SITE WATER SAMPLING RESULTS WATER SAMPLES COLLECTED: Yes / No

Sample no.	**1**	**2**	**3**	**4**	**5**	**6**
Name of sampling site						
pH						
Temp. (^oC)						
Dissolved Oxygen						
Others (specify)						

Attach map/diagram showing total area of fish kill and sample sites. Colour photographs would also assist analysis and identification.

OTHER COMMENTS: (eg behaviour/appearance of fish) ………………………………………………………

……..

AFFECTED FISH SPECIES (Full name)	**LENGTH RANGE (cm)**	**NUMBERS**	**SAMPLES COLLECTED**
			Yes / No
			Yes / No
			Yes / No
			Yes / No

SUSPECTED CAUSE OF FISH KILL: ....

....

WATER SAMPLES DESPATCHED TO:……………………..TO BE TESTED FOR: ....

FISH SAMPLES DESPATCHED TO:………………………..TO BE TESTED FOR: ....

INVESTIGATED BY: …………………………………………. POSITION: ....

ORGANISATION: ……………………………………………. DATE: ....

RECOMMENDATION(S) FOR FUTURE ACTION: ....

……

REMINDER. Send copies of Parts A and B to:

DPI Fisheries Fish Kill Database Coordinator
1243 Bruxner Hwy WOLLONGBAR NSW 2477
ahp.central@dpi.nsw.gov.au

Department of Primary Industries Fisheries NSW

Fishers Watch hotline (24 hr) 1800 043 536

District Offices

Albury	02 6042 4200
Ballina	02 6618 1800
Batemans Bay	02 4472 4032
Bathurst	02 6331 1428
Coffs Harbour	02 6652 3977
Deniliquin	03 5881 9928
Eden	02 6496 1377
Huskisson (Shoalhaven)	02 4428 3402
Illawarra	02 4295 1809
Inverell	02 6722 1129
Jindabyne	02 6451 3400
Maclean	02 6645 0504
Narooma	02 4476 2072
Narrandera	02 6959 9066
Nelson Bay (Port Stephens)	02 4982 3934
Port Macquarie	02 5524 0600
Swansea	02 4971 1201
Sydney Metro (Wollstonecraft)	02 8437 4903
Sydney South (Sans Souci)	02 9529 6021
Tamworth	02 6763 1132
Narara	02 4328 8618
Tumut	02 6947 9028
Tuncurry	02 6591 6300
Tweed Heads	07 5523 6900
Dareton (Lower Murray)	03 5019 8408

Advice on pathology testing, disease and sampling procedures:

DPI Aquatic Biosecurity	02 4916 3911

Media Contact Program Leader - Aquatic Ecosystems 6626 1370 or 0419 253 819

Aquatic Ecosystems – Fisheries Managers

Wollongbar	02 6626 1397
Tamworth	02 6763 1255
Port Stephens	02 4916 3931
Huskisson	02 4428 3401
Batemans Bay	02 4478 9103
Cronulla	02 9527 8522
Albury	02 6042 4213

Environment Protection Authority

Pollution Line (24 hr) 13 15 55

Regional Offices

Albury	02 6022 0600
Armidale	02 6773 7000
Bathurst	02 6332 7600
Grafton	02 6640 2500
Griffith	02 69690700
Newcastle	02 49086800
Queanbeyan	02 62297002
Sydney DIAC	0418 445 035
Wollongong	02 42244100

Specialist Advice

Water Science	02 9995 5539
Ecotoxicology	02 9514 4050
Env Forensics Group	0401 714 440
Inorganic Laboratory	02 6626 1103

COMPLETED FORMS emailed to:
ahp.central@dpi.nsw.gov.au