Annual Report 2016

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

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Executive Summary

GeoLINK and Aquatic Science and Management have been 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. This report (Annual Report 2016) summarises the results of the MPPC monitoring undertaken between June 2015 and May 2016, which consists of the post-closure of the artificial channel monitoring period. Key findings are summarised below.

Water Quality (Monitored at Salty Lagoon and Salty Creek)

- Water level: The water level in Salty Lagoon remained full for the majority of the reporting period for the second consecutive year.
- Conductivity: Conductivity was relatively stable throughout the reporting period with no evidence of water moving from Salty Creek into Salty Lagoon. Key driving factors causing recorded fluctuations were associated with rainfall and evaporation.
- Dissolved oxygen: During this reporting period the DO concentration measured at the Salty Lagoon permanent water quality monitoring stations (PWQMS) dropped below 1 mg/L on a large number of occasions. In the current reporting period the DO concentration was 6 mg/L or less on approximately 60% of occasions and 1 mg/L or less on approximately 5% of occasions. This is the first year since channel closure that this measure of DO concentrations has improved.
- pH: The pH measurements at the Salty Lagoon PWQMS have been very stable throughout this monitoring period.
- Temperature: Over the reporting period temperature fluctuated according to both daily and seasonal patterns. There is a relationship between water level in Salty Lagoon and the magnitude of temperature variation.
- Turbidity: During the current monitoring period turbidity measurements were relatively stable. Recorded fluctuations were in response to various factors such as wind driven sediment suspension and microalgal growth.
- Nitrogen: During the current reporting period the concentrations of TN were relatively stable with a few exceptions. In general, TN concentrations 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. If this is the case, TN concentrations should reduce over coming years as nitrogen is lost to the system in runoff. A low to moderate level algal bloom persisted for much of this reporting period. There is no indication of an association between dissolved inorganic nitrogen concentrations and chlorophyll-a concentrations, indicating that nitrogen was not a limiting factor for algal growth for this reporting period.
- Phosphorus: Variation in phosphorus concentrations at the sites in Salty Lagoon did not conform precisely to a specific pattern. Site S2 is the site most influenced by discharged effluent from the Evans Head STP and is most often the site with the highest phosphorus concentration. TN and TP concentrations appear to have varied independently during this reporting period. 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.

- Chlorophyll-a: Chlorophyll-a concentrations at the two open water sites in Salty Lagoon did not comply with guiding values for the majority of the reporting period, indicating an algal bloom of small to moderate proportions with the exception of samples collected in April and May 2016, which indicated an algal bloom of moderate to large proportions. The highest chlorophyll-a concentrations measured were not generally associated with increased total nutrient concentrations or bioavailable nutrient concentrations, nor seasonal or climatic conditions. It is possible that the more stable freshwater conditions are contributing to a stabilisation of the microalgal population in the water column.
- Chlorophyll-a concentrations again remained high for the majority of the reporting period, indicating an algal bloom of small to moderate proportions for much of the 12 months. The persistent algal bloom was caused by the increased nutrient concentrations and contributed to by the high water temperatures experienced over the same period. The algal concentrations were highest during the dry period when nutrient concentrations increased as a result of evaporative distillation.
- Blue green algae: Blue green algae were detected on one occasion (January 2016) during the reporting period from three sites in Salty Lagoon. This was the first time since the closure of the artificial channel that blue green algae have been detected in samples from Salty Lagoon.
- Faecal indicator organisms: With the exception of a few spikes in concentration the enterococcus and faecal coliform concentrations were low at all sites during the reporting period. The major contributors to the observed variation in the concentration of faecal indicator organisms are runoff from the catchment and the presence of waterfowl. 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.
- STP discharge monitoring: All discharge quality results for the monitoring period were within the licensing limits set for the Evans Head STP by the EPA, with the exception of one TP measurement. STP discharge is not enough to maintain water levels and water losses due to evaporation and groundwater being larger than the input from the STP. In general, faecal coliform concentrations in discharged effluent are very low. It is highly unlikely that discharged effluent is contributing significantly to faecal coliform measurements in Salty Lagoon. 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 and is diluted by unpolluted water from around the catchment. 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.

  The concentrations of TP in discharged effluent are generally comparable to those measured at S2, where the drainage channel opens out into Salty Lagoon. The increasing trend of TP concentration along the drainage channel from the STP to Salty Lagoon is 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 will continue for some time into the future.

Macroinvertebrates

- A total of 23 macroinvertebrate taxa have been recorded during the MPPC.
- There have been variations in the numbers of macroinvertebrate taxa captured between seasons, indicating temporal fluctuations in diversity around Salty Lagoon. However, as with the previous reporting periods there are no clear patterns of association with seasonal or measured environmental changes that can be concluded with certainty.

- The specific makeup of benthic macroinvertebrate communities 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.

Aquatic Vegetation/ Weeds

- No significant introduced species of aquatic weeds have been recorded in the current monitoring period, though an introduced (naturalised) species and four native species sometimes considered nuisance plants have been recorded.
- The risk of weed invasion into Salty Lagoon remains, particularly as the system continues the transition to a freshwater ecosystem. Plants that have not been recorded in Salty Lagoon prior to the MPPC were observed during the current reporting period, indicating pathways for recruitment of new species.

Fish

- Across all surveys during the reporting period a total of five finfish species were captured. The number of species captured at each of the sites has varied over time. There is no clear pattern to the overall observed variation.
- There was wide variation in the number (abundance) of fish captured at each site over time. Patterns evident are in relation to season and Mosquitofish numbers.

Waterfowl

- The current reporting period observed continued and consistent high levels of both diversity and abundance of waterfowl. The data shows a relatively consistent increase in abundance and diversity in summer and spring when more migratory species are utilising Salty Lagoon.

- The data shows a relatively consistent increase in abundance and diversity in summer and spring when more migratory species are utilising Salty Lagoon. With more stable water levels and less variation occurring as a result of changes in habitat availability this pattern is expected to continue.

- There has also been a consistent shift in the observed bird community towards a community dominated by waterfowl from the families *Anatidae* and *Rallidae* with fewer observations of shorebirds from the families *Scolopacidae* and *Charadriidae*.

Frogs

- The overall amphibian species diversity was lower in the current monitoring period (with the exception of the 2014-2015 monitoring period) when compared with previous MPPC monitoring. There is no obvious trend in total species diversity to date suggesting that this reduction is likely to be associated with climatic conditions and general survey limitations
- 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 broad segregation was noted 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 least common in these same habitats.

- Wallum Froglet distribution has remained relatively stable within the Sedge Swamp and Swamp Forest habitats, though has retracted westward along Transect 1 from the Fringing Marsh. *L. freycineti* and *L. olongburensis* have been recorded in such low numbers in the MPPC monitoring as to make it impossible to detect any changes in relation to these species, though *L. olongburensis* occurrences within the Sedge Swamp appear stable.

1. Introduction

1.1 Background

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). This engagement is part of a detailed rehabilitation strategy for Salty Lagoon that has been implemented by RVC.

The rehabilitation strategy comprises three parts:

- Part 1: Issues evaluation and information gap analysis.
- Part 2: Rehabilitation and management options assessment.
- Part 3: Implementation strategy.

A comprehensive description of the rehabilitation strategy is provided in the *Salty Lagoon Rehabilitation Plan* (Hydrosphere 2011).

Prior to this current engagement, RVC implemented the *Salty Lagoon Ecosystem Response Monitoring Program* (ERMP). In brief, the ERMP sought to monitor the ecological health of the system for a two year period, and to collect data across a range of disciplines to allow for further planning to be undertaken in accordance with the broader aims of the rehabilitation strategy. The study site for the ERMP was more extensive than that being monitored under the current engagement and included sampling sites along the entire length of the drainage channel from the Evans Head Sewage Treatment Plant (STP) to Salty Lagoon, and areas of adjoining bushland to the north of this facility. This work was completed in March 2010 (Hydrosphere 2010a) and included the following components:

- Water quality and hydrology.
- Diatoms.
- Macroinvertebrates.
- Fish.
- Frogs and waterbirds.
- Flora and vegetation mapping.
- Weeds.

The current engagement is part of the final phase of work (Part 3), which documents the implementation strategy and deals specifically with the closure of the artificial channel and associated actions. As part of this strategy RVC is implementing the MPPC (Hydrosphere 2010b).

1.2 Objectives

The objectives of the monitoring 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 STP.

The MPPC was initiated in March 2011 and will end in June 2017. The full scope of works for this part of the strategy comprises:

- Ecosystem health and trend assessment, including:
  - Targeted terrestrial vertebrate survey and monitoring.
  - Fish survey and monitoring.
  - Macroinvertebrate survey and monitoring.
  - Flora survey and monitoring assessments.
  - Water quality monitoring and review.
- Environmental status and risk assessment including:
  - Surface water quality and hydrology.
  - Field observations and monitoring data review.
  - Photo record for nominated sites.
- Adaptive management response including:
  - Water level and surface water quality.
  - Field observations.
- Existing water quality logger management (including calibration and maintenance).
- Professional advice on a range of issues including:
  - Adequacy of monitoring and recommendations for change over the course of the program.
  - Status of the ecosystem and emerging risks.
  - Assessment of the outcomes of the artificial channel closure trial.
  - Requirement for further monitoring beyond this engagement (anticipated to 2017).
  - Other matters as appropriate.
- Close liaison with RVC, Office of Environment and Heritage (OEH) and the Salty Lagoon Stakeholder Group, as well as attendance at meetings throughout the course of the project.

This report (*Annual Report 2016)* summarises the results of the monitoring undertaken between June 2015 and May 2016 as part of the MPPC program.

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 2009). Water quality monitoring is central to the MPPC 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 forms 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 (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

2.2.1 Permanent Water Quality Monitoring Stations

There are two permanent water quality monitoring stations (PWQMS) in place for the duration of the MPPC, measuring water level, temperature, pH, conductivity, turbidity and dissolved oxygen (DO) concentration. Each PWQMS is fitted with an YSI Series 6 sonde and a CRS 800 data logger. Data from the PWQMS is sent to a Richmond Valley Council (RVC) server via a telemetry system. This data was accessed at least weekly, checked for errors and outlying data, and incorporated into a database for the current reporting period. The water level data was corrected prior to being included in this report using the surveyed levels of the measuring boards at each of the permanent water quality monitoring stations. Each YSI sonde is removed from the PWQMS, calibrated and serviced after a two month deployment.

The data from the PWQMS is used to inform the adaptive management strategy. Automatic alarms are received from the RVC server when DO concentration or water level changes at a specific rate. The triggers for the alarms were reviewed in April 2013 and adjusted during this reporting period. This is discussed further in **Section 2.2.3**.

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. 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. Depth profiling is undertaken to improve the understanding of stratification of the water column at times when the water level is high. The results of depth profiling are reported in monthly ecosystem health reports and will not be repeated here.

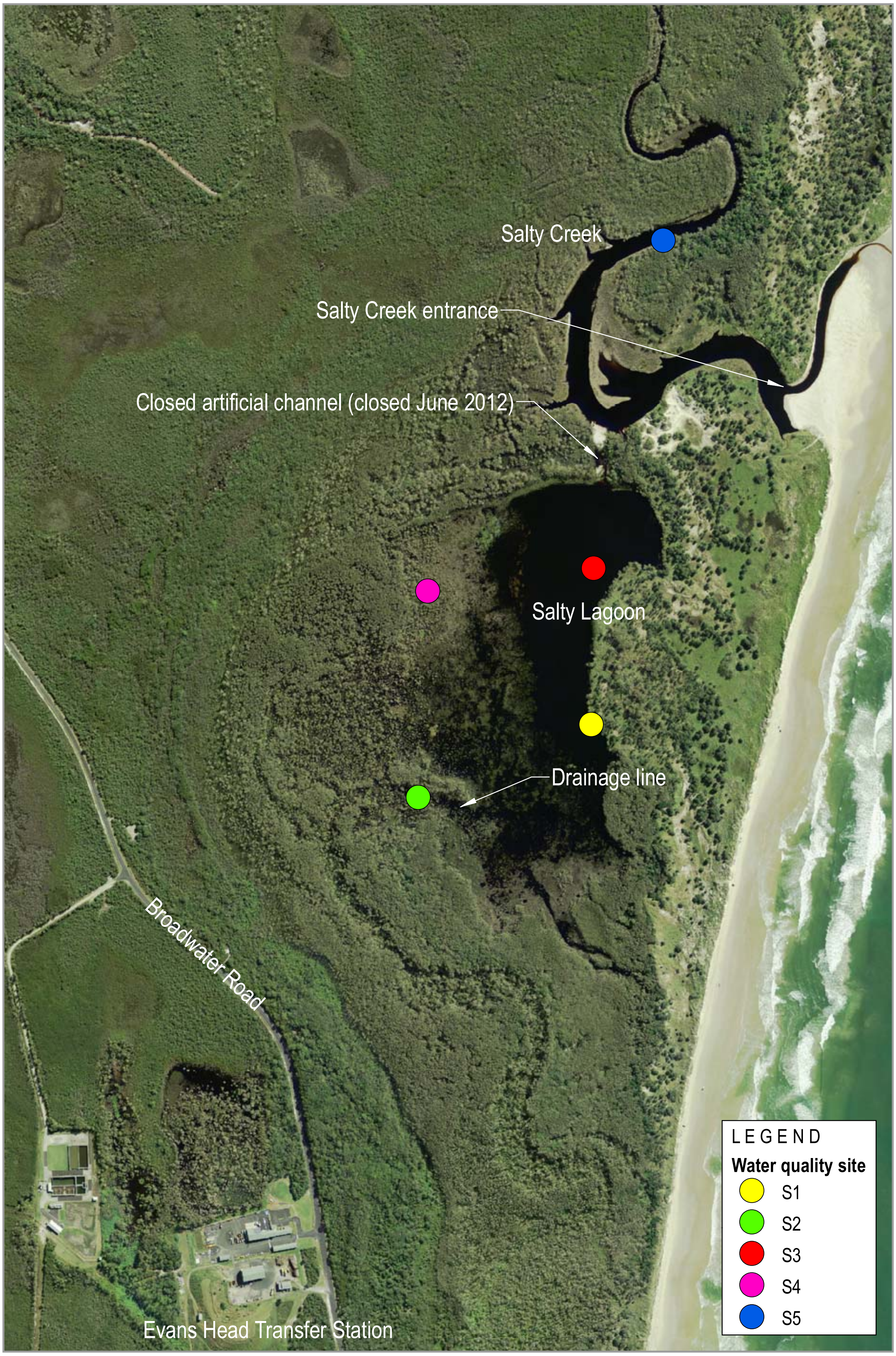
Discrete samples were collected in jars for analysis of chemical and biological parameters at the Coffs Harbour Laboratory (CHL). Sterile jars were used for bacteriological analysis and brown glass jars were used for analysis of chlorophyll-a and blue green algal (BGA) content. Samples were placed upon ice in an Esky and delivered to CHL within 24 hours of collection.

2.2.3 Adaptive Management WQ Sampling

The final water quality monitoring component of the MPPC is the 'adaptive management response'. The response process is documented in detail in the Environmental Incident Response Protocol (Hydrosphere Consulting 2009) that was developed previously for the Salty Lagoon Ecosystem Recovery Monitoring Program (refer to Hydrosphere Consulting 2010a). A review of the response process was prepared in April 2013 and adjustments have been implemented.

Drawn by: AB Checked by: RE Reviewed by: DSA Date: 8/09/2016
Source of base data: Richmond Valley Council

Information shown is for illustrative purposes only



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North

Location of Water Quality Sites

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Illustration 2.1

Essentially the adaptive management response component of the MPPC relates directly to the monitoring of potential significant environmental incidents that have periodically been known to occur at Salty Lagoon. It is informed by the two PWQMS, which record data at 15 minute intervals. Automatic alarms alert GeoLINK/ Aquatic Science and Management (ASM) and RVC staff via email if certain water quality or water level parameters are detected. The triggers for an adaptive management response were revised as part of the review process. They are currently:

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

When an alarm is received the need for a site inspection is assessed based upon the perceived risk of an environmental incident using all the available information and understanding of the system gained from the monitoring to date.

2.2.4 Guiding Values

Guiding values for use in the preparation of the monthly report card were revised in September 2012 and were generated using water quality data collected between April 2011 and September 2012 as part of the MPPC project. Guiding values were developed separately for Salty Lagoon and Salty Creek. These guiding values were developed based on data collected from surface water at all sites and incorporated all parameters measured as part of the MPPC.

Guiding values were set at the 80th percentile value of the collected data set for the lagoon and the 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.

Guiding values that have been developed based on the above methodology for all water quality parameters being sampled under the current monitoring program are presented in **Table 2.3**. The guiding values were developed to assist with the contextualisation of results, rather than as a measure of the health of the waterway. However, guiding values also provide a yardstick, around which the adaptive management of Salty Lagoon can be discussed.

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 conditions, providing an improved picture of dry and wet periods, are displayed in **Figure 2.1**. Daily rainfall for the reporting period is displayed in **Figure 2.2** and **Figure 2.3**. The monitoring period was characterised by particularly dry weather in October 2015 and May 2016, along with a relatively dry period between December 2015 and February 2016.

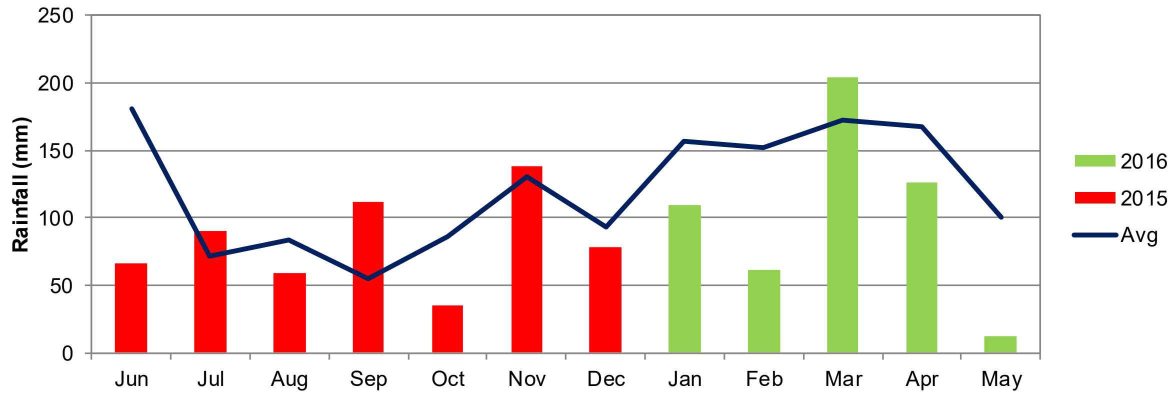


Figure 2.1 Monthly rainfall at the Evans Head BOM weather station for the reporting period displayed against average monthly rainfall (BOM 2016)

2.3.2 Permanent Water Quality Monitoring Stations

2.3.2.1 Data Quality and Consistency

There are 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;
- A gap in the Salty Creek PWQMS dataset resulting from data loss;
- Gaps in the Salty Lagoon PWQMS dataset resulting from battery failure; or
- Gaps where erroneous data, occurring as a result of faulty water quality probes, have been highlighted within the dataset. A monthly review of the status of each sonde has been implemented in order to avoid these issues and there have been less of these gaps during this reporting period than there had been in the two past annual reporting periods.

Over the monitoring period from 1 June 2015 to 31 May 2016 there were 5544 (15.8%) missed data points from the Salty Lagoon PWQMS and 1045 (3.0%) from the Salty Creek PWQMS. Most of the missed data points from Salty Lagoon occurred in between December 2015 and February 2016 due to poor battery performance.

As part of routine maintenance the logged results are compared in the field with data collected from a handheld water quality probe on a monthly basis. In general, the results correlate very well.

The battery failure at the Salty Lagoon PWQMS was rectified in March 2016 by removing branches from a Paperbark tree shading the solar panel. This was done with the permission of the NPWS Ranger.

2.3.2.2 Key Points Arising from the Salty Lagoon Data Set

The results from the Salty Lagoon PWQMS are presented in **Figure 2.2** and are discussed below.

Water Level

Salty Lagoon remained full for the majority of the reporting period for the second consecutive year. As a result, water moved from Salty Lagoon into Salty Creek for most of the reporting period and there is no evidence of water movements in the opposite direction. The water level chart in **Figure 2.2** indicates that:

- 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.
- Flow from Salty Creek into Salty Lagoon is unlikely when the entrance berm to Salty Creek remains low.
- Salty Lagoon still drains into Salty Creek when water levels are around 1.80 m AHD, albeit very slowly.

Conductivity

Conductivity is a measure of the saltiness of the water. The key driving factors causing fluctuations in the conductivity of the water recorded in Salty Lagoon during this reporting period were rainfall and evaporation. Evaporation causes a gradual increase in conductivity measurements. Rainfall has the opposite effect but typically operates over shorter timeframes. Small and short term variations in the conductivity measured at the Salty Lagoon PWQMS often result from changes in the intensity of wind and flow driven mixing of the water column. This is most apparent when water levels are low. Overall conductivity was relatively stable throughout the reporting period with no evidence of water moving from Salty Creek into Salty Lagoon.

Dissolved Oxygen

The main dynamics of Dissolved Oxygen concentrations in Salty Lagoon post-channel closure are now well understood. The observed variations in DO concentrations include daily fluctuations in response to light availability (diurnal fluctuations), short term irregular variation in response to wind driven mixing, seasonal variation relating to water temperatures and medium term fluctuations in response to rapid changes in the water quality, such as heavy rainfall runoff. The key factors that influence 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 DO concentrations measured in surface waters between 1 June 2015 and 31 May 2016 are reported in **Section 2.3.3**.

During this reporting period the DO concentration measured at the Salty Lagoon PWQMS dropped below 1 mg/L on a lesser number of occasions. In the current reporting period the DO concentration was 6 mg/L or less on approximately 60% of occasions and 1 mg/L or less on approximately 5% of occasions. This is the first year since channel closure that this measure of DO concentrations has improved significantly. In the previous reporting period the DO concentration at the Salty Lagoon

PWQMS dropped below 1 mg/L on 19% of occasions and in the reporting period before that it was 22%.

pH

The pH measurements at the Salty Lagoon PWQMS have been very stable throughout this monitoring period. The major features are small daily fluctuations in pH associated with other diurnal changes in water quality such as dissolved oxygen concentration.

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. This may warrant further investigation, as the wetlands around Salty Lagoon are typically low pH.

Temperature

Over the reporting period temperature fluctuated according to both daily and seasonal patterns. There is also 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. For example, at higher temperatures water has a lower oxygen carrying capacity and higher temperatures encourage microalgal growth and activity and contribute to algal blooms.

Turbidity

Turbidity is a measure of the capacity of water to transmit light. As light is scattered by particulate matter turbidity measurements give an indication of the sediment and other material suspended in the water column. Turbidity measurements fluctuate in response to various other factors such as wind driven sediment suspension and microalgal growth. During the current monitoring period turbidity measurements were relatively stable. Higher turbidity measurements were associated with algal blooms and low water levels. 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.

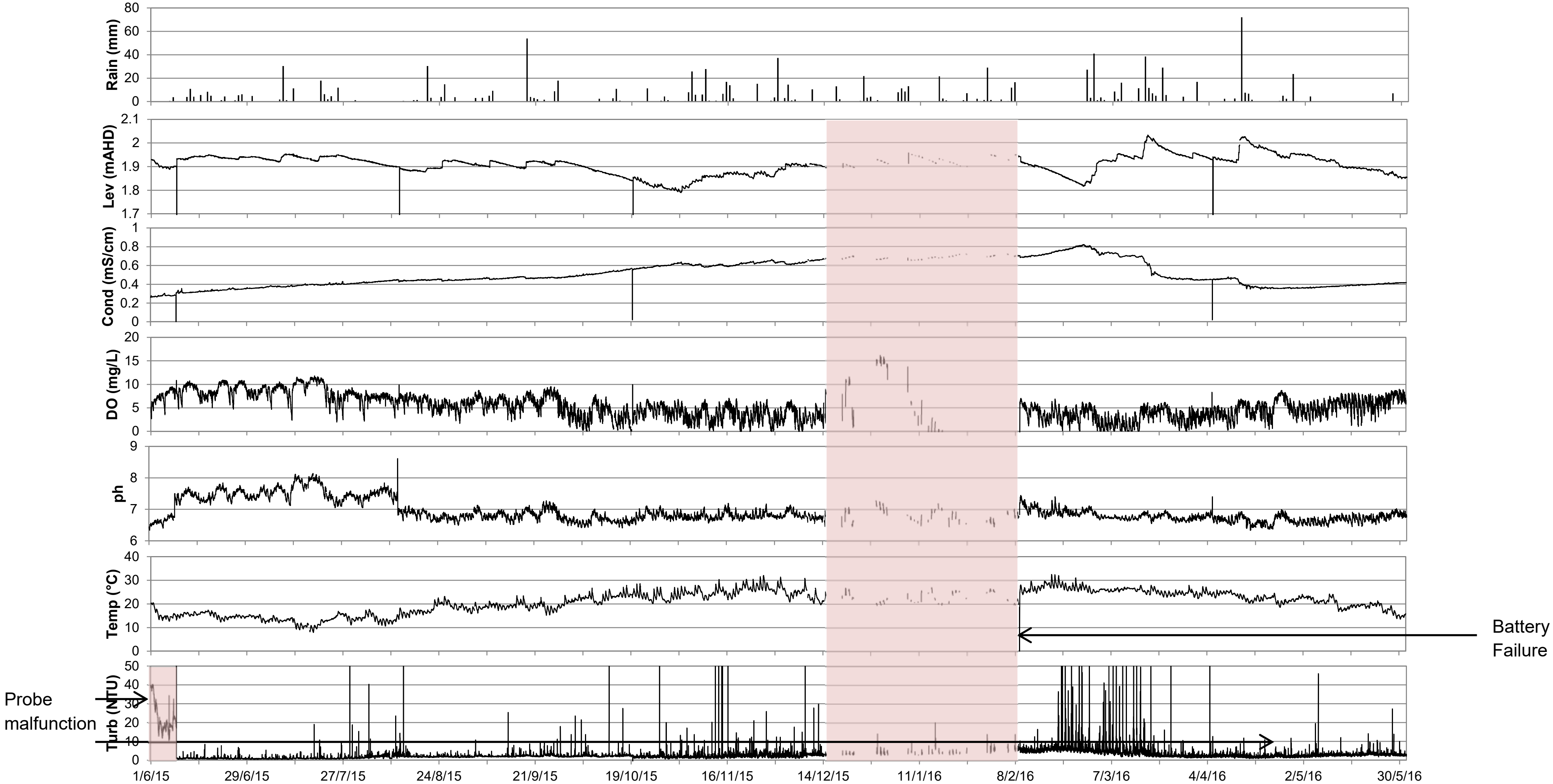


Figure 2.2 Data from the Salty Lagoon PWQMS for the current reporting period

2.3.2.3 Key Points Arising from the Salty Creek Data Set

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 **Figure 2.3**.

Water Level

The most important factor affecting the water level in Salty Creek is the status of its entrance. The entrance to Salty Creek opened nine times in the current reporting period, compared with 17 times in the previous reporting period and two times, five times and 17 times respectively in the reporting periods before that. The entrance to Salty Creek was very dynamic during the current reporting period and rarely closed over completely. The level of Salty Creek increased sharply on a number of occasions during the reporting period as a result of seawater ingress during large swell and storm surge conditions.

Conductivity

The conductivity measurements from the Salty Creek PWQMS fluctuated widely in response to the dynamic state of the entrance during this reporting period. The dataset indicates varying influences of heavy rainfall, tidal movements and seawater ingress. During the times when conductive saline water dominated the readings from the Salty Creek PWQMS, discrete water quality samples from the surface of the water frequently showed that the water column was stratified into a heavy saline layer and a freshwater surface layer.

Dissolved Oxygen

Dissolved Oxygen (DO) concentrations measured at the Salty Creek PWQMS fluctuated widely throughout the year. A variety of factors influence the DO concentrations in Salty Creek. The general patterns of variation were as follows:

- DO concentration tended to be higher during periods of freshwater dominance and when water levels were low.
- DO concentrations in Salty Creek fluctuated diurnally over the majority of the reporting period but these fluctuations tend to be weak and are most pronounced when freshwater dominates.
- The water column is often stratified with respect to DO concentration, although this is not apparent from the logged information.

The DO concentration measured at the Salty Creek PWQMS was 6 mg/L or less for approximately 81% of the reporting period and 1mg/L or less for approximately 25% of the reporting period. These figures are comparable to those reported in previous years.

pH

The pH measurements from the Salty Creek PWQMS fluctuated regularly during this reporting period and were closely associated with conductivity and the state of the entrance. Runoff from the catchment is naturally acidic, resulting in a pH of < 5 in Salty Creek following heavy rainfall. This contrasts strongly with the pH after seawater ingress which can have the effect of increasing the pH measurements to over pH 7. The pH in Salty Creek thus tends to be either quite high or very low, depending upon the dominant source of water.

Temperature and Turbidity

Temperature measurements in Salty Creek fluctuated on a daily and seasonal basis. Daily fluctuations in temperature are strongest when water levels are low. Turbidity measurements from the Salty Creek PWQMS were generally low, with periods of greater turbidity following seawater ingress and heavy rainfall.

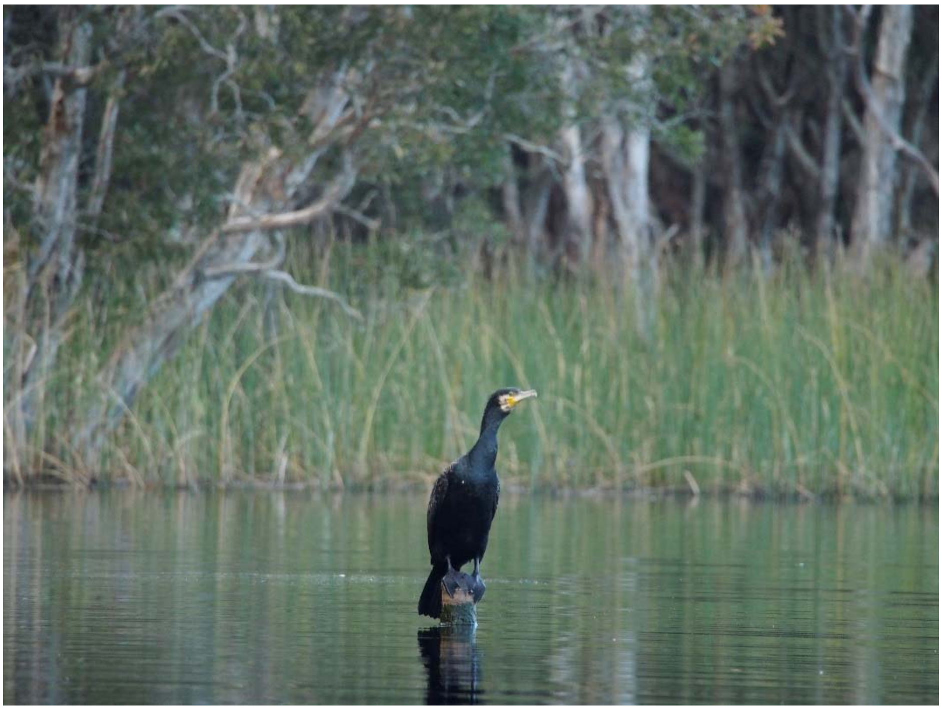


Plate 2.1 A Great Cormorant making the most of water quality monitoring infrastructure

Figure 2.3 Data from the Salty Creek PWQMS for the current reporting period

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. A summary of median results for all samples from all sites is presented in **Table 2.4**. Results from individual sites are compared in **Section 2.3.3.1** to **Section 2.3.3.5**.

Table 2.4 Median Results of Discrete Samples from Surface Waters at all Sites Between 1 June 2015 and 31 May 2016

Indicator	*Site*				
	S1	*S2*	*S3*	*S4*	*S5*
Nitrite nitrogen (mg/L)	0.00	0.00	0.00	0.00	0.00
Nitrate nitrogen (mg/L)	0.00	0.00	0.00	0.00	0.00
Oxidized nitrogen (mg/L)	0.00	0.00	0.00	0.00	0.00
Ammonia nitrogen (mg/L)	0.00	0.00	0.00	0.00	0.01
Total kjeldahl nitrogen (mg/L)	1.59	1.14	1.57	**1.74**	1.31
Total nitrogen (mg/L)	**1.60**	1.14	1.57	**1.75**	1.32
Total phosphorus (mg/L)	0.12	0.12	0.13	0.04	0.00
Orthophosphate (mg/L)	0.06	0.06	0.07	0.01	0.00
Chlorophyll-a (µg/L)	**6.50**	2.50	**8.00**	0.00	0.00
Enterococcus (CFU/100mL)	16.50	141.50	15.00	30.00	5.00
Faecal coliforms (CFU/100mL)	26.00	36.00	16.00	7.00	46.00
Blue green algae (cells/L)	0	0	0	0	0
Temp (˚C)	22.84	20.30	22.63	20.14	23.50
pH	**6.90**	6.21	**6.92**	5.52	4.87
ORP (mV)	171.5	172.0	187.5	186.0	244.5
Cond (mS/cm)	0.51	0.40	0.51	0.60	1.30
Turbidity (NTU)	3.05	1.55	3.20	1.05	0.55
DO (mg/L)	6.65	**2.26**	7.48	**2.13**	6.34
DO (% sat)	78.25	26.75	87.50	22.90	73.90
TDS (ppt)	0.33	0.26	0.33	0.39	0.83
Salinity (ppt)	0.25	0.20	0.25	0.30	0.65

Note: ***red text:*** *not compliant with MPPC guiding values (GeoLINK 2012b)*

2.3.3.1 Nitrogen

Nitrogen is an element that is essential to life. In waterways it plays an important role in supporting food webs. However, problems arise from excessive nitrogen concentrations in water. Nitrogen is frequently monitored as an indicator of water quality and its capacity to support a healthy aquatic ecosystem. Nitrogen is present in water in a number of forms. It can be dissolved or particulate and can be present in organic molecules that are unavailable for biological uptake or inorganic molecules that are bioavailable. For the MPPC nitrogen is measured as total nitrogen (TN), and the dissolved inorganic nitrogen (DIN) forms; ammonia, nitrate and nitrite.

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 TN at S2 are often lower than those measured downstream.

During the current reporting period the concentrations of TN were relatively stable with a few exceptions (**Figure 2.4**). Although the TN concentrations at S4 tend to be higher than those from other sites, the differences between the individual sites appear to have been less prominent during this reporting period, probably as a result of more stable water levels. In general, TN concentrations 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. If this is the case, TN concentrations should reduce over coming years as nitrogen is lost to the system in runoff.

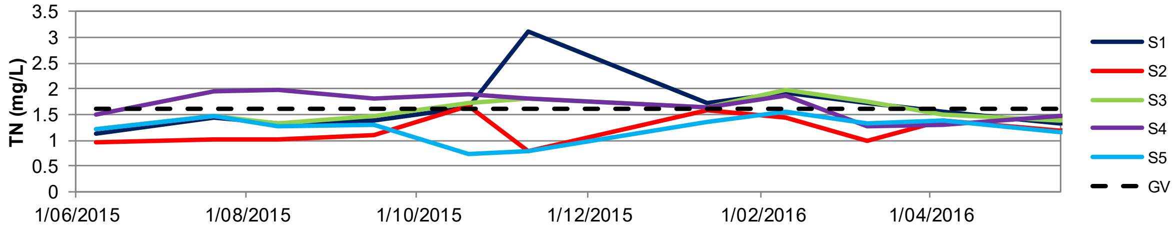


Figure 2.4 Time series of TN concentrations at all sites for the current reporting period

Aside from high concentrations at S1 and S3 early for the first two months, overall DIN concentrations remained low at all sites throughout the reporting period (**Figure 2.5**). There was no obvious seasonal trend notable in the temporal variation though there may be an association between periods of low rainfall and higher DIN concentrations, particularly during the colder months.

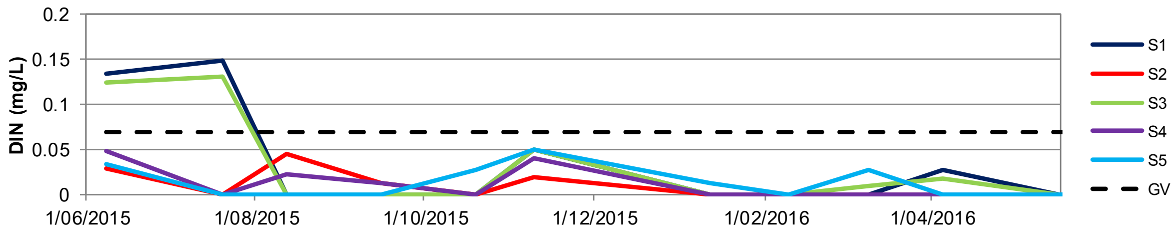


Figure 2.5 Time series of DIN concentrations at all sites for the current reporting period

A low to moderate level algal bloom persisted for much of this reporting period, particularly at S1, S3 and, to a lesser extent, S2 (**Section 2.3.3.3**). There is no indication of an association between DIN concentrations and chlorophyll-a concentrations, indicating that nitrogen was not a limiting factor for algal growth, at least for this reporting period.

2.3.3.2 Phosphorus

Phosphorus is also essential to life and, like nitrogen, plays a role in supporting aquatic food webs and can be detrimental to aquatic ecosystems at excessive concentrations. Phosphorus exists in a number of different forms in water, either as bioavailable phosphorus (orthophosphate) or organic molecules containing phosphorus unavailable for biological uptake.

The variation in phosphorus concentrations at the sites in Salty Lagoon did not conform precisely to a specific pattern (refer to **Figure 2.6** and **Figure 2.7**). However, the data does allow for some general observations:

- Site S2 is the site 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. This was also the case for the previous annual reporting period.
- TN and TP concentrations appear to have varied independently during this reporting period.

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.

The phosphorus concentrations at the Salty Creek site remained low for the entire monitoring period.

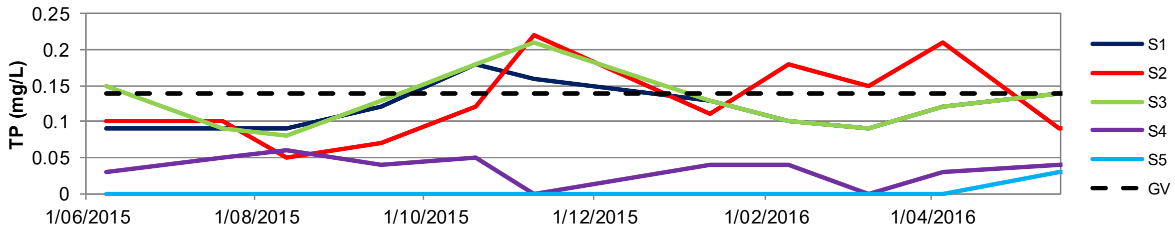


Figure 2.6 Time series of TP concentrations at all sites for the current reporting period

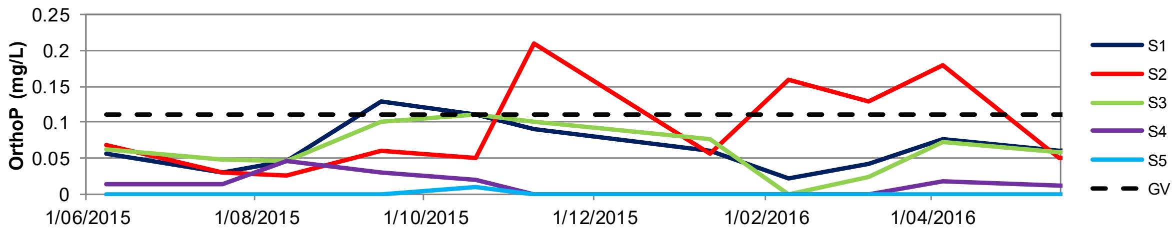


Figure 2.7 Time series of orthophosphate concentrations at all sites for current reporting period

2.3.3.3 Chlorophyll-a

The concentration of chlorophyll-a is a measurement of microalgae in the water column. Microalgal abundance fluctuates naturally in response to temperature, nutrient concentrations and light availability, but algal blooms are usually considered to be an indication of poor ecosystem health. Chlorophyll-a concentrations at the two open water sites in Salty Lagoon did not comply with guiding values for the majority of the reporting period (refer to **Figure 2.8**). Most of the results from these two sites indicated an algal bloom of small to moderate proportions with the exception of samples collected in April and May 2016, which indicated an algal bloom of moderate to large proportions.

The highest chlorophyll-a concentrations measured were not generally associated with increased total nutrient concentrations or bioavailable nutrient concentrations (DIN and orthophosphate). Nor were they generally associated with seasonal or climatic conditions in ways that would be expected. It is possible that the more stable freshwater conditions are contributing to a stabilisation of the microalgal population in the water column.

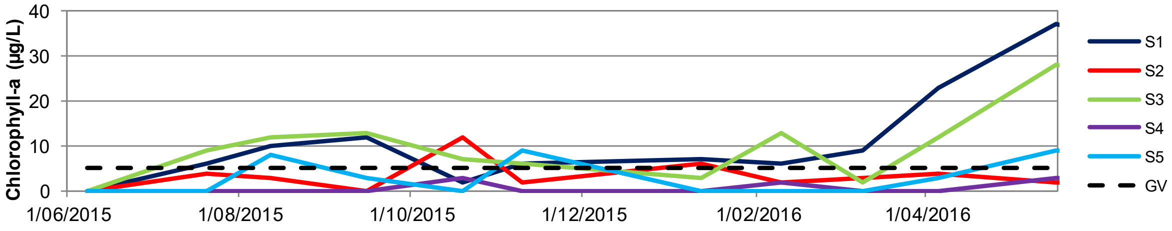


Figure 2.8 Time series of chlorophyll-a concentrations at all sites for the current reporting period

2.3.3.4 Blue Green Algae

Blue green algae are naturally occurring photosynthetic bacteria. Under bloom conditions they can be toxic to humans and aquatic fauna and can cause other problems related to deoxygenation of the water column and reduced light penetration. Blue green algae were detected on one occasion (January 2016) during the reporting period from three sites in Salty Lagoon. This was the first time since the closure of the artificial channel that blue green algae have been detected in samples from Salty Lagoon.

2.3.3.5 Faecal Indicator Organisms

Enterococcus and faecal coliforms are bacteria that can be measured as an indication of faecal pollution of waterways. Both enterococcus and faecal coliforms can be sourced from humans or animals and sometimes from rotting vegetation. Faecal indicator organisms are most commonly measured to assess the risks associated with recreational activity in and on waterways.

With the exception of a few spikes in concentration the enterococcus and faecal coliform concentrations were low at all sites during the reporting period (refer to **Figure 2.9** and **Figure 2.10**).

The major contributors to the observed variation in the concentration of faecal indicator organisms are runoff from the catchment and the presence of waterfowl. 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.

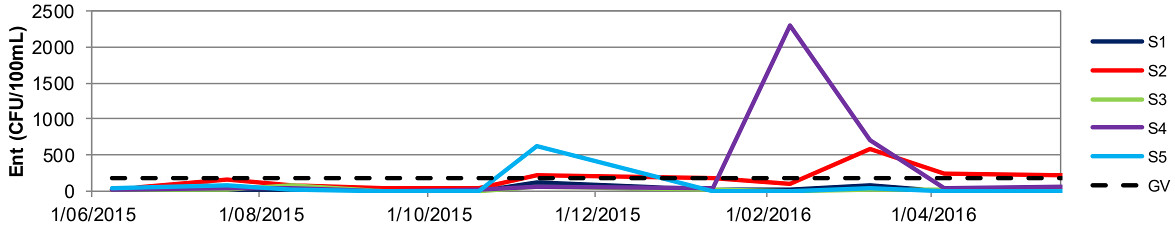


Figure 2.9 Time series of enterococcus concentrations at all sites for the current reporting period

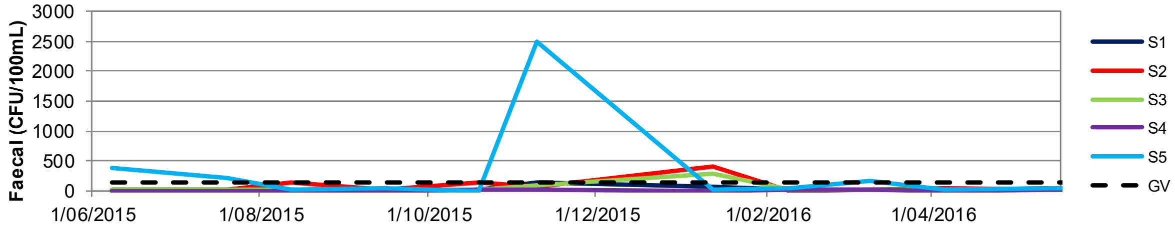


Figure 2.10 Time series of faecal coliform concentrations at all sites for current reporting period

2.3.4 STP Discharge Monitoring

As part of licensing conditions, the Evans Head STP is required to monitor discharge quality on a fortnightly basis. A suite of effluent quality parameters is sampled including faecal coliform, TN and TP concentrations. The data collected from the Evans Head STP is used to contextualise results collected during the MPPC and inform any pollution incidents that may occur during the project. Monitoring results from the Evans Head STP are presented in **Figure 2.11**, **Figure 2.12**, **Figure 2.13** and **Figure 2.14**. With the exception of one TP measurement, which exceeded the maximum limit, all results for the entire monitoring period were within the licensing limits set for the Evans Head STP by the EPA.

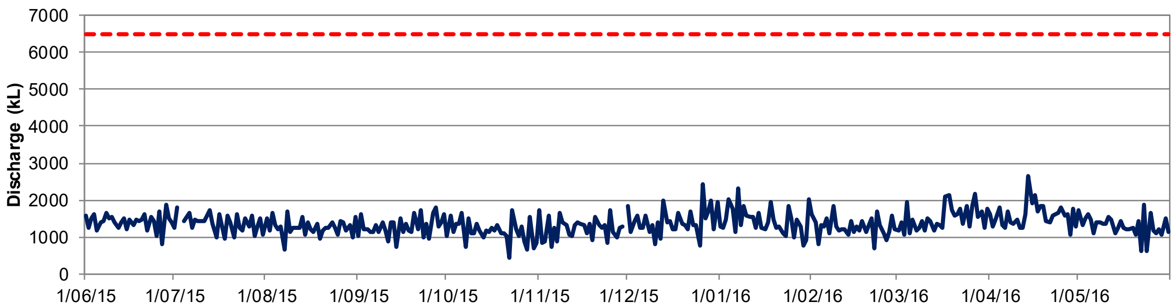


Figure 2.11 Time series of daily discharge volumes from the Evans Head STP (maximum allowed discharge volume in red)

The daily discharge volumes from the Evans Head STP were within the licensing limits set by the EPA for the entire reporting period. The discharge from the Evans Head STP does not appear to increase the water levels in Salty Lagoon. There have now been a number of 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.

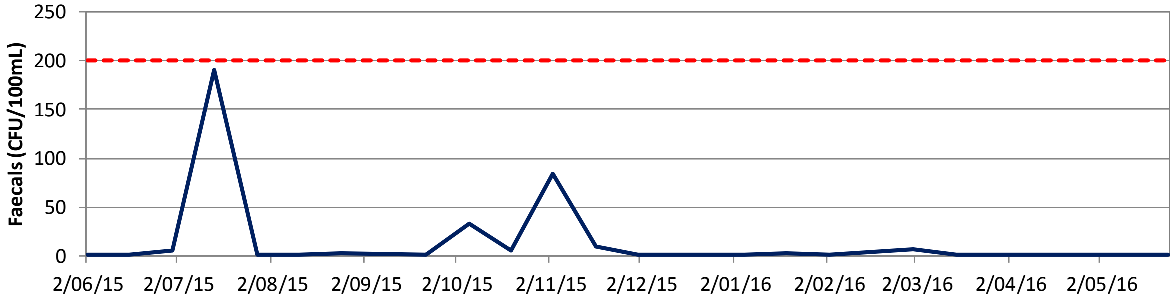


Figure 2.12 Time series of faecal coliform concentrations from the Evans Head STP discharge (90th percentile limit in red)

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 2010a). 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.

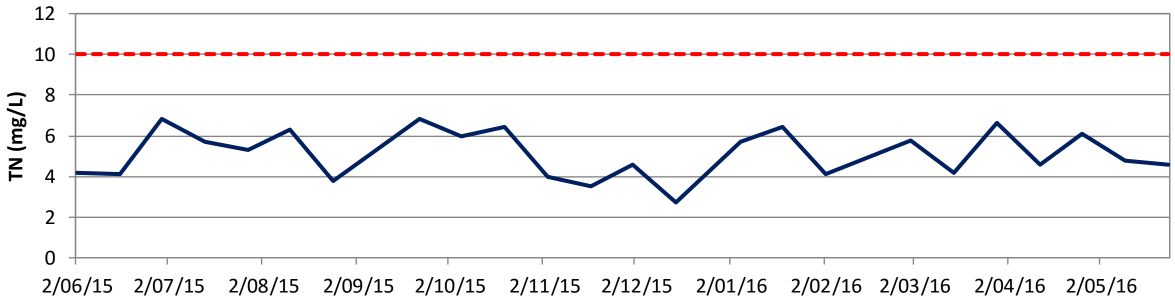


Figure 2.13 Time series of TN concentration from the Evans Head STP discharge (90th percentile limit in red)

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. Hydrosphere (2010a) 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.

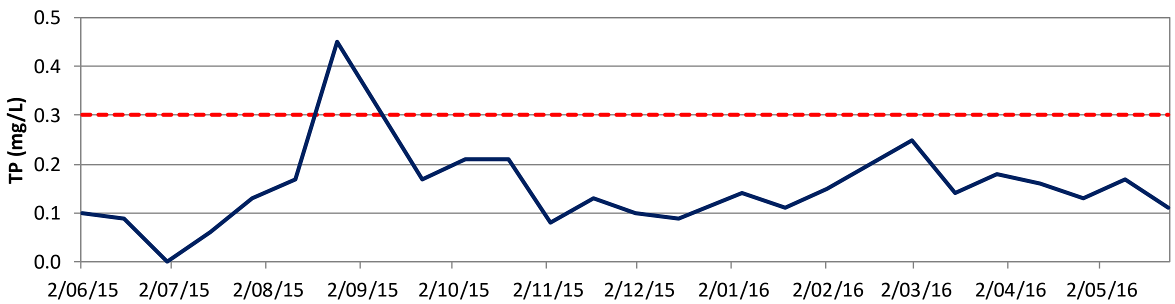


Figure 2.14 Time series of TP concentration from the Evans Head STP discharge (90th percentile limit in red)

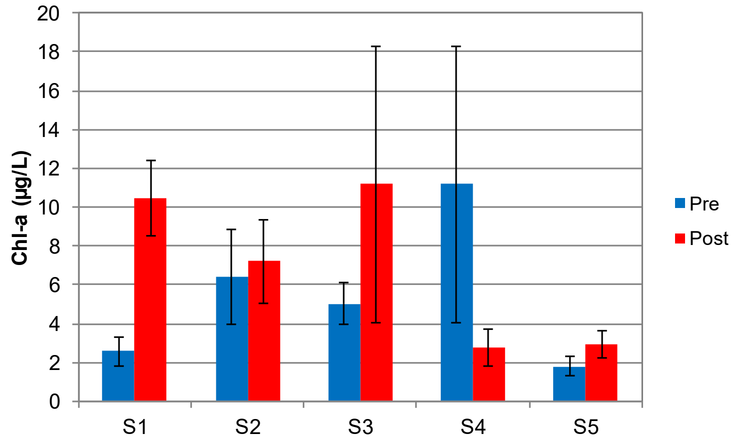
2.3.5 Comparison against Rehabilitation Targets

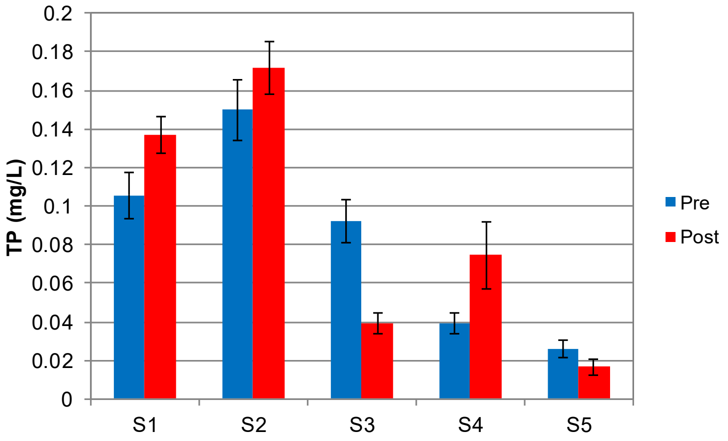
Closure of the artificial channel was anticipated to have a dramatic effect on the hydrology and water quality of Salty Lagoon (Hydrosphere 2011). Alongside the general goal of improved water quality Hydrosphere (2010 and 2011) listed a number of anticipated benefits and changes resulting from channel closure. These followed on from an ecosystem response model (ABER 2010) and are listed in **Table 2.5** along with a summary of the outcomes to date from data collected during the MPPC.

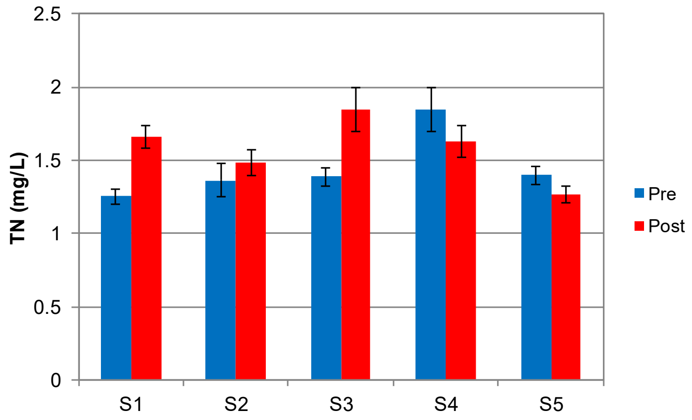
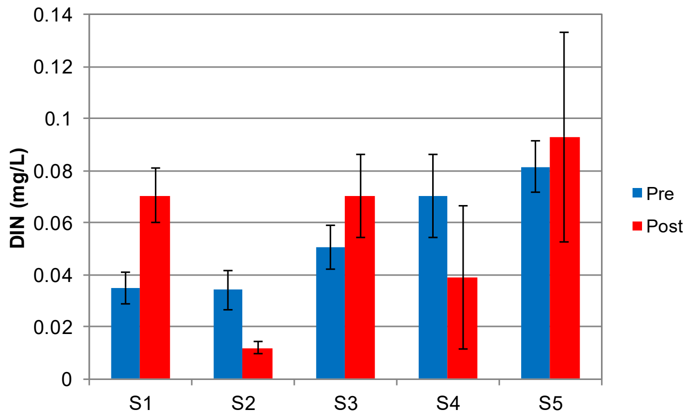
In general, the data to date indicates that many of the predicted changes are being realised but that some are not. The data from the post-closure period are strongly affected by extreme dry weather between September 2013 and March 2014 when water quality became very poor and water levels very low. There 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.

Table 2.5 Predicted Water Quality Changes and Outcomes to Date for the MPPC

Predicted Change	*Outcome to Date*
More natural hydrology and salinity regime including higher water levels – 1.9 m AHD for approximately 63% of the time.	This change has been realised. In the previous reporting period the water levels in Salty Lagoon were > 1.85 m AHD for approximately 64% of the time. In the previous reporting period the respective value was 40%. The total for the period since the closure of the artificial channel is 58%. Prior to closure (from January 2011) the figure was 2%. In addition the mean water level has increased from 1.29 m AHD to 1.80 m AHD. Note that these figures include a period of extreme drought between September 2013 and March 2014.
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 10th and 90th percentile water levels since the closure has reduced from 0.65 m AHD to 0.37 m AHD.

Predicted Change	Outcome to Date
Less frequent saline water ingress.	This anticipated change has been realised. There have been four occurrences of saline water ingress since the closure of the artificial channel in July 2012 and none in the current reporting period. 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 2.28 mS/cm and the 90th percentile has reduced from 44.1 mS/cm to 6.70 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 DO concentrations at the bottom of the water column have improved slightly since channel closure (and variation in DO concentrations at the bottom of the water column has reduced), turbidity has reduced and the reduced incidence of saline water ingress has created a more stable environment for benthic macroalgae. However, average DO concentrations at the surface of the water column have reduced overall since closure and nutrient concentrations have increased slightly.
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. This is likely to be related to a number of other changes, including increased nutrient concentrations and a more stable freshwater environment.  **Figure 2.15 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 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. Poor water quality conditions resulted in algal blooms but have not resulted in a fish kill or other ecological incident.
Less temperature variability.	This logged data from the Salty Lagoon PWQMS indicates that this has been realised with the exception of the period between December 2013 and March 2014 when water levels were very low and temperature variability was extreme.
Reduced average and maximum pH values.	There has been a significant reduction in the average pH at sites S2 and S4 since channel closure but only slight reductions at S1 and S3. Since closure of the channel there have been no incidences of the high pH maxima that occurred with seawater ingress prior to closure.

Predicted Change	*Outcome to Date*
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. 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	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. There have been no draining related turbidity spikes 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.
Reduced TP concentrations over time resulting from greater benthic microbial uptake and higher burial rates.	This prediction has not yet been realised. There have been significant but small increases in the average TP concentrations at S1 and S4, a small increase at S2 and a significant decrease at S3.  **Figure 2.16 Mean ± SE TP concentrations at all sites before and after channel closure**
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 water quality became very poor when water levels were at extreme lows and temperatures were very high.

Predicted Change	Outcome to Date
Reduced TN concentrations and continued dominance of DON.	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.  **Figure 2.17 Mean ± SE TN concentrations at all sites before and after channel closure** The predicted continued dominance of DON as the major form of nitrogen in samples has continued although at S1 and S3 the proportion of TN as DIN has increased slightly in the post closure period.  **Figure 2.18 Mean ± SE DIN concentrations at all sites before and after channel closure**
Reduced severity of Salty Creek drawdown during draining events.	This change has been comprehensively realised. The 95th percentile values for level reduction over 15 minutes at the Salty Creek PWQMS before and after closure are 0.4 cm and 0.2 cm respectively. For level reduction over one hour the values are 1.3 cm and 0.8 cm respectively. The 98th percentile values for level reduction over 15 minutes at the Salty Creek PWQMS before and after closure are 1.0 cm and 0.3 cm respectively. The 98th percentile values for level reduction over one hour at the Salty Creek PWQMS before and after closure are 2.7 cm and 1.1 cm respectively.

Predicted Change	Outcome to Date
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.

2.3.6 Emerging Trends and Issues

The erosive headcut to the east of the old artificial channel continues to present a threat to the project. Ongoing monitoring has observed continued advancement of the headcut, though at a reduced rate to that observed in the previous year. 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.

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 2010a). 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 2010). As a part of the MPPC project, benthic macroinvertebrate communities are being 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 study area (BM1 - BM4). The sites are distributed at points around the study area that broadly reflect the different physical, chemical and biological processes that occur in Salty Lagoon. The specific locations of all sites sampled are presented in **Table 3.1** and mapped in **Illustration 3.1**.

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. A description of the key factors present at each site is presented in **Table 3.1**.

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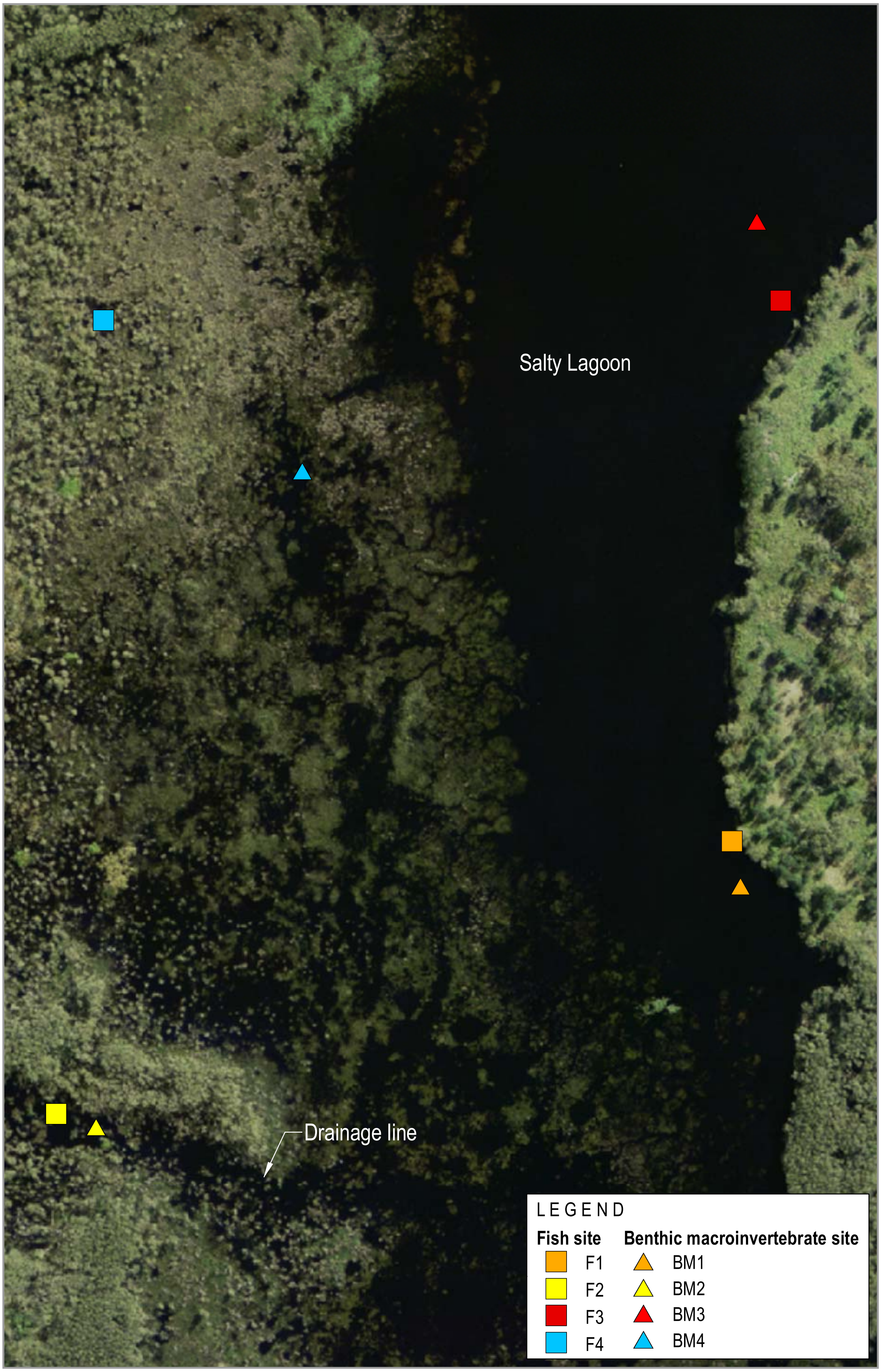
Source of base data: Richmond Valley Council

Information shown is for illustrative purposes only



Location of Benthic Macroinvertebrate and Fish Sites

GeoLINK environmental management and design

Annual Report 2016 - Salty Lagoon Monitoring Program:
Pre-Post Closure of Artificial Channel

1731-1220

Illustration 3.1

Table 3.1 Description of Benthic Macroinvertebrate Sites and Locations (WGS84)

Site	Description	Easting	Northing
BM1	This site is located near to the Salty Lagoon PWQMS. The benthic material is mostly silt and mud with some coarse organic matter. The surrounding vegetation consists mostly of Saltwater Couch (*Paspalum vaginatum*), although the nearby extent of this is reducing and Common Reed (*Phragmites australis*) is increasing. The average water levels at this site have increased since the closure of the artificial channel. Water quality and water level at this site were relatively consistent during the current monitoring period.	0542065	6782781
BM2	This site is located near the outlet of the drainage channel from the STP into Salty Lagoon. The benthos at this site is dominated by coarse organic material bound by a low percentage of mud. Fallen branches from overhanging vegetation are common. The vegetation at this site is dominated by Cumbungi (*Typha orientalis*), Common Reed (*Phragmites australis*), Jointed Twig-rush (*Baumea articulata*), and Broad-leaved Paperbark (*Melaleuca quinquenervia*). Twigs, leaves, matted algae and fungal hyphae dominate sieved samples from this site. This site was freshwater for the duration of the current reporting period and experienced relatively stable water levels and water quality. The quality of the freshwater changes at this site in response to rainfall. When effluent discharge dominates freshwater inflow higher pH values are recorded. During wet times lower pH values are recorded.	0541981	6782659
BM3	This site is located in open water towards the northern end of Salty Lagoon. The benthic material consists of sand and silt, and organic matter is uncommon at this site. This site is affected the most by saltwater flow from Salty Creek. Water levels and water quality were relatively stable at this site during the current reporting period. The nearest vegetation consists of Saltwater Couch and Bacopa (*Bacopa monnieri*), which is reducing in its nearby extent.	0542073	6783082
BM4	This site is located in the rushlands in the north-western part of Salty Lagoon. The benthic material is primarily coarse organic material bound by a low percentage of mud. Leaves, fungal hyphae and matted algae dominate sieved samples. The surrounding vegetation is in a state of rapid flux, with nearby saltmarsh vegetation receding rapidly and being replaced slowly by freshwater tolerant vegetation dominated by Saltwater Couch and a variety of rushes. The water quality in this part of the lagoon is dominated by freshwater runoff from the catchment and generally has a low pH. Water levels and water quality were relatively consistent during the current reporting period.	0541738	6783005

3.2.2 Sample Collection

Benthic macroinvertebrates were sampled once per season. The dates of benthic macroinvertebrate collection were 21 July 2015, 19 October 2015, 21 January 2016 and 5 April 2016. At each of four sites, 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.

3.2.3 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.

3.3 Results and Discussion

3.3.1 Conditions at the Time of Sampling

In comparison to other years of the MPPC the conditions at the time of sampling were relatively stable between seasons at each of the four sites. Water quality is among the most important environmental factors driving variability in benthic macroinvertebrate communities. A summary of water quality results collected from all sites on the survey days is presented in **Table 3.2**. The water levels were consistent between surveys with a difference of 0.15 m between the highest and lowest levels. However, water temperature, conductivity and nutrient concentrations varied within sites and between sampling times.

The main water quality factor providing background environmental variation during the benthic macroinvertebrate sampling events was seawater ingress that occurred outside of this reporting period but was still evident at the time of the first macroinvertebrate survey.

Table 3.2 Water Quality at all Sites at the Time of Benthic Macroinvertebrates Sample Collection

Site	Survey	Date	Water Level (mAHD)	Temp (˚C)	pH	Cond (mS/cm)	TN (mg/L)	TP (mg/L)
BM1	Winter 2015	20/07/2015	**1.94**	**13.72**	6.71	**0.37**	**1.45**	**0.09**
	Spring 2015	19/10/2015	**1.85**	26.32	**6.66**	0.55	1.65	**0.18**
	Summer 2016	21/01/2016	1.91	**30.50**	**7.17**	**0.67**	**1.71**	0.13
	Autumn 2016	5/04/2016	**1.94**	23.92	6.90	0.46	1.53	0.12
BM2	Winter 2015	20/07/2015	**1.94**	**12.91**	**6.07**	**0.32**	**1.02**	**0.10**
	Spring 2015	19/10/2015	**1.85**	20.85	6.21	**0.53**	**1.68**	0.12
	Summer 2016	21/01/2016	1.91	**27.65**	6.10	**0.53**	1.59	0.11
	Autumn 2016	5/04/2016	**1.94**	21.49	**6.52**	0.37	1.37	**0.21**
BM3	Winter 2015	20/07/2015	**1.94**	**13.95**	**6.81**	**0.37**	**1.46**	**0.09**
	Spring 2015	19/10/2015	**1.85**	27.94	6.85	0.56	**1.71**	**0.18**
	Summer 2016	21/01/2016	1.91	**28.61**	**6.92**	**0.66**	1.64	0.13
	Autumn 2016	5/04/2016	**1.94**	23.83	6.85	0.46	1.49	0.12
BM4	Winter 2015	20/07/2015	**1.94**	**12.21**	**5.06**	0.50	**1.96**	**0.05**
	Spring 2015	19/10/2015	**1.85**	20.33	5.53	0.69	1.90	**0.05**
	Summer 2016	21/01/2016	1.91	**27.39**	**6.33**	**0.71**	1.63	0.04
	Autumn 2016	5/04/2016	**1.94**	23.09	5.09	**0.33**	**1.28**	**0.03**

Notes: Highest value of each parameter measured at each site reported in ***red*** *and the lowest in* ***blue****.*
Water levels reported are the average measurement from the Salty Lagoon PWQMS over the survey day.
Site BM4 is not located at the same position as water quality S4. However, it is part of the same functional area of Salty Lagoon and results are considered adequately representative.

3.3.2 Diversity

A total of 23 macroinvertebrate taxa have been identified from samples collected to date. Of the 23 taxa identified, nine have only been observed in one of the 21 seasonal surveys undertaken. Only 14 of the 23 taxa were collected during the five surveys prior to channel closure. Twenty-one taxa have been collected in the 16 surveys since channel closure. The list of all taxa collected and their presence throughout the various surveys is presented in **Table 3.3**. Only one of the 23 taxa collected (*Capitellidae*) to date has been observed in each of the 21 surveys. One of the taxa has been collected in 20 of the 21 surveys (*Chironominae*) and one in 18 of the 21 surveys (*Hydrobiidae*).

The most common taxa captured during the current reporting period were the *Chironominae, Leptoceridae* and *Tanypodinae*. In the previous reporting period they were *Chironominae, Hydrobiidae* and *Capitellidae* (**Table 3.4** and **Table 3.5**) and in the first annual reporting period (prior to channel closure) the most common taxa were the *Chironominae, Spionidae, Hydrobiidae* and *Capitellidae*.

Table 3.3 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
Spring 2015	9	84
Summer 2016	8	133
Autumn 2016	7	192

With respect to the whole system, the clearest changes over time have been the increase in the number of *Chironominae*, *Corixidae* and *Hydrobiidae* and a reduction in the number of *Spionidae* and *Capitellidae*. The *Capitellidae* are found mostly at S3 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*, *Hydrobiidae* and *Sphaeromatidae* (see **Table 3.4**). These taxa appear to be adapting well to changing conditions.

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 at all sites in all surveys since the beginning of the MPPC are represented in **Figure 3.1**.

Table 3.4 Annual Totals of Benthic Macroinvertebrate Taxa at BM1 and BM2

Taxa	Common Name	BM1					BM2				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Chironominae	Non biting midge	19	7	318	13	37	98	137	43	51	156
Tanypodinae	Non biting midge	0	0	0	3	16	0	0	0	0	2
Ceratopogonidae	Biting midge	10	1	0	2	0	0	2	2	0	3
Chaoboridae	Phantom midges	0	0	0	0	0	0	0	0	0	0
Sialidae	Alderfly	0	0	0	0	0	0	0	0	0	0
Libellulidae	Dragonfly	0	0	0	0	0	5	4	0	0	0
Hemiphlebidae	Damselfly	1	0	0	0	0	0	0	0	0	0
Ecnomidae	A Caddis Fly	0	0	0	0	0	0	0	0	0	0
Leptoceridae	Stick Caddis	0	0	0	1	27	0	0	0	0	2
Pyralidae	Aquatic Caterpillar	0	0	0	1	0	0	1	0	1	0
Hygrobiidae	Screech Beetle	0	0	0	0	0	0	0	0	0	0
Hydrophiidae	Water Scavenger Beetle	0	0	1	1	0	0	0	5	0	0
Dytiscidae	Diving Beetle	0	0	0	0	0	0	0	1	0	1
Corixidae	Water Boatmen	0	0	20	2	0	0	0	0	0	0
Veliidae	Small Water Strider	0	0	0	0	0	0	0	0	1	0
	Springtail	2	7	2	1	3	1	0	4	2	2
Capitellidae	Polychaete	5	2	4	5	2	0	0	0	0	0
Spionidae	Polychaete	92	8	11	1	0	1	0	0	0	0
Mytilidae	Mussel	1	85	4	1	0	1	0	0	0	0
Hydrobiidae	Snail	3	4	31	22	1	3	20	0	0	0
Planorbidae	Snail	0	0	0	0	0	0	1	0	1	2
Sphaeromatidae	Isopod	0	4	5	0	0	3	1	0	0	0

Taxa	Common Name	BM1					BM2				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Hymenosomatidae		0	0	0	0	0	0	0	0	0	0
	Copepod	0	0	0	0	0	0	0	0	0	0
	Cladoceran	0	0	0	0	3	0	0	0	0	0
Total animals		**133**	**118**	**396**	**53**	**86**	**112**	**166**	**55**	**56**	**168**
Total taxa		**8**	**8**	**9**	**12**	**7**	**7**	**7**	**5**	**5**	**7**

Table 3.5 Annual Totals of Benthic Macroinvertebrate Taxa at BM3 and BM4

Taxa	Common Name	BM3					BM4				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Chironominae	Non biting midge	23	23	197	38	82	2	3	12	28	276
Tanypodinae	Non biting midge	0	0	0	0	4	2	1	3	0	5
Ceratopogonidae	Biting midge	0	1	1	1	2	3	0	0	0	8
Chaoboridae	Phantom midges	0	0	0	0	0	0	0	0	1	0
Sialidae	Alderfly	0	0	0	0	0	1	0	0	0	0
Libellulidae	Dragonfly	0	0	0	0	0	2	0	1	0	0
Hemiphlebidae	Damselfly	0	0	0	0	0	0	0	0	0	0
Ecnomidae	A Caddis Fly	0	0	0	0	1	0	0	0	0	0
Leptoceridae	Stick Caddis	0	0	0	5	23	0	0	0	1	0
Pyralidae	Aquatic Caterpillar	0	0	0	0	0	0	0	0	0	0
Hygrobiidae	Screech Beetle	0	0	0	0	0	1	0	0	0	0
Hydrophiidae	Water Scavenger Beetle	0	0	0	0	0	0	1	1	2	0
Dytiscidae	Diving Beetle	0	0	0	0	0	0	1	0	0	0
Corixidae	Water Boatmen	0	0	40	1	0	0	0	4	2	11

Taxa	Common Name	BM3					BM4				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Veliidae	Small Water Strider	0	0	0	0	0	0	0	0	0	0
	Springtail	1	1	0	0	1	0	3	3	3	3
Capitellidae	Polychaete	42	14	17	25	7	0	0	0	0	0
Spionidae	Polychaete	11	91	26	1	0	2	0	0	0	0
Mytilidae	Mussel	3	172	56	2	0	0	0	0	0	0
Hydrobiidae	Snail	0	6	66	58	14	54	1	5	0	0
Planorbidae	Snail	0	0	0	2	0	0	0	4	1	1
Sphaeromatidae	Isopod	1	5	16	2	0	9	3	0	0	0
Hymenosomatidae		1	0	0	0	0	0	0	0	0	0
	Copepod	0	0	0	0	1	0	0	0	0	0
	Cladoceran	0	0	0	0	0	0	0	0	0	0
Total animals		**82**	**313**	**419**	**135**	**134**	**76**	**13**	**33**	**38**	**304**
Total taxa		**7**	**8**	**8**	**10**	**9**	**9**	**7**	**8**	**7**	**6**

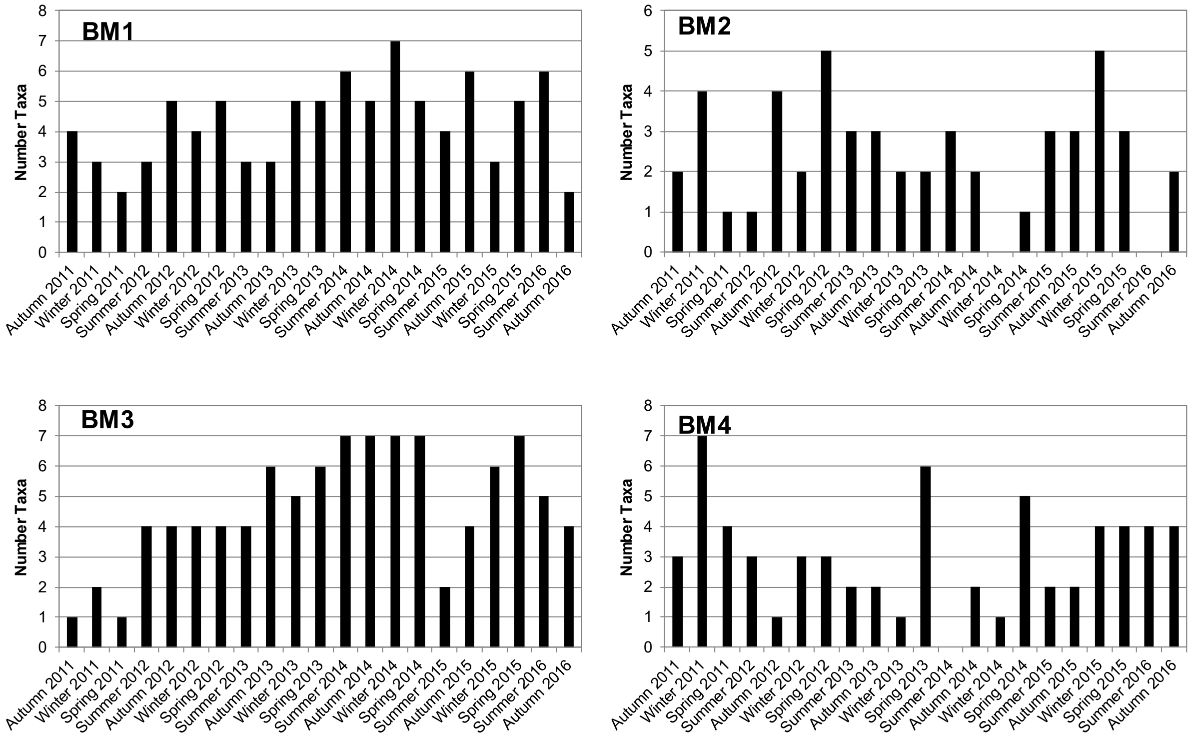


Figure 3.1 Number of macroinvertebrate taxa at all sites in all surveys since the beginning of the MPPC

3.3.3 Abundance

The numbers of benthic macroinvertebrates captured at each site have also varied over time (**Figure 3.2**). However, again there are no clear patterns evident in the data set. A closer look at the available data indicates that the majority of variation in the total number of individuals is due to spikes in different taxa at different times.

At BM1 there does not appear to be a trend with respect to abundance. However, except for large numbers of *Spionidae* observed in the winter 2011, *Mytilidae* observed in the autumn 2013 sample and *Chironominae* in spring 2013, summer 2014 and autumn 2014 surveys, the numbers have been relatively stable since the beginning of the MPPC. As Salty Lagoon continues its conversion to a predominantly freshwater system, there may be a change in the species makeup, with a reduction in the numbers of taxa that prefer brackish water, such as *Spionidae*, to taxa more aligned with freshwater such as *Chironominae* and *Hydrobiidae*. At BM1 there have been stable or increase captures of *Tanypodinae*, *Leptoceridae* and *Chironominae* (all predominantly freshwater taxa) indicating a move towards a more stable freshwater environment.

At BM2 there does not appear to be a trend with respect to abundance. The majority of the variation in the total number of individuals is explained by the number of *Chironominae* and, to a lesser extent, *Hydrobiidae* captured. At this stage of the project the observed variation is not adequately explained by the collected environmental factors. The first collection of animals from the freshwater taxa *Tanypodinae* and *Leptoceridae* are encouraging signs that freshwater taxa are becoming more dominant.

At BM3 there is no apparent pattern to the overall variation of abundance (**Figure 3.2**). 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* and an increase in the numbers of freshwater taxa such as *Leptoceridae* since the closure of the artificial channel. In addition, during the current reporting period the first individuals were collected from the predominantly freshwater taxa *Tanypodinae* and *Ecnomidae*.

At BM4 there has been a recent increase in overall abundance (**Figure 3.2**), though abundances have generally been low since the beginning of the MPPC. There has also been a shift in the dominant taxa, from *Hydrobiidae* to *Chironominae* since closure of the artificial channel.

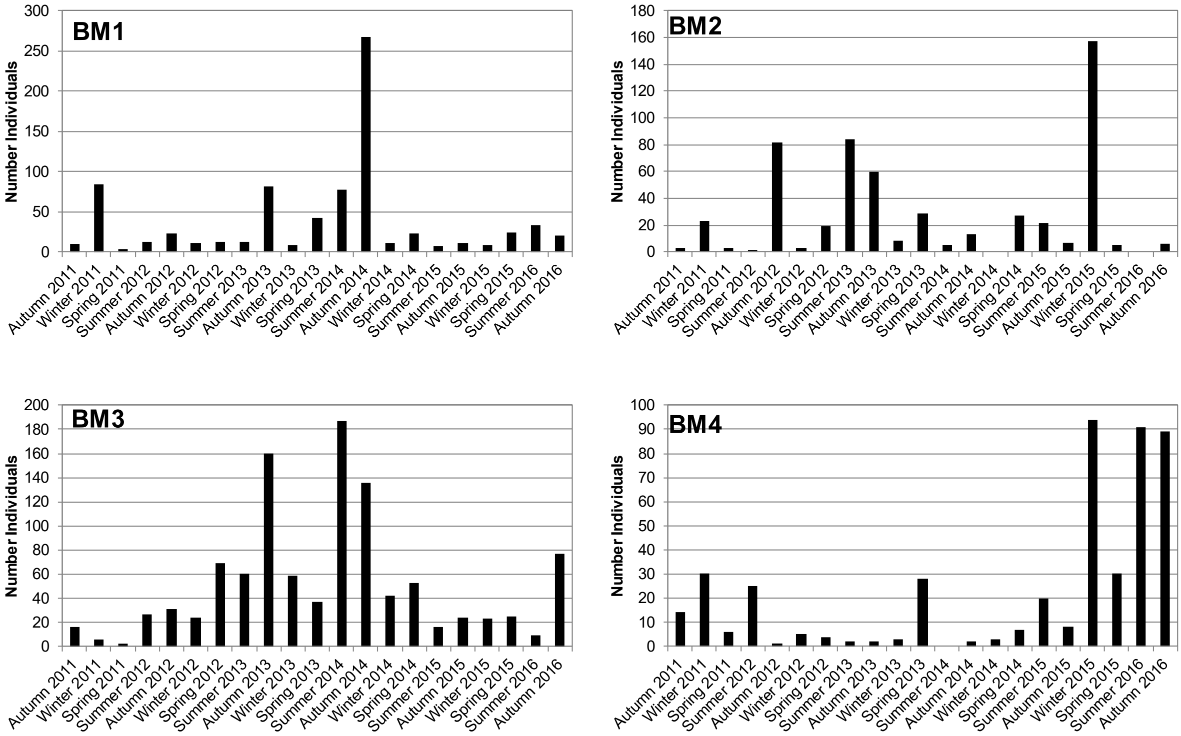


Figure 3.2 Number of macroinvertebrate individuals at all sites in all surveys since the beginning of the MPPC

3.3.4 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.

At each site there have been variations in the numbers of macroinvertebrate taxa captured between seasons, indicating temporal fluctuations in diversity around Salty Lagoon. However, as with the previous reporting periods there are no clear patterns of association with seasonal or measured environmental changes that can be concluded with certainty.

There has also been considerable variation in the numbers of individual macroinvertebrates captured at each site over time, indicating that macroinvertebrate abundance has fluctuated throughout Salty

Lagoon throughout the MPPC. The direction of change has varied over time and between sites. Again there is no clear evidence that the variation is strongly linked to either seasonal changes or short term water quality changes. Most of the variation observed to date has been in the form of short term spikes in the numbers of individual taxa. However, there are some signs that the numbers of individuals and the variety of species being collected are becoming more stable. Continued monitoring should allow for stronger conclusions to be made.

The specific makeup of benthic macroinvertebrate communities 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. There have also been a number of freshwater taxa collected for the first time during this reporting period and the prior reporting period, another indication of a shift towards a freshwater ecosystem. Again, continued monitoring will improve the clarity from which reliable conclusions can be drawn.

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.

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. However, it is likely that future results will show a lower degree of variability as the environment in and around Salty Lagoon stabilises.

3.3.5 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 to date 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 previous two reporting periods. There has also been a reduction in the abundance and diversity of the salt water tolerant taxa that have been captured, particularly in the current reporting period. 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 from previous reporting periods appear to be becoming less prevalent.

4. Aquatic Vegetation/ Weeds

4.1 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. In order 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.

4.2 Methods

Aquatic weeds were monitored on a seasonal basis across all seasons except winter. The dates of the aquatic weed surveys undertaken during this reporting period are 19 October 2015, 12 January 2016 and 5 April 2016.

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.

The pathway of the meandering transect was recorded using the tracking feature of a handheld GPS set to track points at intervals of 20 seconds. The approximate transect pathways used during weed surveys and the location and species of all aquatic weeds encountered is displayed in **Illustration 4.1**.

4.3 Results

There have been no notable aquatic weeds observed during the current 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. A total of 35 plant taxa have now been observed during the aquatic weed surveys since the beginning of the MPPC. Of these, 22 were observed during the current reporting period (refer to **Table 4.1**). 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. flilculoides*) 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. One of these two times was during the current annual reporting period, in January 2016. Pacifc Azolla and Duckweed have been encountered at varying densities to the west of Salty Lagoon, particularly around 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.

During the aquatic weed surveys, a list of all aquatic plant species encountered was collected and a basic estimate of their abundance made. The list of aquatic plant species encountered is shown in **Table 4.1**.

Table 4.1 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
Avicennia marina	Grey Mangrove	UC	UC	UC	UC	UC											
Sesuvium portulacastrum	Sea Purslane	UC	UC														
Hydrocotyle verticillata	Shield Pennywort		UC			UC			C	UC	C	C	UC	UC	C	VC	C
Lomandra sp.	A Mat-rush							UC									
Enydra fluctuans	Buffalo Spinach	UC	UC					UC	C	UC	C	C	C	C	C	C	C
Lobelia anceps	Angled Lobelia	UC		UC											UC		
Sarcocornia quinqueflora	Bead Weed	UC	UC														
Suaeda australis	Seablite	UC															
Baumea articulata	Jointed Twig-rush		UC				UC	UC	UC				UC				C
Baumea sp.	A Rush								UC	C	C	C	C	C	VC	VC	VC
Baumea sp 2.	A Rush														UC		
Cyperus exaltatus	Giant Sedge	UC		UC							C						UC
Cyperus difformis	Dirty Dora	UC		UC	UC		UC	UC		C	VC		C	UC		C	UC
Gahnia sieberiana	Red-fruit Saw-sedge						UC	UC	UC		UC		C	UC	UC	C	UC
Shoenoplectus validus	River Club-rush	VC	VC	VC	VC	VC	C	C		C	C	VC	C	VC	VC	C	C
Shoenoplectus mucronatus	Marsh Club-rush	VC	VC	UC	UC						C						

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**
Juncus krausii	Sea Rush	VC	VC	VC	VC	VC	VC	C	C	C	UC	C	C	VC	C	C	C
Juncus usitatus	Common Rush						UC		C								UC
Triglochin sp.	Water Ribbonss																UC
Lemna sp.	Duckweed								UC			C	VC	VC	VC	VC	C
Utricularia spp.	Bladderwort													VC	VC		C
Nymphoides indica	Water Snowflake												UC	C	UC	C	C
*Nymphaea capensis^*	Cape Waterlily											UC	UC	UC			
Bacopa monnieri	Water Hyssop	C	VC	C	UC	C	C	UC	C	C	VC	VC	C	VC	UC	VC	VC
Diplachne (Leptochloa) fusca	Brown Beetle Grass										VC						
Paspalum vaginatum	Saltwater Couch	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC		VC	VC	VC
Phragmites australis	Common Reed	VC	C	C	C	C	C	C	C	C	VC	VC	VC	VC	VC	VC	VC
Sporobolus virginicus	Saltwater Couch	C	C	C	C									VC			
Persicaria decipiens	Slender Knotweed		UC														
Rhizophora stylosa	Red Mangrove	UC															
Azolla pinnata	Ferny Azolla	UC	VC	UC	UC	UC	UC	UC	UC								
Azolla filiculoides	Pacific Azolla											C	VC	VC	VC	VC	C

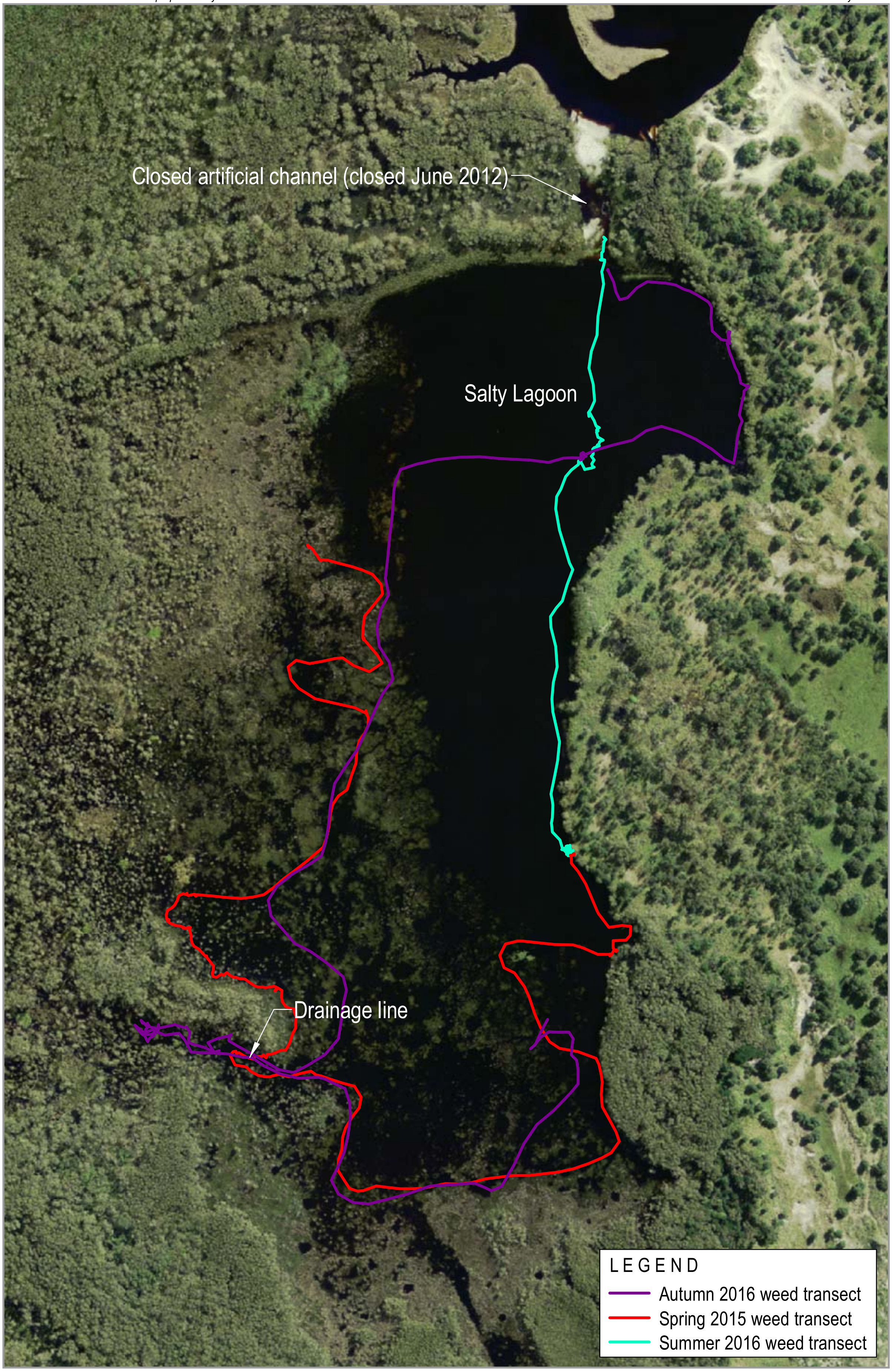
Species Name	Common Name	Survey															
		Aut '11	**Spr '11**	**Sum '12**	**Aut '12**	**Spr '12**	**Sum '13**	**Aut '13**	**Spr '13**	**Sum '14**	**Aut '14**	**Spr '14**	**Sum '15**	**Aut '15**	**Spr '15**	**Sum '16**	**Aut '16**
Typha orientalis	Cumbungi		UC	UC		UC	UC	UC	C	C	UC	UC	C	C	VC	C	UC
Enteromorpha sp.	Enteromorpha					C	VC		VC				VC		VC	VC	
Various	Blue Green Algae	C	C	C	UC	UC											

Note *UC = Uncommon, C = Common, VC = Very Common*

^ *Introduced Species*

Drawn by: AB Checked by: RE Reviewed by: DSA Date: 8/09/2016
Source of base data: Richmond Valley Council

Information shown is for illustrative purposes only



0 80

North

GeoLINK
environmental management and design

Aquatic Weed Transects

Annual Report 2016 - Salty Lagoon Monitoring Program:
Pre-Post Closure of Artificial Channel

1731-1223

Illustration 4.1

4.4 Discussion

The aquatic weed surveys undertaken to date have not resulted in the detection of 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 most recent surveys, 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 this reporting period. 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.

Plate 4.1 River Club-rush reflected in the water

Plate 4.2 Flowers of Angled Lobelia (*Lobelia anceps*)

4.4.1 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 is being consistently realised with respect to the aquatic plants being identified. 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 to date. There have been no significant freshwater weeds observed since the closure of the artificial channel.

5. Fish

5.1 Introduction

Fish are 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 are expected to be impacted positively in the long term as a result of the closure of the artificial channel (Hydrosphere 2010b). 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).

In the first year after the closure of the artificial channel, the water level in Salty Lagoon stabilised higher and the salinity regime was less variable. However, there were still occasions where saltwater ingress led to periods of higher salinity. In the second year after closure the water level in Salty Lagoon became very low as a result of drought conditions leading to higher conductivity and nutrient concentrations, and large temperature fluctuations. The last two reporting periods have been characterised by more stable water levels and water quality conditions.

The fish populations of Salty Lagoon had been sampled on a small number of occasions prior to the beginning of the MPPC (listed in Hydrosphere 2010a; 2010b). The results of these surveys were used to describe the impacts of physical and chemical processes operating as a result of changes to the effluent quality from the Evans Head STP and the hydrological connection to Salty Creek. A wide variety of sampling methods have been applied including bait traps, dip nets, backpack electrofishers and seine nets. Bait traps, whilst not the most effective nor representative measure have proven the most consistent in terms of their applicability across all of the available habitat types and during all phases of water quality cycles (Hydrosphere 2010b). For this reason they have been selected as the method for continuing monitoring of Salty Lagoon.

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

5.2 Methods

5.2.1 Site Selection

Fish fauna are sampled at four separate sites within Salty Lagoon. The sites were selected in order to cover the major physical, chemical and ecological zones throughout the lagoon. The location of the sites is presented in **Illustration 3.1**. A brief description of each site is given in **Table 5.1**. As expected, some of the sites have 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.

Table 5.1 A Description of the Fish Sampling Sites in Salty Lagoon being used for the Duration of the MPPC

Site	***Habitat***	***Hydrological Regime***
F1	The traps at this site were set along the eastern edge of the lagoon among sparse River Club-rush (*Shoenoplectus validus*) and Sea rush (*Juncus krausii*) and the roots of Broad-leaved Paperbark trees (*Melaleuca quinquenerva*). The banks of the lagoon at this position are relatively steep with small overhangs under the water surface. The sediment is a mixture of mud and sand.	This part of the lagoon was formerly subject to significant saltwater ingress and following this a stratified water column was common. In the current monitoring period this site has had more stable water levels and consistently low conductivity.
F2*	This site is an area of shallow ponded open water where the drainage channel from the STP traverses rushlands in the SW part of the lagoon. The vegetation around the pond margins is dominated by Jointed Rush (*Baumea articulata*), Saw Sedge (*Ghania sieberiana*) and Cumbungi (*Typha orientalis*), but also includes Sea Rush, *Baumea sp*. and Saltwater couch (*Paspalum vaginatum*). There are a number of snags in the channel and the bank at this point slopes gently. The sediment is a mixture of mud and coarse organic detritus.	This site has always been predominantly freshwater, dominated during most times by input from the Evans Head STP. Saltwater ingress past this point in the Lagoon has been recorded at times but very rarely since closure of the artificial channel. This site had stable water levels during the current reporting period.
F3	The traps at this site were set along the eastern edge of the lagoon among sparse River Club-rush and overhanging branches. There are a few large snags amongst the site. The bank of the lagoon at this position is gently sloping. The sediment is a mixture of mud and sand.	This part of the lagoon was previously subject to significant saltwater ingress and following this a stratified water column was common. In the current monitoring period this site has had more stable water levels and consistently low conductivity.
F4	This site is a series of small pools of open water in a low lying area that drains water from a paperbark swamp forest to the NW of the lagoon. The pools are lined mostly with Common Reed (*Phragmites australis*), Sea Rush and Broad-leaved Paperbark. The sediment is a mixture of mud and coarse organic detritus.	This site was always dominated by freshwater input from the catchment. Seawater ingress at this point in the lagoon only occurred very rarely and under specific circumstances. This site had stable water levels during the current monitoring period.

* *This site was sampled previously as part of the ERMP (Hydrosphere 2010b)*

5.2.2 Timing

Fish fauna are sampled on a seasonal basis once during every three month period. In the current reporting period fish were surveyed on 20 July 2015, 19 October 2015, 12 January 2016 and 5 April 2016. The traps are generally set within 2.5 hours of dawn and collected within 2.5 hours of dusk. Due to license conditions imposed by Industry and Investment NSW (I&I now DPI) the traps are not able to be set through the night as they were during previous monitoring within Salty Lagoon.

5.2.3 Capture and Handling

Fish fauna were sampled under Scientific Collection Permit (P13/0035-1.0) and Animal Research Authority (14/1357). Five standard bait traps were set at intervals of between two and five metres at each site, depending on the available habitat. The traps were baited with pilchards and left unattended for the day. Upon collection captured fauna were identified and counted prior to being released. At least one photo of each native finfish species encountered was taken. In keeping with licence conditions non-native fauna were euthanased in ice slurry. To minimise the stress upon fauna during counting and identification, traps were left in a suitable depth of water until they were emptied and physical handling of fish was kept to a minimum.

5.3 Results

5.3.1 Conditions at the Time of Monitoring

Environmental variables such as water quality and depth are likely to significantly affect the distribution of fish in Salty Lagoon. The temperature, conductivity, average dissolved oxygen (DO) concentration and water depth at the Salty Lagoon PWQMS are all listed in **Table 5.2** along with the rainfall in the 72 hours prior to sampling. The water quality measurements collected at the Salty Lagoon PWQMS are not always representative of water quality conditions at all sites. In particular, DO concentrations can vary significantly at different locations and at different points in the water column. The water quality at F2 and F4 is often very different to the water quality at F1 and F3.

Table 5.2 Water Quality and Rainfall Information at the Time of Surveys

Survey	*Date*	*Temp (°C)*	*Cond (mS/cm)*	*DO (mg/L)*	*Depth (mAHD)*	*72 Hr Rain (mm)*
Winter 2015	20/07/2015	12.03	0.39	10.96	1.97	18
Spring 2015	19/10/2015	24.05	0.54	2.98	1.81	0.2
Summer 2016	12/01/2016	30.50	0.67	5.43	-	0
Autumn 2016	5/04/2016	23.80	0.44	4.46	1.90	0

Note: *Water quality and depth expressed as averages of readings taken at the Salty Lagoon PWQMS over the time of trap deployment.*

5.3.2 Fish Diversity

The number of fish species captured at each site has been used as a measure of fish diversity. Whilst not representative of the entire fish fauna of the system, the fish captured in bait trap surveys are indicative of the broader diversity.

A variety of vertebrate and invertebrate fauna have been captured during the surveys including fish, crustaceans, snails and insects. However, reporting for fish surveys will focus on the targeted finfish species and does not include the invertebrates captured. Across all surveys during the reporting period a total of five finfish species were captured. This is the greater than the two previous reporting periods, equal to the five species captured during the annual reporting period before that and lower than the eight species captured during the first annual reporting period. A list of fish species captured since the beginning of the MPPC is presented in **Table 5.3**.

Variation in the diversity of fish species captured at each site since the beginning of the MPPC is displayed in **Figure 5.1**. 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 last two reporting periods there have generally been more diverse captures in Spring and Summer than in the other two seasons.

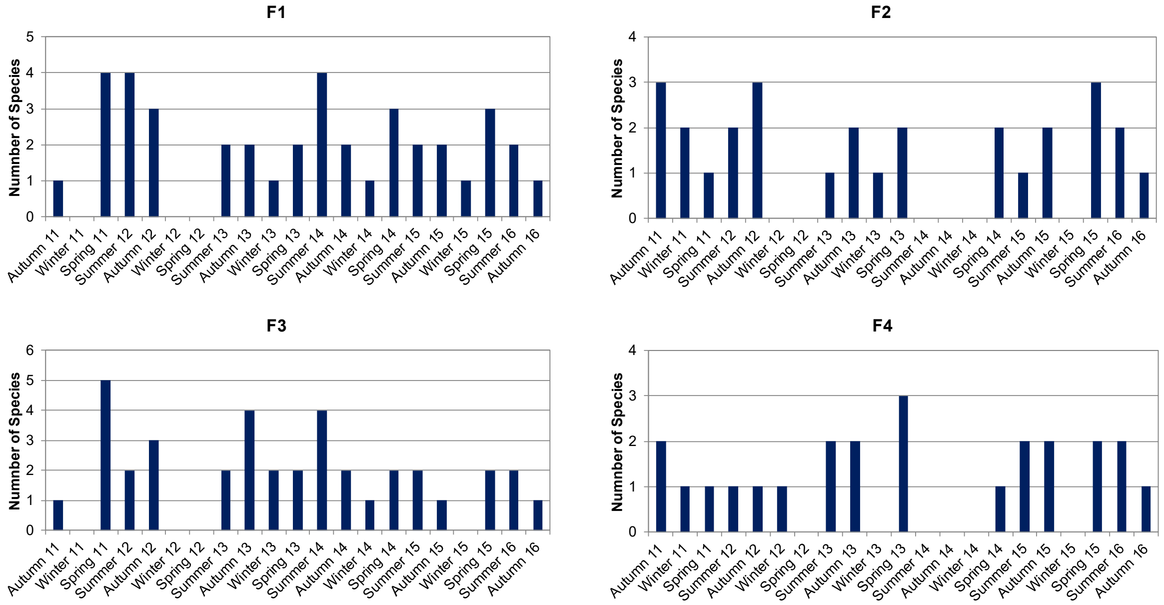


Figure 5.1 Number of fish species captured at all sites in all surveys since the beginning of the MPPC

Table 5.3 A List of Fish Species Captured During Fish Surveys since Beginning of the MPPC

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
Anguillidae	-																					
Anguilla reinhardtii	Longfin Eel	*				*															*	
Eleotriidae	-																					
Gobiomorphus australis	Striped Gudgeon	*	*	*	*	*	*		*	*	*	*	*	*	*	*		*		*		
Hypseleotris compressa	Empire Gudgeon					*						*	*				*	*		*		
Hypseleotris galii	Firetail Gudgeon				*																	
Philypnodon grandiceps	Flathead Gudgeon			*		*				*	*	*	*			*	*	*	*	*	*	*
Philypnodon macrostomas	Dwarf Flathead Gudgeon	*		*	*	*			*	*												
Gobiidae	-																					
Afurcagobius tamarensis	Tamar River Goby			*	*	*			*	*												
Poecilidae	-																					
Gambusia holbrooki	Mosquito Fish^	*	*	*	*	*			*	*	*	*	*	*		*	*	*		*	*	*

^ *Introduced Species*

5.3.3 Abundance

The number of individual fish captured at each site is used as a measure of abundance for the duration of the project. There was wide variation in the number of fish captured at each site over time (**Figure 5.2**). 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.
- More variation in the numbers of fish captured at F2 and F4, mostly coinciding with the numbers of Mosquitofish captured at those sites.

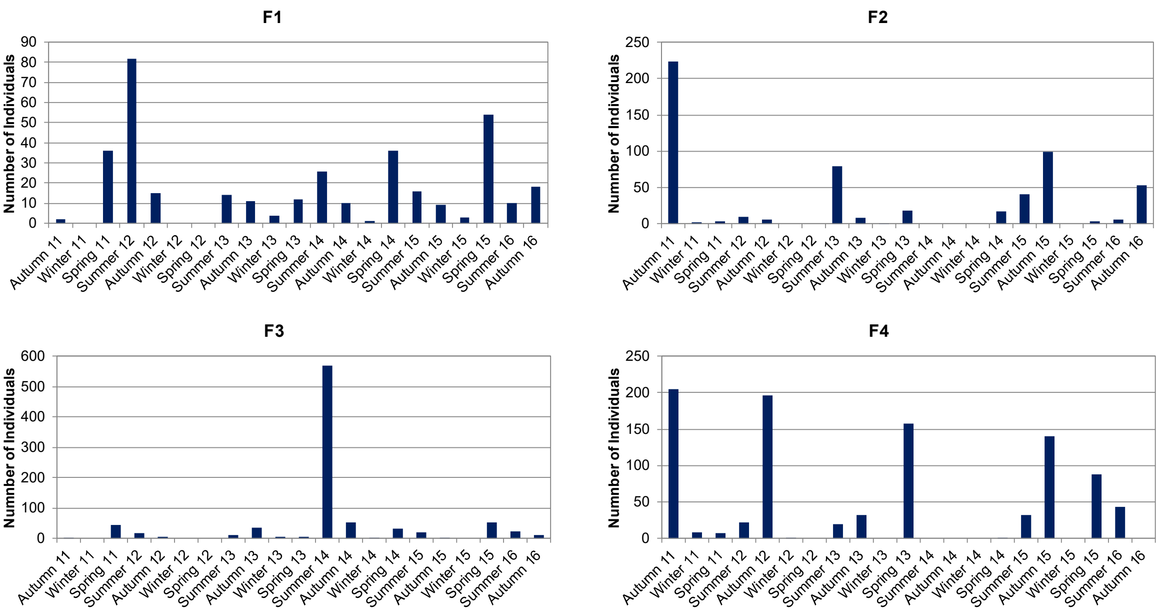


Figure 5.2 Number of individual fish captured at all sites in all surveys since the beginning of the MPPC

5.4 Discussion

Fish monitoring provides 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. However, although the Salty Lagoon fish monitoring program is relatively small in scale, over the long term it should prove sufficient to confirm or reject predicted changes to the fish fauna.

A considerable degree of within site variation in fish abundance and diversity has been detected during the sixteen fish surveys undertaken thus far. Detecting long-term trends in the variation of fish communities using the data at hand 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 led to Salty Lagoon being utilised as a drought refuge, as evidenced by the high numbers and greater diversity of fish captured at F1 and F3 in the summer 2014 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 the closure of the artificial channel. It would appear that there is a reduction in the number of species generally associated with brackish water utilising Salty Lagoon following the 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 since the beginning of the MPPC but 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 survey. At this time, most of the wetlands in Broadwater National Park were dry, as were sites F2 and F4. The results from F1 and F3 indicate that Salty Lagoon was acting as a drought refuge for fish from the surrounding wetlands as high numbers and diverse species were captured during that survey.
- Fluctuations in conductivity at F1 and F3 in the 2013-2014 reporting period. The conductivity of the water in Salty Lagoon has not been as stable as may have been expected due to a number of 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.
- Temporary changes in the density of fish populations at the chosen sites resulting from the fluctuations of available habitat associated with increases and decreases in the water level.

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

The conditions at the time of monitoring were relatively stable between the four surveys undertaken, with the exception of the dissolved oxygen, which was higher in the winter 2015 survey. This is in line with the general stabilisation of water levels and water quality that have been noted over the last two annual reporting periods (**Section 2**).

The abundance and diversity of species trapped during this reporting period was low. The largest number of species trapped at any one site was three. Despite this, the results were comparable to those reported from previous surveys using bait traps (GeoLINK 2012a, GeoLINK 2013a, Hydrosphere 2010a) and are reflective of coastal lagoons and ICOLLs in general. The lowest numbers and diversity continue to be measured during the winter periods. Some of this observed variation can be attributed to seasonal changes in abundance but shallow water bodies such as Salty Lagoon typically display this type of temporal pattern of variation due to low temperatures experienced during winter and autumn. Fish, being cold blooded (poikilothermic), tend to be much less active in cold water temperatures and therefore less susceptible to trapping.

5.4.1 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. In general, the data to date indicates that many of the predicted changes are being realised but that some are not. Predicted changes and the outcomes to date are listed in **Table 5.4**.

Table 5.4 Predicted Changes to Fish Fauna and Outcomes to Date for the MPPC

Predicted Change	*Outcome to Date*
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.
Increased Mosquitofish dominance.	This perceived risk has not been realised. The average mosquito fish capture per survey has reduced since the closure of the artificial channel. However, variation in this dataset is very large and it is difficult to draw strong conclusions about a reduction in the Mosquitofish population.

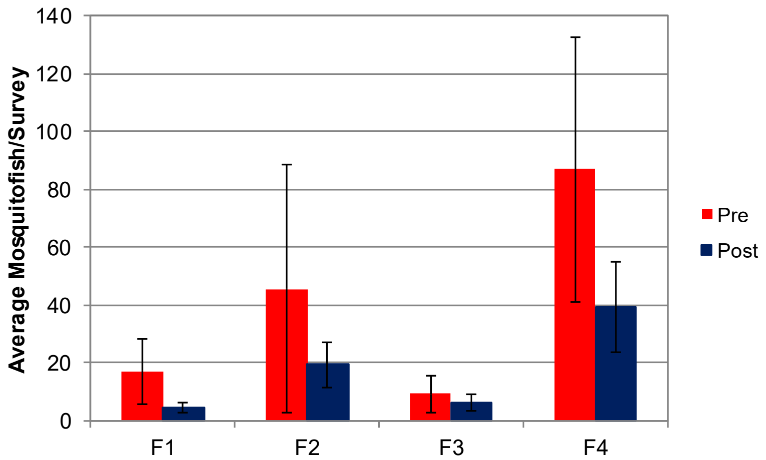


Figure 5.3 Average ± SE Mosquitofish capture per survey in the pre and post-closure periods

Predicted Change	Outcome to Date
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. Large freshwater eels are regularly observed disturbing the water around Salty Lagoon and three individual Longfin Eels were captured in the Spring 2015 survey. The potential for upstream migration of recruiting freshwater eels into Salty Lagoon has been very good in the current reporting period with water flowing from Salty Lagoon into Salty Creek for the majority of the time.
A dominance of freshwater fish species, a larger fish population and reduced fish diversity.	This anticipated change has not been consistently realised. There has been a dominance of freshwater fish species, though the Flathead Gudgeon (a brackish water tolerant species) is still the most commonly encountered native fish in traps. There is no clear evidence of an increase or decrease in the fish population. There is some evidence, though not yet consistent, that fish diversity has reduced, as expected.

6. Waterfowl

6.1 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. In the first year after channel closure the water level stabilised, leading to a dominance of waterfowl and waders. In the second year after closure the water levels fluctuated strongly but the last two reporting periods have been characterised by stable water levels and consistent habitat availability.

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

6.2 Methods

6.2.1 Timing

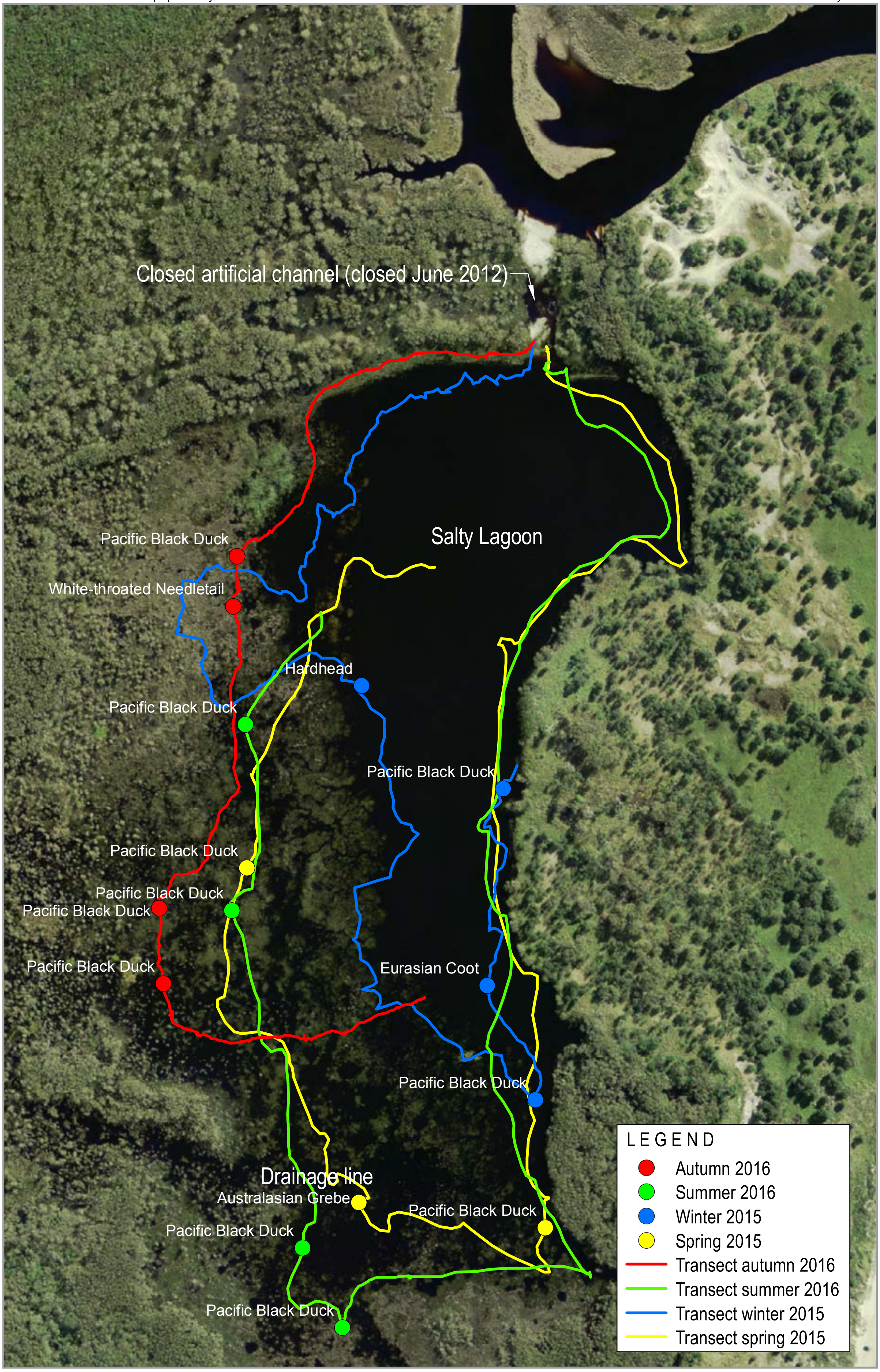
Water bird surveys were completed on a seasonal basis once every three months. The dates of surveys during the current reporting period were 21 July 2015, 19 October 2015, 12 January 2016 and 19 April 2016.

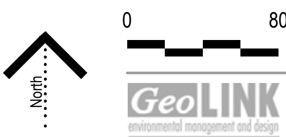
6.2.2 Surveys

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. Waterbird surveys are completed within two hours of dawn. Birds were identified using a field guide (Simpson and Day 2010) and counted using Bushnell 8 x 42 binoculars. 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 **Illustration 6.1**.

Drawn by: AB Checked by: RE Reviewed by: DSA Date: 8/09/2016
Source of base data: Richmond Valley Council

Information shown is for illustrative purposes only





Mapped Locations of Bird Flocks

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Illustration 6.1

6.3 Results

6.3.1 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. The state of these factors at the time of sampling is shown below in **Table 6.1** and **Figure 6.1**.

Table 6.1 Environmental Conditions at the Time of Waterfowl Monitoring

Survey	Date	Water Depth (mAHD)	72 Hour Rainfall (mm)	Weather	Wind
Winter 2015	21/07/2015	1.94	24.4	Overcast	Light SE
Spring 2015	19/10/2015	1.84	0.2	Fine	Calm
Summer 2016	12/01/2016	1.93	0	Fine	Calm
Autumn 2016	19/04/2016	1.98	0.4	Fine	Calm

Note: *Water depth expressed as an average of the depth recorded at the Salty Lagoon PWQMS during the time of the survey.*

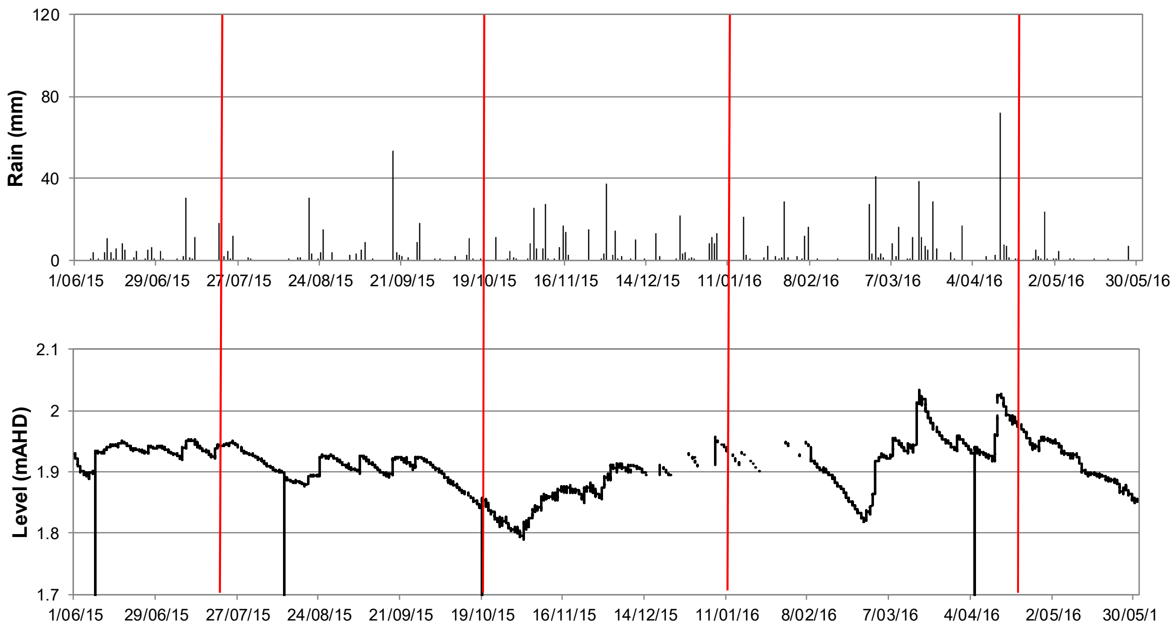


Figure 6.1 Rainfall and water level charts for the reporting period showing bird survey times (red)

The water level at the time of sampling was relatively consistent between sample times (< 15 cm range), as it was for the majority of the reporting period. Apart from normal seasonal variations in temperature the key differences between the conditions present at the times of sampling were light wind conditions during the winter 2015 survey and light to moderate rainfall in the days leading up to that survey.

6.3.2 Diversity

The diversity of species observed in waterbird surveys undertaken during the current reporting period only varied slightly from season to season. In addition to stable, high species diversity the current reporting period was characterised by the highest recorded species diversity in winter and autumn since the beginning of the MPPC (**Figure 6.1**).

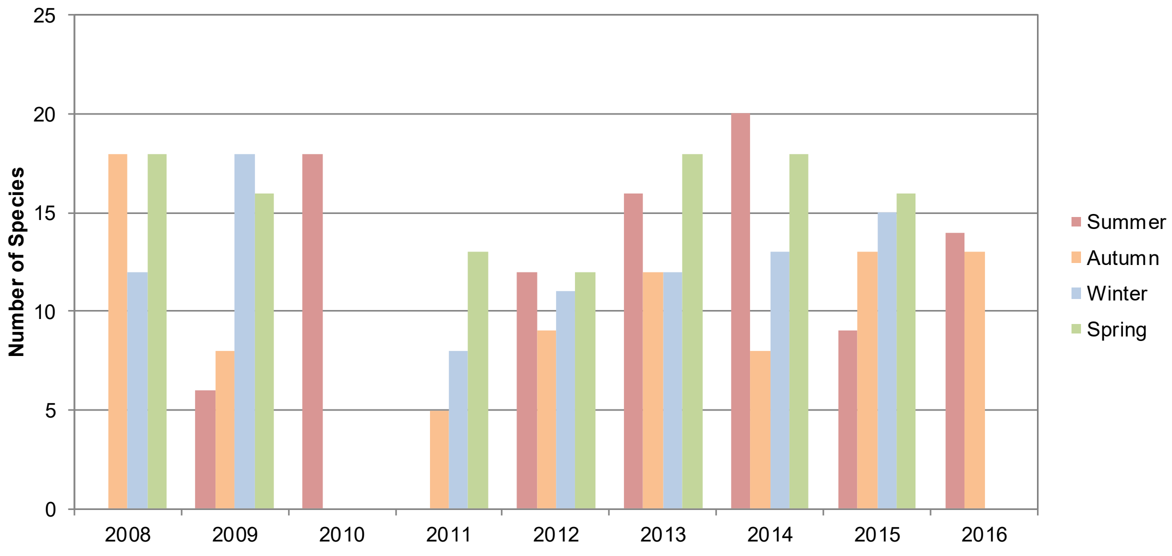


Figure 6.1 Number of bird species observed in previous seasonal surveys on Salty Lagoon (autumn 2008 until summer 2010 [Hydrosphere 2010a]) and during the MPPC (Autumn 2011 until autumn 2016)

During the current reporting period there were a small number of species observed for the first time since the beginning of the MPPC (**Table 6.2**). These were the Musk Duck (*Biziura lobata*), Dusky Moorhen (*Gallinula tenebrosa*), Common Tern (*Sterna hirundo*) and the Forest Kingfisher (*Todiramphus macleayii*). Alternately, there were a variety of species that were observed in earlier surveys but not during this reporting period, including Australian Spotted Craike (*Porzana fluminea*), Purple Swamphen (*Porphyrio porphyrio*), Black Bittern (*Ixobrychus flavicollis*), Little Egret (*Ardea garzetta*), Brolga (*Grus rubicunda*), Whimbrel (*Numenius phaeopus*), Sharp-tailed Sandpiper (*Calidris acuminata*) Black-winged Stilt (*Himantopus himantopus*), Masked Lapwing (*Vanellus miles*), Pacific Golden Plover (*Pluvialus fulva*), Black-fronted Dotterel (*Elseyornis melanops*), Crested Tern (*Thallasseus bergii*), Osprey (*Pandion haliaetus*), Brahminy Kite (*Haliastur indus*), Whistling Kite (*Haliastur sphenurus*) and Wedge-tailed Eagle (*Aquila audax*). It is notable that the majority of these species are waders and shore-birds or birds that were seldom observed in previous surveys at Salty Lagoon. The waders and shore-birds are less likely to be seen in Salty Lagoon now that water levels have stabilised at higher levels and there is less foraging habitat available to them.

6.3.3 Abundance

Overall waterbird abundance has varied since the beginning of the MPPC in autumn 2011. The numbers of individual birds observed during the current reporting period were comparable to those from previous years' surveys with the exception of the spring 2016 survey, which had lower than usual numbers. The numbers of individual birds observed during the winter 2015 and autumn 2016 surveys were the highest for those seasons since the beginning of the MPPC.

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 (**Figure 6.2**). These species include Pacific Black Duck (*Anas superciliosa*), Hardhead (*Aythya australis*), Black Swan (*Cygnus atratus*), Eurasian Coot (*Fulica atra*) and Australasian Grebe (*Tachybaptus novaehollandiae*).

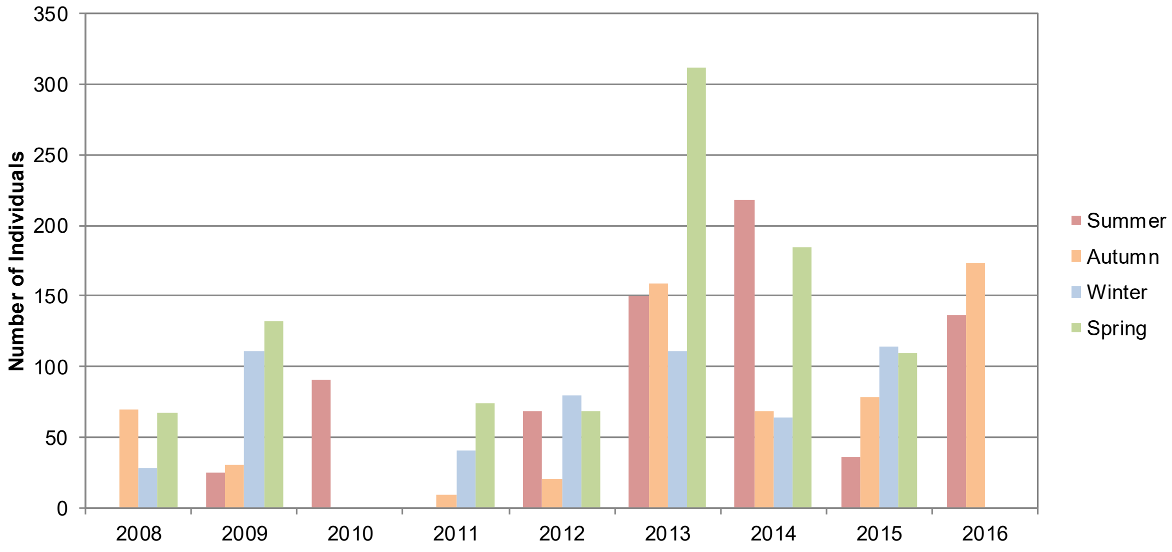


Figure 6.2 Number of individual birds observed in previous seasonal surveys on Salty Lagoon (Autumn 2008 until Summer 2010 (Hydrosphere 2010a)) and during the MPPC (Autumn 2011 until Autumn 2015)

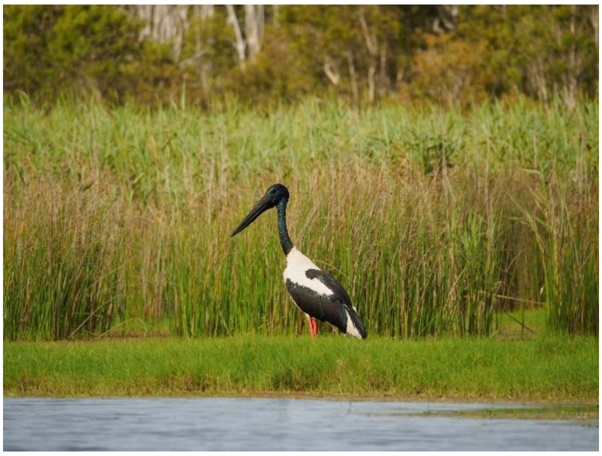


Plate 6.1 A Black-necked Stork on the margins of Salty Lagoon

Table 6.2 Results of Waterbird Surveys since the Beginning of the MPPC

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
Little Black Cormorant			4	3			2	4	8	2	1	3			4	2	2		7	4	1
Little Pied Cormorant	2	1		1		1				1		2			2				3	1	
Pied Cormorant				9	2	1		1		1			1		4		1	2		6	
Great Cormorant						1			1	2	4		1	1	6	1				1	
Darter				1	1	1	1	2							1		1	1	2	1	1
Pelican		30	10						13	9	16	1		8	7			1	1		
Australasian Grebe		1		2			6	18	9	22	38	11	3	7	19	2	8	5	20		2
Grey Teal	1	3	29	23				16	20	5		28			2					2	5
Pacific Black Duck				7	4	59	31	42	52	13	82	42	33	7	44	25	24	41	48	108	46
Chestnut Teal			1				6			2		14						2	7		
Australasian Shoveler														25				7			
Hardhead							11		20	28					33			12	7		
Musk Duck																		1			
Black Swan				2	4	2			1		4		4	3		2	2	2	2	3	2
Dusky Moorhen																					1
Australian Spotted Crake															1						
Purple Swamphen								33													
Eurasian Coot								22	24	25	125	6			29		33	35			1
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
Black Bittern*			1																		
White-necked Heron			2					1			4			1				1	1		
Little Egret			1																		
Intermediate Egret							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
White Ibis			2				1				7	12			2				2		

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***
Royal Spoonbill											5			1					5		
Black-necked Stork*												2								1	
Brolga*											2										
Whimbrel								1													
Sharp-tailed Sandpiper												44									
Black-winged Stilt	3				2						11	13									
Masked Lapwing		2	2								2	3			3						
Pacific Golden Plover												12									
Black-fronted Dotterel			7																		
Common Tern																				1	
Crested Tern																1					
Rainbow Bee Eater				3																1	
Forest Kingfisher																					1
Welcome Swallow			7		3	3	3				3	3			22					4	
White-throated Needletail				15								17	22								80
Raven				1																	
Eastern Osprey*									1							1					
Sea Eagle	2	1			1	1				1				1		1	1		1	2	
Wedge-tailed Eagle							1	1													
Black Kite											1						1	2			
Brahminy Kite																	1				
Whistling Kite		1				4		2				1		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**
Total No. Individuals	**9**	**41**	**74**	**68**	**20**	**80**	**69**	**150**	**159**	**111**	**312**	**218**	**69**	**64**	**184**	**36**	**78**	**114**	**110**	**136**	**173**

* *Species listed as vulnerable under the TSC Act.*

6.4 Discussion

Waterbird surveys continue to be a cost effective means of assessing an important ecological aspect of the Salty Lagoon ecosystem.

Waterbird abundance and diversity have fluctuated since the beginning of the MPPC. The results of waterbird surveys indicate that there has been an increase in both species diversity and waterbird abundance since the closure of the artificial channel. In the current reporting period we observed continued and consistent high levels of both diversity and abundance. 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. Continued monitoring should improve our capacity to make firmer conclusions.

The data shows a relatively consistent increase in abundance and diversity in summer and spring when more migratory species are utilising Salty Lagoon. With more stable water levels and less variation occurring as a result of changes in habitat availability this pattern is expected to continue.

6.4.1 Comparison against Rehabilitation Targets

In general the data to date indicates that the predicted changes with respect to waterfowl are being realised. The predicted changes are listed in **Table 6.3** along with the outcomes to date.

Table 6.3 Predicted Waterfowl Changes and Outcomes to Date for the MPPC

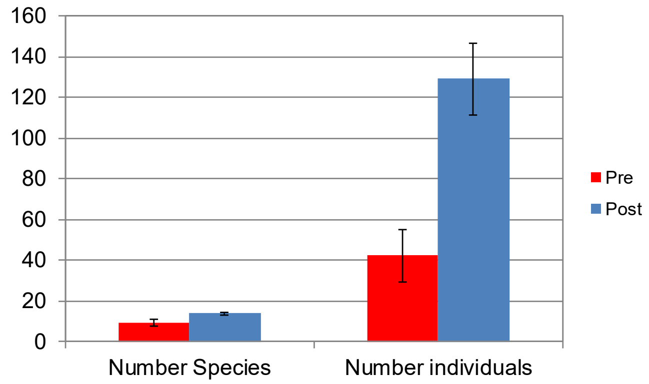
<table>
<tr><th>Predicted Change</th><th>Outcome to date</th></tr>
<tr><td>A positive impact on bird populations with an increased abundance of waterfowl but a reduction in opportunistic waders.</td><td>This anticipated change has been realised. The average diversity and abundance of waterbirds observed during surveys has increased post-channel closure (Figure 6.3).


Figure 6.3 Average ± SE of bird species and individuals in surveys pre and post-channel closure
There has also been a consistent shift in the observed bird community towards a community dominated by waterfowl from the families Anatidae and Rallidae with fewer observations of shorebirds from the families Scolopacidae and Charadriidae.</td></tr>
<tr><td>Reduction in area of wading bird habitat</td><td>This anticipated change has also been realised. With the exception of the low water levels in spring 2014 and summer 2015 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.</td></tr>
</table>

Plate 6.2 A Black Swan (*Cygnus atratus*) and cygnets on Salty Lagoon

7. Frogs

7.1 Introduction

7.1.1 General

Frogs are good indicators of ecosystem health, particularly in relation to water quality (Robinson 1998). They are a prominent component of coastal wetlands, including Salty Lagoon which supports both habitat generalists and specialist 'acid' frog species (Hydrosphere 2010a; Sandpiper 2010). Their responsiveness to changes in water quality (including salinity and nutrient levels) and the variability of microhabitat requirements between species/species groups known at the site makes them a valuable indicator of ecosystem change for the Salty Lagoon 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 2010b).

Acid frogs previously recorded at Salty Lagoon include the Wallum Froglet (*Crinia tinnula*), Wallum Rocket Frog (*Litoria freycineti*) and Wallum Sedge Frog (*Litoria oblongburensis*). The Wallum Froglet and Wallum Sedge Frog are listed as Vulnerable species under the *Threatened Species Conservation Act 1995* (TSC Act). The latter is also listed as Vulnerable under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act).

7.1.2 ERMP Frog Monitoring Results

Frog monitoring was a key part of the ERMP between 2008 and 2010 (Hydrosphere 2010a), with previous ecological baseline surveys undertaken by GHD (2006). The ERMP covered a larger study area than that of this MPPC monitoring program (the former having included sites at Salty Creek and adjacent to the Sewage Treatment Plant) and the frog monitoring locations varied from those of this program. Notwithstanding, the ERMP frog sampling methodology was the same as the sampling methodology used in this program and provides useful baseline data for the general trends that were recorded. Key findings from the ERMP that will assist in identifying changes in species composition and distribution include:

- Fourteen species of amphibian were recorded within the Salty Lagoon study area between 2008-2010, including:
  - Seven species of tree frogs (Family Hylidae).
  - Six species of burrowing frogs (Family Myobatrachidae).
  - One species of toad (Family Bufoniadae).
- Three 'acid' frog species were recorded including:
  - Wallum Froglet: Recorded in Sedge Swamp, Swamp Forest and (upper parts of) the drainage line habitats.
  - Wallum Rocket Frog: Recorded only once in the Swamp Forest habitat.
  - Wallum Sedge Frog: Recorded only in the Sedge Swamp habitat.

- No acidic frogs were recorded in the Fringing Marsh, the Melaleuca dieback area or south of the lagoon and drainage channel.
- The Striped Marsh Frog (*Limnodynastes peronii*), Common Froglet (*Crinia signifera*), Dwarf Tree Frog (*Litoria fallax*), Rocket Frog (*Litoria nasuta*) and Tyler's Tree Frog (*Litoria tyleri*) were the most widely distributed species recorded at four of the six habitats within the study area (Sandpiper 2010).
- Comparisons were made of the distribution of the Wallum Froglet (acid frog) and Dwarf Tree Frog (habitat generalist). These species were selected as they rarely co-exist in undisturbed environments due to the differences in preferred habitat. Comparisons found that:
  - Wallum Froglets were:
    - Recorded predominantly within Swamp Forest with a sedge understorey and Sedge Swamp along the upper part of the drainage line and adjoining Salty Creek.
    - Not recorded in the Fringing Marsh, areas of Melaleuca dieback or along the drainage line east of from approximately 100 metres east of Evans Head-Broadwater Road culvert; area with an understorey of Salt Couch or Juncus spp. in the vicinity of Salty Lagoon.
  - Dwarf Tree Frogs were:
    - Recorded in all habitats except in Sedge Swamp with emergent Paperbarks. They occurred throughout the Marshland and drainage line habitats and parts of the Swamp Forest, including the Melaleuca dieback area.
    - Not recorded in 'undisturbed' Swamp Forest and Sedge Swamp.
    - An overlap in distribution was found along much of the drainage line and adjacent Swamp Forest (Hydrosphere 2010a).

7.1.3 Baseline (Pre Channel-closure) Frog Monitoring Results

Frog sampling was undertaken at Salty Lagoon in mid-2011 to mid-2012, to establish a baseline against which potential changes to frog assemblages following the closure of the artificial channel could be assessed (GeoLINK 2012a). Key findings from this baseline frog monitoring that were used in identifying changes in species composition and distribution included:

- Ten amphibian species were recorded in total, with:
  - Four species recorded during the winter monitoring events, comprising 44 'onsite' specimens.
  - Seven species recorded during the spring monitoring events, comprising 67 'onsite' specimens.
  - Eight species recorded during the summer monitoring events, comprising 81 'onsite' specimens.
- Two 'acid' frog species were recorded consisting of:
  - Wallum Froglet: Recorded in Sedge Swamp, Swamp Forest and Fringing Marsh (one point count location).
  - Wallum Sedge Frog: Recorded in the Sedge Swamp and Swamp Forest habitats.
- The species with the overall highest numbers of individuals recorded 'onsite' during the point count surveys were the Stripped Marsh Frog, Dwarf Tree Frog, Common Eastern Froglet and Wallum Froglet.

- Striped Marsh Frog and Tyler's Tree Frog were the most widely distributed species occurring in all four habitats in the study area, while Common Eastern Froglet, Dwarf Tree Frog, Rocket Frog, Wallum Froglet and Wallum Sedge Frog were recorded in three out of four habitats.
- Comparisons were made of the distribution of the Wallum Froglet (acid frog) and Dwarf Tree Frog (habitat generalist). These species were selected as they rarely co-exist in undisturbed environments due to the differences in preferred habitat. Comparisons found that:
  - The comparison in distribution of the Wallum Froglet and Dwarf Tree Frog varied between Transect 1 and Transect 2 and 3. At Transects 2 and 3.
  - Only the Dwarf Tree Frog was recorded east of transect point count site T2PC5 and T3PC4 which comprises Fringing Marsh and Swamp Forest (including the Melaleuca dieback areas).
  - An overlap in distribution was recorded along the western portion of the Swamp Forest and adjacent edge of Sedge Swamp (the latter at Transect 3 only).
  - The Wallum Froglet was the dominant species within the Sedge Swamp.

7.2 Methods

7.2.1 Surveys

Frogs were sampled using two methods:

- Point counts undertaken at six fixed points along three fixed transects.
- Transect traverses undertaken along three fixed transects which corresponded with the point counts.

The point count methodology was as described in Hydrosphere (2010a and 2010b). Point counts were undertaken at six fixed sites along the three frog transects located on the western side of Salty Lagoon (refer to **Illustration 7.1**). Habitats sampled include Sedge Swamp, Fringing Marsh and Swamp Forest, and ecotones between these communities. Approximate transect lengths and average distance between the fixed point count sites were:

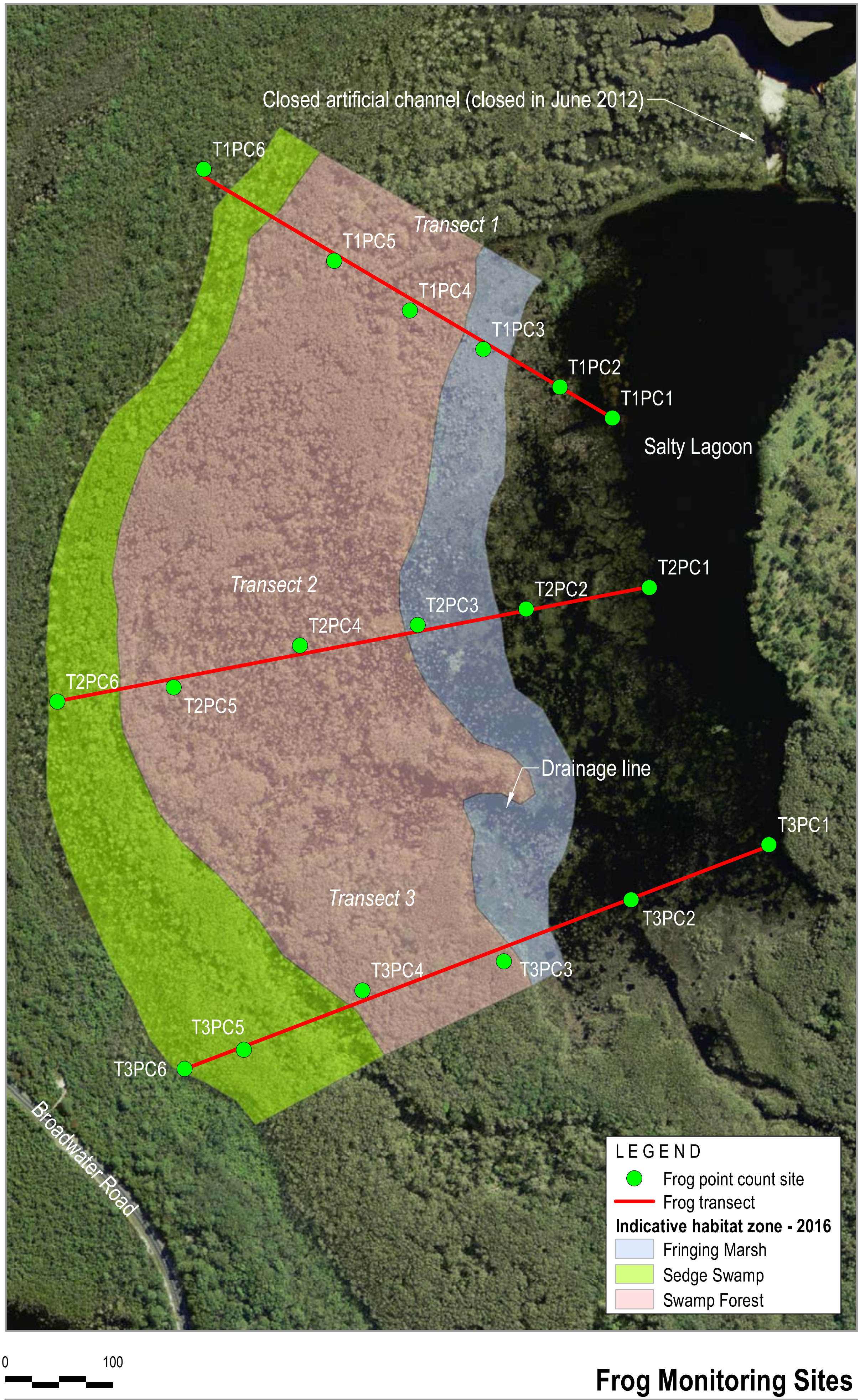
- Transect 1 – 440 m long with an average distance of 73 m between point count sites.
- Transect 2 – 575 m long with an average distance of 96 m between point count sites.
- Transect 3 – 580 m long with an average distance of 97 m between point count sites.

Since the closure of the artificial channel in June 2012 the water level of Salty Lagoon initially increased and has subsequently fluctuated according to seasonal rainfall/ drought and related run-off input. One consequence of the closure of the artificial channel has been conversion from Fringing Marsh to open water at the three fixed monitoring points closest to the lagoon. Consequently, frog monitoring was not undertaken at these localities due to a lack of suitable vegetated habitat for frogs. However, if future changes occur that are conducive to supporting frogs (e.g. establishment of Water Lilies *Nymphaea sp*. and other emergent vegetation), sampling at these points will be resumed.

The location of the point count sites is shown in **Table 7.1**.

Drawn by: AB Checked by: RE Reviewed by: DSA Date: 8/09/2016
Source of base data: Richmond Valley Council

Information shown is for illustrative purposes only



Frog Monitoring Sites

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Illustration 7.1

Table 7.1 Point Count Locations (GDA 84)

Point Count Reference	Easting	Northing
T1PC1	541930	6783016
T1PC2	541881	6783045
T1PC3	541810	6783080
T1PC4	541742	6783116
T1PC5	541672	6783162
T1PC6	541551	6783247
T2PC1	541964	6782859
T2PC2	541850	6782839
T2PC3	541749	6782824
T2PC4	541640	6782805
T2PC5	541523	6782766
T2PC6	541415	6782753
T3PC1	542075	6782620
T3PC2	541947	6782569
T3PC3	541829	6782512
T3PC4	541698	6782485
T3PC5	541588	6782430
T3PC6	541533	6782412

Point count surveys involved:

- A two minute settling period after reaching each site, followed by;
- A five minute listening period during which the number of calling frogs within a 20 metre radius were recorded independently by two observers; and
- After five minutes, counts were discussed between observers and a consensus reached on abundance and diversity. Frogs calling within 20 – 50 metres of point count sites were recorded as 'off-site' recordings.

The transect traverse involved walking along the fixed transect between point count site surveys. Data recorded along each transect included:

- The location of individual or groups of Dwarf Tree Frogs and Wallum Froglet using a GPS. Data was collected at 20 metre intervals and involved recording the presence of any individuals of this species within a 20 metre radius of the point.
- Any additional species not recorded during the point count surveys.

The transect data that was used to determine the distribution of the Dwarf Tree Frog (a 'habitat generalist') and Wallum Froglet (an 'acid' frog species) in the study area. As mentioned previously, these species rarely co-exist in undisturbed environments due to the differences in preferred habitat, hence their presence is considered indicative of habitat conditions (Hydrosphere 2010a). Further information on why these species were selected for comparison is provided in Hydrosphere (2010a).

Frogs were identified using Robinson (1998) and Nature Sound (2001). They were primarily identified by call identification, with 30-Watt head torches used to actively find frogs if confirmation was needed and during transverse transect surveys to opportunistically observe frogs.

Frog sampling was undertaken twice per season (excluding autumn) during appropriate weather conditions (refer to Hydrosphere 2010a) on non-consecutive nights. Weather conditions (rainfall, air temperature, cloud cover, relative humidity and wind speed) and water depth at each fixed point transect site was recorded during each survey event.

7.2.2 Timing

The post-closure frog monitoring events were undertaken on the following dates:

- Winter 2015 surveys: 20 August and 25 August 2015.
- Spring 2015 surveys: 16 November and 24 November 2015.
- Summer 2016 surveys: 8 February and 4 March 2016.

7.2.3 Conditions at the Time of Monitoring

The call behaviour of frogs is highly variable and associated with season, weather conditions and behavioural patterns. Weather conditions during the post artificial channel closure frog monitoring events are provided in **Table A.1** of **Appendix A**. Weather conditions were dry or cloudy without rainfall for all monitoring events with the exception of the first winter monitoring event and the first summer monitoring event in which showers were experienced. All monitoring events had rain in the 24 hours prior to monitoring being undertaken. Temperature generally ranged from mild to warm during most monitoring events. Winds were variable across seasons and ranged from calm to moderate-strong. Relative humidity was generally moderate to high during monitoring events.

7.3 Results

7.3.1 Point Count

7.3.1.1 Species Richness and Abundance

The raw frog point count results are provided in **Table A.2** of **Appendix A**. Seven amphibian species were recorded in total, with:

- Five species recorded during the winter monitoring events, comprising 115 'on-site' specimens.
- Six species recorded during the spring monitoring events, comprising 142 'on-site' specimens.
- Four species recorded during the summer monitoring events, comprising 60 'on-site' specimens.

The Dwarf Tree Frog was consistently the most commonly recorded species in all of the monitoring seasons. Tyler's Tree Frog and Striped Marsh Frog were also commonly recorded during all monitoring seasons, but at a lower abundance compared to the Dwarf Tree Frog.

The acid frog species Wallum Froglet was recorded in all monitoring seasons, but was relatively rare in summer.

In general, results varied between habitats and transects. Frog species recorded 'on-site' at point count sites within each habitat are shown in **Table 7.2**. The highest diversity of species at point counts sites was recorded within the Swamp Forest and the least diversity was recorded in the Fringing Marsh and Fringing Marsh/ Open Water Ecotone.

The species with the overall highest abundance recorded 'on-site' during the point count surveys were the Dwarf Tree Frog (*Litoria fallax*) – 187 individuals, Striped Marsh Frog (*Limnodynastes peroni*) – 31 individuals and Wallum Froglet (*Crinia tinnula*) – 28 individuals.

The least abundant species recorded were Wallum Sedge Frog (*Litoria olongburensis*) – 1 individual and Rocket Frog (*Litoria nasuta*) – 8 individuals.

7.3.1.2 Distribution

The habitats for the subject frog monitoring sites comprised Sedge Swamp, Swamp Forest, Fringing Marsh (with a broad ecotone between the Swamp Forest and Fringing Marsh along Transects 2 and 3) and open water (with emergent rushes). An additional habitat was defined as 'Fringing Marsh/ Open Water ecotone', corresponding to the area of ex-Fringing Marsh around the edge of Salty Lagoon that was inundated following closure of the artificial channel.

As shown in **Table 7.2**, the most widely distributed species were the Striped Marsh Frog (recorded in all five of the habitats) and the Dwarf Tree Frog (recorded in four out of five of the habitats). The Wallum Froglet, Common Eastern Froglet, Tyler's Tree Frog and Wallum Sedge Frog were not recorded in the Fringing Marsh or the Fringing Marsh/ Open Water Ecotone.

Four frog species were recorded in each of the Fringing Marsh/ Swamp Forest Ecotone, Fringing Marsh/ Swamp Forest Ecotone, and Open Water (with emergent rushes) habitats, while five species were recorded in the Sedge Swamp and Swamp Forest habitats.

Wallum Froglet was the only species recorded within the Sedge Swamp across Transects 3 for this monitoring period. This species was also recorded within the Swamp Forest.

Table 7.2 Frog Occurrence at 'On-site' Point Counts

Scientific Name	***Common Name***	***Sedge Swamp***			***Swamp Forest***			***Fringing Marsh/ Swamp Forest Ecotone***			***Fringing Marsh and Fringing Marsh/ Open Water Ecotone***			***Open Water (with emergent rushes)***		
		T1	***T2***	***T3***	***T1***	***T2***	***T3***	***T1***	***T2***	***T3***	***T1***	***T2***	***T3***	***T1***	***T2***	***T3***
Common Eastern Froglet	*Crinia signifera*					x	x									
Wallum Froglet	*Crinia tinnula*	x	x	x	x	x										
Striped Marsh Frog	*Limnodynastes peroni*	x	x		x	x	x		x				x	x	x	x
Dwarf Tree Frog	*Litoria fallax*		x		x	x	x		x		x	x	x	x	x	x
Wallum Sedge Frog	*Litoria olongburensis*	x														
Rocket Frog	*Litoria nasuta*								x		x			x		
Tyler's Tree Frog	*Litoria tyleri*		x		x	x			x					x	x	

7.3.2 Transect Traverse

7.3.2.1 Occurrence and Distribution of Wallum Froglet and Dwarf Tree Frog

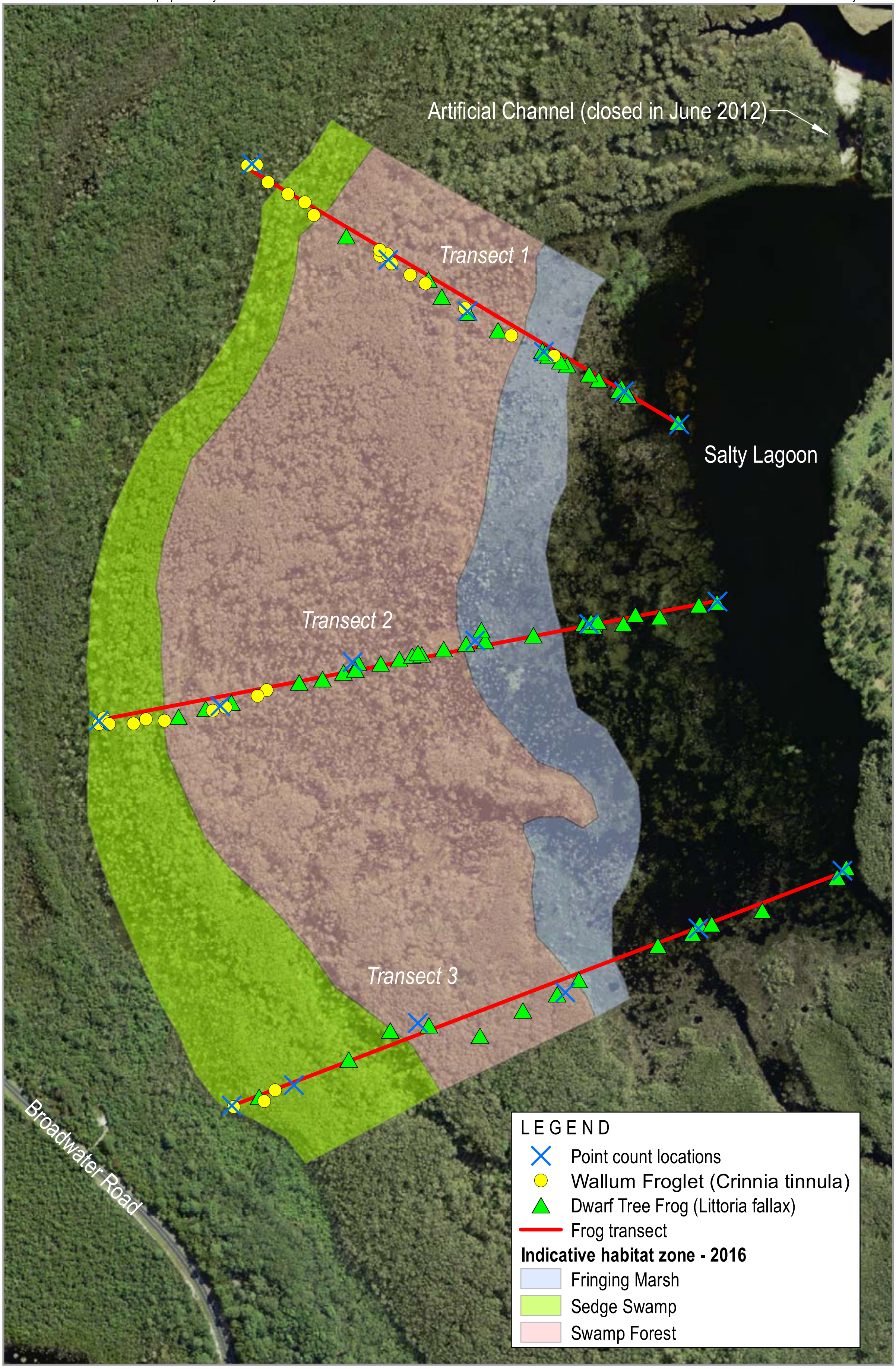
The transect traverse Wallum Froglet and Dwarf Tree Frog comparison results are shown in **Illustration 7.2** and **Table A3** of **Appendix A**. Along Transect 1 Wallum Froglet was commonly recorded within Sedge Swamp and Swamp Forest, with a lesser occurrence further east in the Melaleuca dieback area and a single record within Open Water/ Fringing Marsh. Along Transect 2 Wallum Froglet was recorded in the Sedge Swamp and Swamp Forest and was only recorded in the Sedge Swamp along Transect 3.

Along Transect 1 Dwarf Tree Frog was recorded predominantly in the Fringing Marsh and Melaleuca dieback area. Along Transect 2 Dwarf Tree Frog was recorded in both the Fringing Marsh and Swamp Forest (including the Melaleuca dieback area). The distribution of Dwarf Tree Frog along Tansect 3 was more evenly spread between habitats, with no clear preference being noted. Only a small number of Dwarf Tree Frogs were recorded in the Sedge Swamp habitat zone in the current monitoring period.

The following summary can be made relating to the distribution of the Wallum Froglet and Dwarf Tree Frog in the study area:

- Dwarf Tree Frogs were particularly dominant in the Fringing Marsh and Swamp Forest habitats; including the Melaleuca dieback area.
- Wallum Froglet was dominant in the Sedge Swamp habitat, and to a lesser extent in the Swamp Forest habitat.
- 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 Wallum Froglet was recorded within habitats along Transect 1 and the narrowest distribution was along Transect 1 where this species only occurred in Sedge Swamp.
- The location of records of the two species displayed some overlap in the current monitoring period but a preference for those habitats further from Open Water for Wallum Froglet was noted.

Drawn by: AB Checked by: RE Reviewed by: DSA Date: 9/09/2016
Source of base data: Richmond Valley Council
Information shown is for illustrative purposes only



Distribution of the Wallum Froglet (Crinia tinnula) and Dwarf Tree Frog (Litoria fallax)

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Illustration 7.2

7.4 Discussion and Comparison with Pre-channel Closure Monitoring

The findings of the current monitoring period are discussed in **Section 7.4.1** to **Section 7.4.4**. Where trends are evident in the MPPC frog monitoring data collected thus far (for the period of mid-2011 to mid-2016, and subsequently referred to as: baseline monitoring [GeoLINK 2012a], 2012-2013 monitoring [GeoLINK 2013a], 2013-2014 monitoring [GeoLINK 2014], 2014-2015 monitoring (GeoLINK 2015) and the current monitoring [2015-2016]), this is noted. Particular focus is given to any apparent differences between the current monitoring and the baseline monitoring undertaken immediately prior to the closure of the artificial channel (GeoLINK 2012a).

An evaluation of the frog monitoring data from the current monitoring period in relation to predictions from the ERMP monitoring (Hydrosphere 2010a) is also provided in **Section 7.4.5**.

7.4.1 Overall Species Diversity

The overall amphibian species diversity was lower in the current monitoring period (with the exception of the 2014-2015 monitoring period) when compared with previous MPPC monitoring. Only seven species were recorded in the current monitoring period and six species in 2014-2015, compared with nine species in 2013-2014, eight species in 2012-2013 and nine species in the baseline monitoring. There is no obvious trend in total species diversity to date suggesting that this reduction is likely to be associated with climatic conditions (e.g. dry summer conditions) and general survey limitations (e.g. species not occurring or calling from the survey footprint).

All species recorded in the current monitoring had previously been recorded in the study area in both the ERMP monitoring (Sandpiper 2010) and MPPC monitoring. A number of species recorded in previous monitoring were not recorded in the current monitoring, including Broad-palmed Rocket Frog (*Litoria latopalmata*), Bleating Tree Frog (*L. dentata*) and Dainty Green Tree Frog (*L. gracilenta*).

7.4.2 Frog Seasonal Abundance

The highest abundance of frogs for the current monitoring was recorded during spring. Frog seasonal abundance has been very variable throughout MPPC monitoring, with the highest abundance recorded in summer in 2014-2015 monitoring, winter in 2013-2014 monitoring, spring in 2012-2013 monitoring, and summer in baseline monitoring.

The species with the highest abundance in the current monitoring was the Dwarf Tree Frog, with a total of 187 individuals recorded at point counts, the highest number recorded in a monitoring season thus far. This species has consistently been the most abundant species recorded at Salty Lagoon, with 85 individuals recorded in 2014-2015 monitoring, 64 individuals recorded in 2013-2014 monitoring, 169 individuals recording in 2012-2013 monitoring, and 78 individuals recorded in baseline monitoring.

Abundance of the threatened Wallum Froglet (acid frog) has been variable throughout the MPPC monitoring, with 28 individuals recorded in the current monitoring, 12 individuals recorded in the 2014-2015 monitoring, 26 individuals recorded in 2013-2014 monitoring, 19 individuals recorded in 2012-2013 monitoring and 29 individuals recorded in baseline monitoring. The yearly abundance of this species appears to be fluctuating in response to variable environmental factors (e.g. seasonal weather conditions/ water level) and is displaying no clear trend.

7.4.3 Species Diversity by Vegetation Habitat Zone

Six species were recorded in the Swamp Forest and Swamp Forest/ Fringing Marsh ecotone (Melaleuca dieback area) in the current monitoring as was also the case in the 2014-2015 monitoring, compared with seven species in 2013-2014 monitoring, eight species in 2012-2013 monitoring and eight species in baseline monitoring.

Four species were recorded in the Fringing Marsh/ Open Water ecotone and Open water (with emergent rushes) habitats compared with five species were recorded in the 2014-2015 monitoring, eight species in 2013-2014 monitoring, seven species in the 2012-2013 monitoring, and eight species in baseline monitoring. Comparatively low species diversity recorded in these habitats over the 2014-2015 and current monitoring period is likely due to increased water levels and less vegetation around the periphery of the lagoon. Sedgeland fringing the lagoon has been 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).

Wallum Froglet was recorded offsite in the Open Water/ Fringing Marsh habitat along Transect 1 during the current monitoring event. With the exception of the 2014-2015 monitoring, Wallum Froglet has also previously been recorded within this habitat zone along Transect 1 (GeoLINK 2012a, 2013a, 2014a). Water quality monitoring during the current monitoring period has shown stable increased water levels within Salty Lagoon, with a buffering pH tendency towards neutral within the core water body. Despite this, it appears that the remaining sedgeland habitat along Transect 1 is still broadly suitable for low numbers of Wallum Froglet.

The trend of a comparatively low diversity of frog species being recorded in the Sedge Swamp in the 2013-2014 monitoring and 2014-2015 monitoring (Wallum Froglet being the only recorded species) has not continued, with five species being recorded in the current monitoring. This increase in frog species diversity supports the assertion that any variability reflects environmental factors such as seasonal weather conditions rather than a change in salinity or water quality attributable to the closure of the artificial channel.

7.4.4 Habitat Segregation and Distribution Patterns

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 broad segregation was noted 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 least common in these same habitats (refer to **Section 7.4.3** and **Illustration 7.2**).

As has been recorded in previous MPPC monitoring (except for 2014-2015 monitoring) a minor occurrence of Wallum Froglet was recorded in the western section of Fringing Marsh along Transect 1. Although water quality monitoring during the current monitoring period has shown stable increased water levels within Salty Lagoon, with a buffering pH tendency towards neutral within the core water body it appears that fringing marsh habitat along Transect 1 remains broadly suitable for low numbers of Wallum Froglet.

7.4.5 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 the 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 2010a).

In Hydrosphere (2010a) 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 2010a) and comparison with the findings of the MPPC frog monitoring are shown in **Table 7.3**.

Table 7.3 Predicted Frog Changes and Outcomes to Date for 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 maps for 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 Swamp Forest habitats, though has retracted westward along Transect 1 from the Fringing Marsh. *L. freycineti* and *L. olongburensis* have been recorded in such low numbers in the MPPC monitoring as to make it impossible to detect any changes in relation to these species, though *L. olongburensis* occurrences within the Sedge Swamp appear stable.

This may indicate that the overriding factor determining acid frog distribution is acidic influence on water quality from adjacent wallum vegetation rather than a cessation of saline intrusion into the system through the artificial channel. It is possible that the generally higher water level within Salty Lagoon following closure of the artificial channel has effectively limited any expansion of suitable acidic habitat out from the Sedge Swamp/ Swamp Forest 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. Conclusion

8.1 Conclusion

Results of the MPPC to date consist of pre-closure of the Artificial Channel baseline dataset and four years of post-closure monitoring. The post-closure monitoring has included both typical and atypical climatic events (including above average wet and dry weather periods); allowing the dataset to cover broad climatic variation. The current monitoring period comprised relatively dry weather for the region.

The data for all monitored environmental attributes appear adequate for allowing pre-closure and post-closure comparisons. Despite the lower than average rainfall, the system has continued to move towards a predominantly freshwater lagoon system, with the monitoring recording relatively stable water quality conditions in comparison to previous years.

During the current monitoring period, the results have continued to indicate that many of the predicted changes are occurring. This includes positive predicted changes such as a more natural hydrology and salinity regime; reduced magnitude, rate of water level variation; less frequent saline water ingress; and reduced risk of fish kill. Conversely, other monitoring attributes have recorded no clear trend (e.g. improved productivity of the benthic microalgal assemblage resulting in nutrient assimilation) or negative trends (e.g. Wallum Froglet distribution has decreased). As the monitoring period increases, trends from the changes within Salty Lagoon will become more apparent.

The erosive headcut to the east of the old artificial channel continues to present a threat to the project. Ongoing monitoring has observed continued advancement of the headcut, though at a reduced rate to that observed in the previous year. 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.

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Appendix A

Frog Monitoring Data

Table A1 Environmental Conditions at the Time of the Frog Monitoring

Season	Date	Transect	Weather	Temperature (ºC)	Relative Humidity (3 pm) (%)	Wind km/hr	Evidence of Rain in 24 hrs	Rain in 72 hrs (mm)	Night Light	Approximate Depth of Surface Water (mm)						Artificial Channel Open or Closed
										PC1	PC2	PC 3	PC 4	PC 5	PC6	
Winter 2015	20/08/15	1	Dry	13.2-17.5 (15 during survey)	98	no wind	yes	29.8	Very Dark	650	350	400	300	100	0	Closed
	20/08/15	2	Light isolated shower	13.2-17.5 (14 during survey)	98	light	yes	29.8	Very Dark	Open water - no measurement recorded	400	500	400	30	10	Closed
	20/08/15	3	Dry	13.2-17.5 (14 during survey)	98	no wind	yes	29.8	Very Dark	1000	500	50	50	10	0	Closed
	25/08/15	1	Dry	9.3-20.1	50	light to moderate	no	0	Detail seen	700	600	300	200	100	0	Closed
	25/08/15	2	Dry	9.3-20.1	50	light to moderate	no	0	Detail seen	Open water - no measurement recorded	600	400	300	200	50	Closed
	25/08/15	3	Dry	20.7-22.4	50	light to moderate	no	0	Detail seen	1000	600	100	50	50	0	Closed
Spring 2015	16/11/15	1	Dry	14.9-22.2 (18.3 during survey)	78	light	no	0	Very Dark	700	300	300	200	50	0	Closed

Season	Date	Transect	Weather	Temperature (ºC)	Relative Humidity (3 pm) (%)	Wind km/hr	Evidence of Rain in 24 hrs	Rain in 72 hrs (mm)	Night Light	Approximate Depth of Surface Water (mm)						Artificial Channel Open or Closed
										PC1	PC2	PC 3	PC 4	PC 5	PC6	
	16/11/15	2	Dry	14.9-22.2 (18.7 during survey)	85	light	no	0	Very Dark	Open water - no measurement recorded	500	400	100	50	0	Closed
	16/11/15	3	Dry	14.9-22.2 (18.2 during survey)	86	light	no	0	Very Dark	1000	500	50	0	0	0	Closed
	24/11/15	1	Fine, partly cloudy	19.1-26.6	90	light	no	0	Bright	700	500	350	300	50	0	Closed
	24/11/15	2	Fine, partly cloudy	19.1-26.6	90	light	no	0	Bright	Open water - no measurement recorded	400	350	150	30	0	Closed
	24/11/15	3	Fine, partly cloudy	19.1-26.6	90	light	no	0	Bright	1000	400	50	0	0	0	Closed
Summer 2016	8/02/16	1	Scattered cloud cover occasional showers	19.6 - 20.2	75 – 80	light	yes	19.4	dark	800	600	500	300	150	0	Closed

Season	Date	Transect	Weather	Temperature (ºC)	Relative Humidity (3 pm) (%)	Wind km/hr	Evidence of Rain in 24 hrs	Rain in 72 hrs (mm)	Night Light	Approximate Depth of Surface Water (mm)						Artificial Channel Open or Closed
										PC1	PC2	PC 3	PC 4	PC 5	PC6	
	8/02/16	2	Scattered cloud cover occasional showers	18.6 - 19.8	76 – 80	no wind	yes	19.4	dark	700	700	400	300	50	10	Closed
	8/02/16	3	Scattered cloud cover occasional showers	18.6 - 19.3	77 – 80	light to moderate	yes	19.4	dark	900	700	100	20	0	0	Closed
	4/03/16	1	Fine, partly cloudy	22.6-22.7	91	calm	yes	5.4	Very Dark	800	600	400	400	80	0	Closed
	4/03/16	2	Fine, partly cloudy	22.5-23.1	85-89	calm	yes	5.4	Very Dark	1100	600	500	400	30	10	Closed
	4/03/16	3	Fine, partly cloudy	23.3-23.8	85-86	calm	yes	5.4	Very Dark	1100	800	50	40	20	10	Closed

Night Light Key: Very Dark = No moon
Dark = Quarter moon or moon with heavy cloud
Detail Seen = moon and clear sky
Bright = Half-moon or more and no cloud

Table A2 Point Count Survey Results

Transect No. and Survey Data	Point Count No.	Habitat Type	Species Count																						
Species Name			***Crinia tinnula***		***Litoria peronii***		***Crinia signifera***		***Limnodynastes peroni***		***Litoria fallax***		***Litoria tyleri***		***Litoria olongburensis***		***Litoria latopalmata***		***Litoria nasuta***		***Litoria dentata***		***Litoria gracilenta***		**Total**
Winter																									
Census 1:			Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	**Total**
T1: 20/08/15 5:30 pm	1	Open Water	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T1: 20/08/15 5:45 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	0	no	3	yes	0	no	0	no	0	no	0	no	0	no	0	no	**3**
T1: 20/08/15 6:00 pm	3	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	2	yes	0	no	0	no	0	no	0	yes	0	no	0	no	**2**
T1: 20/08/15 6:15 pm	4	Swamp Forest	0	yes	0	no	0	yes	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T1: 20/08/15 6:30 pm	5	Sedge Swamp	2	yes	0	no	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	**2**
T1: 20/08/15 6:45 pm	6	Sedge Swamp	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T2 20/08/15 8:45 pm	1	Open Water	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**0**
T2 20/08/15 8:35 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	0	no	5	yes	1	yes	0	no	0	no	0	no	0	no	0	no	**6**
T2 20/08/15 8:10 pm	3	Fringing Marsh/ Swamp Forest Ecotone	0	no	0	no	0	no	5	yes	8	yes	8	yes	0	no	0	no	0	no	0	no	0	no	**21**
T2 20/08/15 7:50 pm	4	Swamp Forest	0	no	0	no	2	yes	0	no	2	yes	1	no	0	no	0	no	0	no	0	no	0	no	**5**
T2 20/08/15 7:30 pm	5	Sedge Swamp	0	yes	0	no	0	no	0	no	1	yes	0	no	0	no	0	no	0	no	0	no	0	no	**1**
T2 20/08/15 7:15 pm	6	Sedge Swamp	1	yes	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**1**
T3 20/08/15 8:55 pm	1	Open Water	0	no	0	no	0	no	2	yes	3	yes	0	no	0	no	0	no	0	no	0	no	0	no	**5**
T3 20/08/15 9:05 pm	2	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	yes	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3 20/08/15 9:15 pm	3	Swamp Forest	0	no	0	no	2	yes	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**2**
T3 20/08/15 9:25 pm	4	Swamp Forest	0	no	0	no	3	yes	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**3**
T3 20/08/15 9:45 pm	5	Sedge Swamp	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3 20/08/15 9:55 pm	6	Sedge Swamp	0	yes	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
C1 Total			**3**	**0**	**0**	**0**	**7**	**0**	**7**	**0**	**24**	**0**	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**51**
Species Name			***Crinia tinnula***		***Litoria peronii***		***Crinia signifera***		***Limnodynastes peroni***		***Litoria fallax***		***Litoria tyleri***		***Litoria olongburensis***		***Litoria latopalmata***		***Litoria nasuta***		***Litoria dentata***		***Litoria gracilenta***		
Census 2:			Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	**Total**

Transect No. and Survey Data	Point Count No.	Habitat Type	Species Count																						
T1: 25/08/15 9:20 pm	1	Open Water	0	n	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T1: 25/08/15 9:10 pm	2	Open Water (with emergent rushes)	0	n	0	no	0	no	0	no	7	yes	0	no	0	no	0	no	0	no	0	no	0	no	**7**
T1: 25/08/15 9:00 pm	3	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	2	yes	0	no	0	no	0	no	0	yes	0	no	0	no	**2**
T1: 25/08/15 8:45 pm	4	Swamp Forest	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T1: 25/08/15 8:35 pm	5	Sedge Swamp	3	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**3**
T1: 25/08/15 8:15 pm	6	Sedge Swamp	3	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**3**
T2: 25/08/15 No sample	1	Open Water	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**
T2: 25/08/15 6:50 pm	2	Open Water (with emergent rushes)	0	no	0	yes	0	no	1	yes	4	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**5**
T2: 25/08/15 7:05 pm	3	Fringing Marsh/ Swamp Forest Ecotone	0	no	0	no	0	no	3	yes	8	yes	7	yes	0	no	0	no	0	no	0	no	0	no	**18**
T2: 25/08/15 7:20 pm	4	Swamp Forest	0	no	0	no	0	no	3	no	5	yes	6	yes	0	no	0	no	0	no	0	no	0	no	**14**
T2: 25/08/15 7:35 pm	5	Sedge Swamp	0	no	0	no	0	yes	0	no	0	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**0**
T2: 25/08/15 8:00 pm	6	Sedge Swamp	3	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**3**
T3: 25/08/15 6:30 pm	1	Open Water	0	no	0	no	0	no	0	yes	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3: 25/08/15 6:20 pm	2	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	0	yes	0	yes	0	no	0	no	0	yes	0	no	0	no	**0**
T3: 25/08/15 6:10 pm	3	Swamp Forest	0	no	0	yes	3	no	0	yes	1	yes	0	yes	0	no	0	no	0	yes	0	no	0	no	**4**
T3: 25/08/15 5:50 pm	4	Swamp Forest	0	no	0	no	4	yes	0	no	1	no	0	no	0	no	0	no	0	no	0	no	0	no	**5**
T3: 25/08/15 5:30 pm	5	Sedge Swamp	0	yes	0	no	0	yes	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	**0**
T3: 25/08/15 5:10 pm	6	Sedge Swamp	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
C2 Total			**9**	**0**	**0**	**0**	**7**	**0**	**7**	**0**	**28**	**0**	**13**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**64**
Winter Total			**12**	**0**	**0**	**0**	**14**	**0**	**14**	**0**	**52**	**0**	**23**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**115**
Spring																									
Census 1:			Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	**Total**
T1: 16/11/15 7.40 pm	1	Open Water	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T1: 16/11/15 7:50 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	0	no	7	yes	0	no	0	no	0	no	3	yes	0	no	0	no	**10**

Transect No. and Survey Data	Point Count No.	Habitat Type	Species Count																						
T1: 16/11/15 8:05 pm	3	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	5	yes	2	yes	0	no	0	no	0	yes	0	no	0	no	**7**
T1: 16/11/15 8:15 pm	4	Swamp Forest	1	no	0	no	0	no	0	no	0	yes	2	yes	0	no	0	no	0	no	0	no	0	no	**3**
T1: 16/11/15 8:25 pm	5	Sedge Swamp	0	no	0	no	0	no	0	no	0	no	0	no	1	no	0	no	0	yes	0	no	0	no	**1**
T1: 16/11/15 8:40 pm	6	Sedge Swamp	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T2 16/11/15 10:50 pm	1	Open Water	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**
T2 16/11/15 10:40 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	0	no	15	yes	0	no	0	no	0	no	0	no	0	no	0	no	**15**
T2 16/11/15 10:10 pm	3	Fringing Marsh/ Swamp Forest Ecotone	0	no	0	no	0	no	1	yes	13	yes	3	yes	0	no	0	no	0	no	0	no	0	no	**17**
T2 16/11/15 9:50 pm	4	Swamp Forest	0	no	0	no	0	no	0	yes	9	yes	2	yes	0	no	0	no	0	no	0	no	0	no	**11**
T2 16/11/15 9:30 pm	5	Sedge Swamp	1	yes	0	no	0	no	0	yes	0	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**1**
T2 16/11/15 9:10 pm	6	Sedge Swamp	0	yes	0	no	0	no	0	no	0	no	0	yes	0	yes	0	no	0	no	0	no	0	no	**0**
T3 16/11/15 10:50 pm	1	Open Water	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3 16/11/15 11:00 pm	2	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3 16/11/15 11:10 pm	3	Swamp Forest	0	no	0	no	0	no	0	no	3	yes	0	no	0	no	0	no	0	no	0	no	0	no	**3**
T3 16/11/15 11:20 pm	4	Swamp Forest	0	no	0	no	0	no	0	no	7	yes	0	no	0	no	0	no	0	no	0	no	0	no	**7**
T3 16/11/15 11:40 pm	5	Sedge Swamp	0	yes	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3 16/11/15 11:50 pm	6	Sedge Swamp	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
C1 Total			**2**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**59**	**0**	**9**	**0**	**1**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**75**
Species Name		**fringe**	***Crinia tinnula***		***Litoria peronii***		***Crinia signifera***		***Limnodynastes peroni***		***Litoria fallax***		***Litoria tyleri***		***Litoria olongburensis***		***Litoria latopalmata***		***Litoria nasuta***		***Litoria dentata***		***Litoria gracilenta***		
Census 2:			Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	**Total**
T1: 24/11/15 10:55 pm	1	Open Water	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T1: 24/11/15 10:45 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	2	yes	6	yes	0	no	0	no	0	no	0	no	0	no	0	no	**8**
T1: 24/11/15 10:30 pm	3	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	5	yes	0	no	0	no	0	no	3	yes	0	no	0	no	**8**
T1: 24/11/15 10:15 pm	4	Swamp Forest	0	yes	0	no	0	no	0	no	4	yes	1	yes	0	no	0	no	0	no	0	no	0	no	**5**

Transect No. and Survey Data	Point Count No.	Habitat Type	Species Count																						
T1: 24/11/15 10:05 pm	5	Sedge Swamp	3	yes	0	no	0	no	1	no	0	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**4**
T1: 24/11/15 9:50 pm	6	Sedge Swamp	2	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**2**
T2: 24/11/15 8:20 pm	1	Open Water	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**
T2: 24/11/15 8:30 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	0	yes	5	yes	0	no	0	no	0	no	0	no	0	no	0	no	**5**
T2: 24/11/15 8:45 pm	3	Fringing Marsh/ Swamp Forest Ecotone	0	no	0	no	0	no	1	no	6	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**7**
T2: 24/11/15 9:00 pm	4	Swamp Forest	0	no	0	no	0	no	1	no	5	yes	4	yes	0	no	0	no	0	no	0	no	0	no	**10**
T2: 24/11/15 9:15 pm	5	Sedge Swamp	2	no	0	no	0	no	3	no	3	yes	1	yes	0	no	0	no	0	no	0	no	0	no	**9**
T2: 24/11/15 9:30 pm	6	Sedge Swamp	2	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**2**
T3: 24/11/15 8:10 pm	1	Open Water	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3: 24/11/15 8:00 pm	2	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	yes	0	no	0	no	**0**
T3: 24/11/15 7:50 pm	3	Swamp Forest	0	no	0	no	0	no	0	yes	3	yes	0	no	0	no	0	no	0	yes	0	no	0	no	**3**
T3: 24/11/15 7:35 pm	4	Swamp Forest	0	no	0	no	0	no	0	yes	3	yes	0	no	0	no	0	no	0	no	0	no	0	no	**3**
T3: 24/11/15 7:25 pm	5	Sedge Swamp	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3: 24/11/15 7:10 pm	6	Sedge Swamp	1	yes	0	no	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	**1**
C2 Total			**10**	**0**	**0**	**0**	**0**	**0**	**8**	**0**	**40**	**0**	**6**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**67**
Spring Total			**12**	**0**	**0**	**0**	**0**	**0**	**9**	**0**	**99**	**0**	**15**	**0**	**1**	**0**	**0**	**0**	**6**	**0**	**0**	**0**	**0**	**0**	**142**
Summer																									
Species Name		**fringe**	***Crinia tinnula***		***Litoria peronii***		***Crinia signifera***		***Limnodynastes peroni***		***Litoria fallax***		***Litoria tyleri***		***Litoria olongburensis***		***Litoria latopalmata***		***Litoria nasuta***		***Litoria dentata***		***Litoria gracilenta***		
Census 1:			Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	**Total**
T1:08/02/16 7:55 pm	1	Open Water	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	yes	0	no	0	no	**0**
T1:08/02/16 7:55 pm	2	Open Water (with emergent rushes)	0	yes	0	no	0	no	0	no	2	yes	0	no	0	no	0	no	1	no	0	no	0	no	**3**
T1:08/02/16 7:55 pm	3	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	3	yes	0	yes	0	no	0	no	0	yes	0	no	0	no	**3**
T1:08/02/16 7:55 pm	4	Swamp Forest	0	no	0	no	0	no	0	no	1	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**1**
T1:08/02/16 7:55 pm	5	Sedge Swamp	0	no	0	no	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	**0**
T1:08/02/16 7:55 pm	6	Sedge Swamp	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**

Transect No. and Survey Data	Point Count No.	Habitat Type	Species Count																						
T2: 08/02/16 9:17 pm	1	Open Water	0	no	0	no	0	no	0	no	1	yes	0	no	0	no	0	no	0	no	0	no	0	no	**1**
T2: 08/02/16 9:17 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T2: 08/02/16 9:17 pm	3	Fringing Marsh/ Swamp Forest Ecotone	0	no	0	no	0	no	0	yes	0	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**0**
T2: 08/02/16 9:17 pm	4	Swamp Forest	0	no	0	no	0	no	0	no	3	yes	10	yes	0	no	0	no	0	no	0	no	0	no	**13**
T2: 08/02/16 9:17 pm	5	Swamp Forest	0	no	0	no	0	no	0	no	0	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**0**
T2: 08/02/16 9:17 pm	6	Sedge Swamp	0	yes	0	no	0	no	0	no	0	yes	0	yes	0	no	0	no	0	no	0	no	0	no	**0**
T3: 08/02/16 10:45 pm	1	Open Water	0	no	0	no	0	no	0	no	2	yes	0	no	0	no	0	no	0	yes	0	no	0	no	**2**
T3: 08/02/16 10:45 pm	2	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	2	no	1	yes	0	no	0	no	0	no	0	yes	0	no	0	no	**3**
T3: 08/02/16 10:45 pm	3	Swamp Forest	0	no	0	no	0	no	0	no	2	yes	0	no	0	no	0	no	0	no	0	no	0	no	**2**
T3: 08/02/16 10:45 pm	4	Swamp Forest	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3: 08/02/16 10:45 pm	5	Sedge Swamp	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3: 08/02/16 10:45 pm	6	Sedge Swamp	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
C2 Total			**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**15**	**0**	**10**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**28**
Species Name			***Crinia tinnula***		***Litoria peronii***		***Crinia signifera***		***Limnodynastes peroni***		***Litoria fallax***		***Litoria tyleri***		***Litoria olongburensis***		***Litoria latopalmata***		***Litoria nasuta***		***Litoria dentata***		***Litoria gracilenta***		
Census 2:			Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	Within 20 m	20 - 50 m	**Total**
T1: 04/03/16 8:00 pm	1	Open Water	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T1: 04/03/16 8:00 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	0	no	3	yes	0	no	0	no	0	no	0	no	0	no	0	no	**3**
T1: 04/03/16 8:00 pm	3	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	4	yes	0	no	0	no	0	no	0	no	0	no	0	no	**4**
T1: 04/03/16 8:00 pm	4	Swamp Forest	0	yes	0	no	0	no	2	yes	2	yes	0	no	0	no	0	no	0	no	0	no	0	no	**4**
T1: 04/03/16 8:00 pm	5	Sedge Swamp	2	yes	0	no	0	no	2	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**4**
T1: 04/03/16 8:00 pm	6	Sedge Swamp	1	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**1**
T2: 04/03/16 9:02 pm	1	Open Water	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T2: 04/03/16 8:55 pm	2	Open Water (with emergent rushes)	0	no	0	no	0	no	0	no	2	yes	0	no	0	no	0	no	0	no	0	no	0	no	**2**

Transect No. and Survey Data	Point Count No.	Habitat Type	Species Count																						
T2: 04/03/16 8:55 pm	3	Fringing Marsh/ Swamp Forest Ecotone	0	no	0	no	0	no	0	no	4	yes	0	no	0	no	0	no	1	no	0	no	0	no	**5**
T2: 04/03/16 8:55 pm	4	Swamp Forest	0	no	0	no	0	no	0	no	2	yes	0	no	0	no	0	no	0	no	0	no	0	no	**2**
T2: 04/03/16 8:55 pm	5	Sedge Swamp	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T2: 04/03/16 8:55 pm	6	Sedge Swamp	1	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**1**
T3: 04/03/16 8.45 pm	1	Open Water	0	no	0	no	0	no	0	yes	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3: 04/03/16 8:43 pm	2	Open Water / Fringing Marsh Ecotone	0	no	0	no	0	no	0	no	4	yes	0	no	0	no	0	no	0	no	0	no	0	no	**4**
T3: 04/03/16 8:22 pm	3	Swamp Forest	0	no	0	no	0	no	1	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**1**
T3: 04/03/16 8:11 pm	4	Swamp Forest	0	no	0	no	0	no	1	yes	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**1**
T3: 04/03/16 7:55 pm	5	Sedge Swamp	0	no	0	no	0	no	0	no	0	yes	0	no	0	no	0	no	0	no	0	no	0	no	**0**
T3: 04/03/16 7:45 pm	6	Sedge Swamp	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	0	no	**0**
C2 Total			**4**	**0**	**0**	**0**	**0**	**0**	**6**	**0**	**21**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**32**
Summer Total			**4**	**0**	**0**	**0**	**0**	**0**	**8**	**0**	**36**	**0**	**10**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**60**
Overall Total			**28**	**0**	**0**	**0**	**14**	**0**	**31**	**0**	**187**	**0**	**48**	**0**	**1**	**0**	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**0**	**317**

Table A3 Wallum Froglet and Dwarf Tree Frog Comparison Results

ID	Northing	Easting	Species	Transect
DTF 1	541707	6783145	Litoria fallax	1
DTF 2	541682	6782808	Litoria fallax	2
DTF 3	541674	6782479	Litoria fallax	3
DTF 4	541637	6782453	Litoria fallax	3
DTF 5	541693	6782811	Litoria fallax	2
DTF 6	541845	6782840	Litoria fallax	2
DTF 7	541841	6782524	Litoria fallax	3
DTF 8	541948	6782573	Litoria fallax	3
DTF 9	542078	6782623	Litoria fallax	3
DTF 10	541929	6783018	Litoria fallax	1
DTF 11	541879	6783049	Litoria fallax	1
DTF 12	541877	6783046	Litoria fallax	1
DTF 13	541884	6783044	Litoria fallax	1
DTF 14	541885	6783042	Litoria fallax	1
DTF 15	541809	6783080	Litoria fallax	1
DTF 16	541808	6783082	Litoria fallax	1
DTF 17	541814	6783077	Litoria fallax	1
DTF 18	541812	6783079	Litoria fallax	1
DTF 19	541743	6783115	Litoria fallax	1
DTF 20	541963	6782858	Litoria fallax	2
DTF 21	541854	6782840	Litoria fallax	2
DTF 22	541854	6782837	Litoria fallax	2
DTF 23	541849	6782838	Litoria fallax	2
DTF 24	541852	6782841	Litoria fallax	2
DTF 25	541858	6782842	Litoria fallax	2
DTF 26	541741	6782822	Litoria fallax	2
DTF 27	541758	6782824	Litoria fallax	2
DTF 28	541754	6782834	Litoria fallax	2
DTF 29	541632	6782796	Litoria fallax	2
DTF 30	541645	6782805	Litoria fallax	2
DTF 31	541643	6782799	Litoria fallax	2
DTF 32	541533	6782769	Litoria fallax	2
DTF 33	542070	6782614	Litoria fallax	3
DTF 34	541942	6782565	Litoria fallax	3
DTF 35	541959	6782573	Litoria fallax	3
DTF 36	541822	6782511	Litoria fallax	3
DTF 37	541708	6782484	Litoria fallax	3
DTF 38	541557	6782420	Litoria fallax	3
DTF 39	541859	6783056	Litoria fallax	1
DTF 40	541850	6783061	Litoria fallax	1
DTF 41	541831	6783069	Litoria fallax	1
DTF 42	541825	6783072	Litoria fallax	1
DTF 43	541719	6783129	Litoria fallax	1
DTF 44	541769	6783099	Litoria fallax	1
DTF 45	541635	6783183	Litoria fallax	1
DTF 46	541880	6782839	Litoria fallax	2
DTF 47	541891	6782848	Litoria fallax	2
DTF 48	541913	6782845	Litoria fallax	2
DTF 49	541947	6782856	Litoria fallax	2
DTF 50	541801	6782829	Litoria fallax	2
DTF 51	541701	6782812	Litoria fallax	2
DTF 52	541698	6782814	Litoria fallax	2

ID	Northing	Easting	Species	Transect
DTF 53	541721	6782817	Litoria fallax	2
DTF 54	541665	6782804	Litoria fallax	2
DTF 55	541613	6782790	Litoria fallax	2
DTF 56	541593	6782787	Litoria fallax	2
DTF 57	541486	6782757	Litoria fallax	2
DTF 58	541510	6782764	Litoria fallax	2
DTF 59	542004	6782585	Litoria fallax	3
DTF 60	541911	6782554	Litoria fallax	3
DTF 61	541791	6782496	Litoria fallax	3
DTF 62	541753	6782474	Litoria fallax	3
WF 1	541740	6783119	Crinia tinnula	1
WF 2	541665	6783165	Crinia tinnula	1
WF 3	541675	6783159	Crinia tinnula	1
WF 4	541671	6783167	Crinia tinnula	1
WF 5	541664	6783170	Crinia tinnula	1
WF 6	541555	6783246	Crinia tinnula	1
WF 7	541547	6783245	Crinia tinnula	1
WF 8	541527	6782765	Crinia tinnula	2
WF 9	541516	6782762	Crinia tinnula	2
WF 10	541416	6782750	Crinia tinnula	2
WF 11	541420	6782755	Crinia tinnula	2
WF 12	541421	6782752	Crinia tinnula	2
WF 13	541535	6782411	Crinia tinnula	3
WF 14	541819	6783076	Crinia tinnula	1
WF 15	541781	6783095	Crinia tinnula	1
WF 16	541692	6783148	Crinia tinnula	1
WF 17	541705	6783141	Crinia tinnula	1
WF 18	541583	6783220	Crinia tinnula	1
WF 19	541606	6783201	Crinia tinnula	1
WF 20	541598	6783213	Crinia tinnula	1
WF 21	541565	6783230	Crinia tinnula	1
WF 22	541564	6782780	Crinia tinnula	2
WF 23	541556	6782775	Crinia tinnula	2
WF 24	541446	6782750	Crinia tinnula	2
WF 25	541473	6782753	Crinia tinnula	2
WF 26	541457	6782754	Crinia tinnula	2
WF 27	541562	6782416	Crinia tinnula	3
WF 28	541571	6782426	Crinia tinnula	3
WF 29	541424	6782750	Crinia tinnula	2