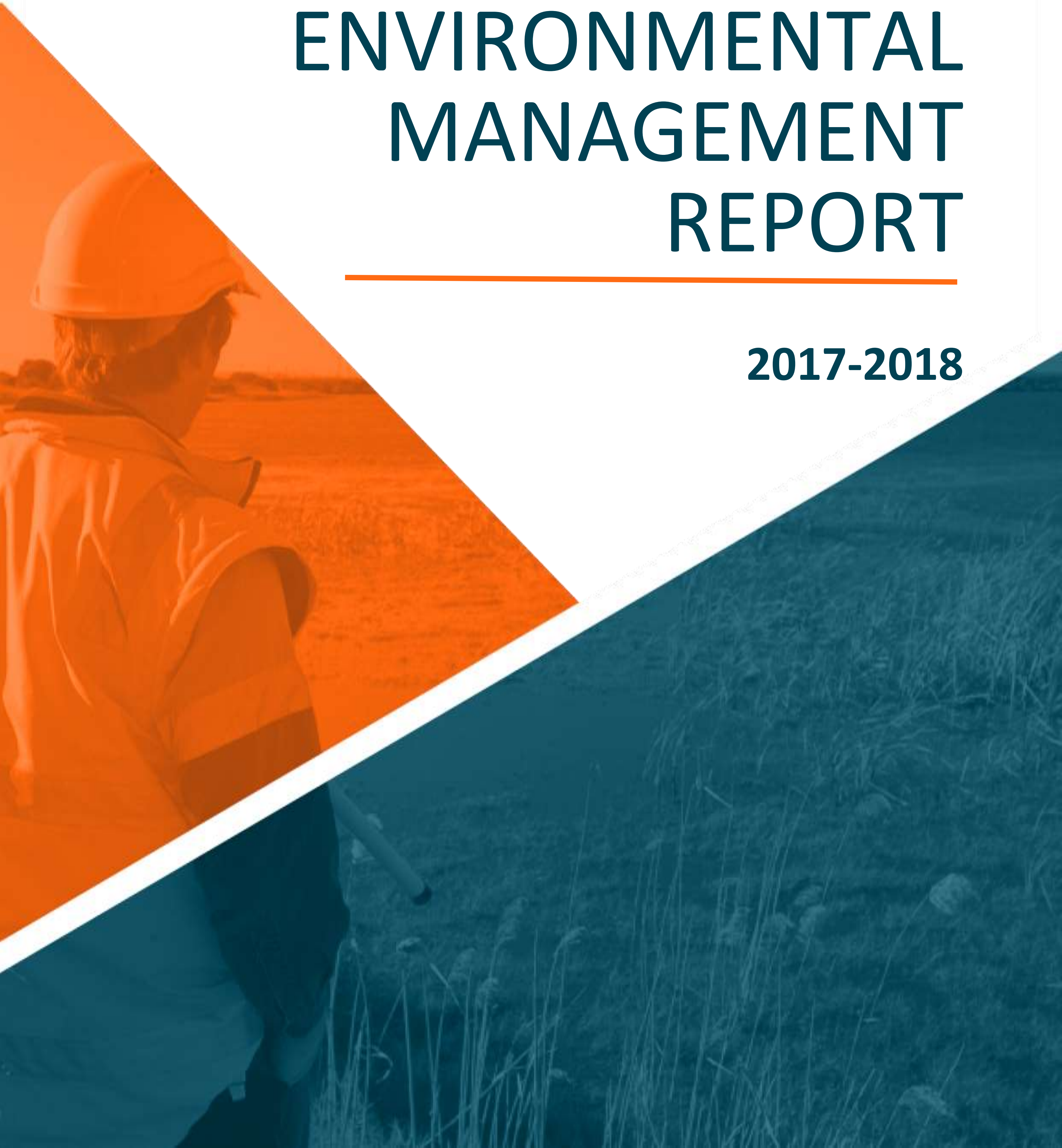
Newcastle Coal
INFRASTRUCTURE GROUP

ANNUAL ENVIRONMENTAL MANAGEMENT REPORT

2017-2018



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1. INTRODUCTION

This Annual Environmental Management Report (AEMR) has been prepared for the Newcastle Coal Infrastructure Group (NCIG) Coal Export Terminal project (the Terminal) in accordance with the conditions of the approved Operation Environmental Management Plan (OEMP). The OEMP was prepared in accordance with Condition 7.5, within Schedule 2 of the Project Approval (PA) (06_0009) which was granted on 13 April 2007.

This is the tenth AEMR prepared for the Terminal which includes the eighth year of terminal operation and it covers the period July 2017 to June 2018 (inclusive).

The AEMR reviews the performance of the Terminal against the requirements of the Project Approval and provides an overview of environmental management actions and summarises monitoring results over the 12 month reporting period. The AEMR will be distributed to relevant government agencies and stakeholders, and copies provided to other interested parties, if requested.

1.1 APPROVALS, LEASES, LICENCES AND PERMITS

Site operations are being undertaken under the approvals, leases, licences and permits presented in **Table 1-1.**

Table 1-1: Project Approval, Leases, Licences and Permits

INSTRUMENT	RELEVANT AUTHORITY	DATE GRANTED	DURATION OF APPROVAL
Project Approval (06_0009)	Department of Planning and Environment	13 April 2007	5 years unless substantially commenced
Modification of Minister's Approval MP06_0009	Department of Planning and Environment	27 November 2007	N/A (conditions appended to the Project Approval)
Modification of Minister's Approval MP06_0009 MOD2	Department of Planning and Environment	13 May 2013	N/A (conditions appended to the Project Approval)
Project Lease	State Property Authority	22 January 2008	35 years
Environmental Protection Licence (EPL) (No. 12693)	NSW Environment Protection Authority	26 October 2007	Until the Licence is surrendered or revoked. The Licence is subject to review every 5 years.
Environment Protection and Biodiversity Conservation Act 1999 Particular Manner Decision (EPBC 2006/2987)	Department of the Environment and Energy	11 October 2006	Perpetuity
Maritime Services Act 1935 s13JE	NSW Roads and Maritime Services	02 October 2007	Perpetuity
Environmental Representative	Department of Planning and Environment	03 October 2007	Perpetuity
Project Ecologist	Department of Planning and Environment	02 May 2007 & 25 October 2007	Perpetuity
Licence for Minor Operations – Green and Golden Bell Frog Research Area (Trial Site)	National Parks and Wildlife Service	25 June 2012	5 years (until 24 June 2017)
Licence for Minor Operations – Green and Golden Bell Frog Compensatory Habitat	National Parks and Wildlife Service	31 March 2013	5 years (until 30 March 2019)
Determination Notice for External Proponents – Green and Golden Bell Frog Compensatory Habitat (Ref No. CCHR 1317_17)	National Parks and Wildlife Service	7 March 2013	Perpetuity
Determination Notice for External Proponents – Green and Golden Bell Frog Trial Ponds (Ref. No. CCHR 1112_28)	National Parks and Wildlife Service	1 June 2012	Perpetuity
Deed for the provision of compensatory habitat for migratory shorebirds on Kooragang Island (Area E)	(the Minister for) National Parks and Wildlife Service	22 February 2016	Cessation of NCIG CET, surrender of Project Approval 06_0009 or expiry of the lease

Determination (National Parks and Wildlife Service) – Shorebird Compensatory Habitat project at Fish Fry Flats (Appl No. CCHR 1415_21)	National Parks and Wildlife Service	28 June 2015	Perpetuity
Licence for Minor Operations – Shorebird Habitat Compensation Area E, Kooragang Island	National Parks and Wildlife Service	30 December 2014	35 years (until 29 December 2039)

1.2 MANAGEMENT PLANS AND MONITORING PROGRAMS

In accordance with the PA 06_0009, the Project is currently being undertaken consistent with the following approved environmental management plans and monitoring programs:

Operations Management Plans

- Operation Environmental Management Plan
- Operation Dust and Air Quality Management Plan
- Operation Noise Management Plan
- Operation Spontaneous Combustion Management Plan
- Operation Water Management Plan

Other Management Plans and Programs

- Ecological and Land Management Plan
- Waste Management Plan
- Site Water Management Plan (incorporated into the Operation Water Management Plan)
- Green and Golden Bell Frog Management Plan (incorporated into the Ecological and Land Management Plan)
- Materials Management Areas Procedure (incorporated into the Waste Management Plan)
- Compensatory Habitat and Ecological Monitoring Program
- Green and Golden Bell Frog Compensatory Habitat Management Plan
- Monitoring, Evaluation, Reporting and Improvement Plan for the Migratory Shorebird Habitat Establishment
- Compliance Tracking Program
- Coordinated Environmental Monitoring and Management Protocol (with PWCS)
- Materials Transport Procedure

Monitoring Programs

- Environmental Monitoring Program (contained within the OEMP)
- Green and Golden Bell Frog Monitoring Program (contained in the ELMP)
- Deep Pond Bird Monitoring Program (contained in the ELMP)

1.3 TERMINAL BACKGROUND

The Terminal is located on Kooragang Island in Newcastle, New South Wales (NSW) (**Figure 1-1**).

NCIG operates the coal export terminal with approval to export up to 66 million tonnes per annum (Mtpa), including associated rail and coal handling infrastructure and wharf/ship loading facilities on the south arm of the Hunter River. All construction activities associated with PA 06_0009 have been completed and this AEMR reports against operations.

NCIG operates the Terminal and is a consortium of the following five companies:

- BHP
- Yancoal Australia
- Whitehaven Coal
- Peabody Energy Corporation
- Banpu Public Company Limited

The Terminal general arrangement is shown on **Figure 1-2.**

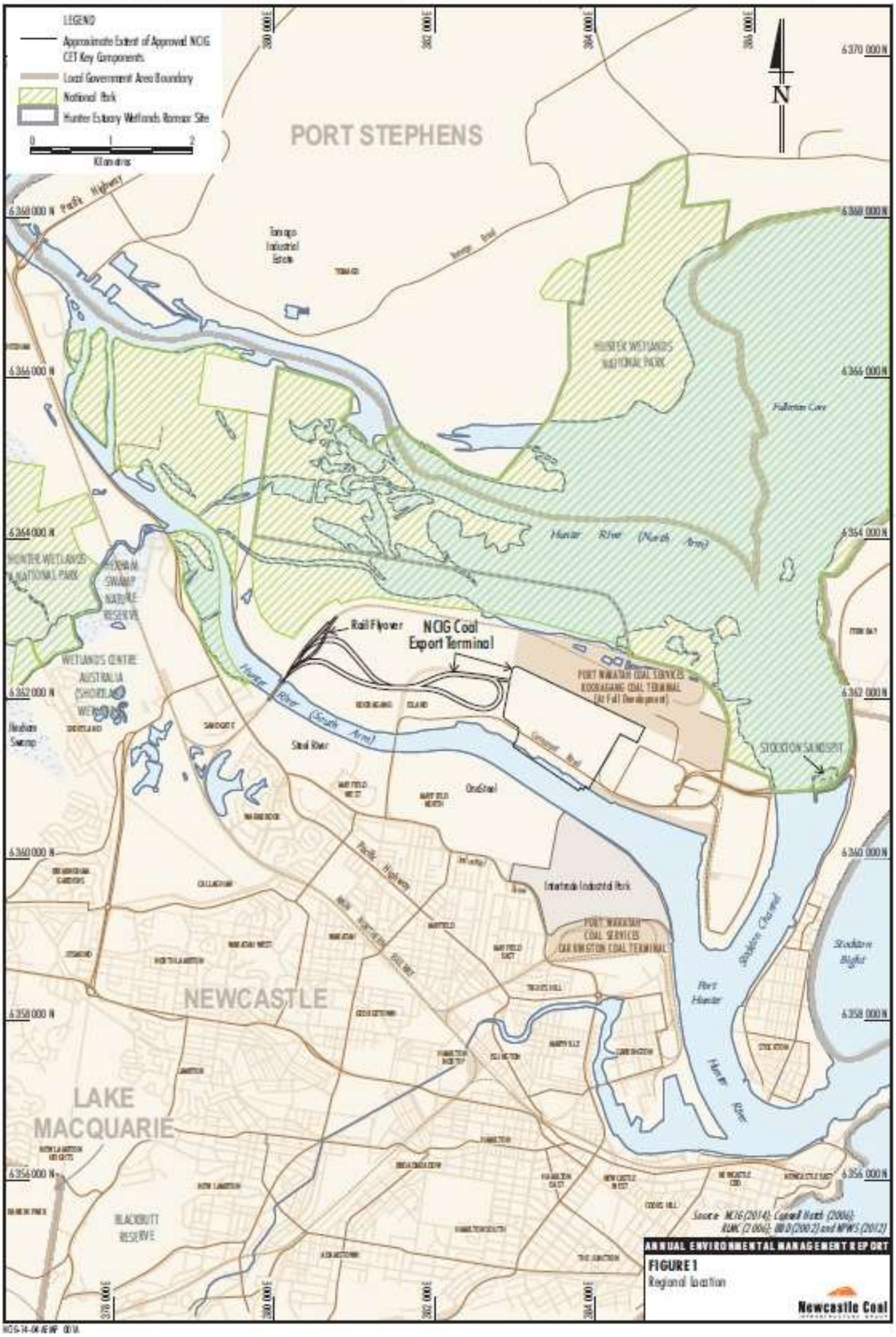


Figure 1-1: Terminal Location

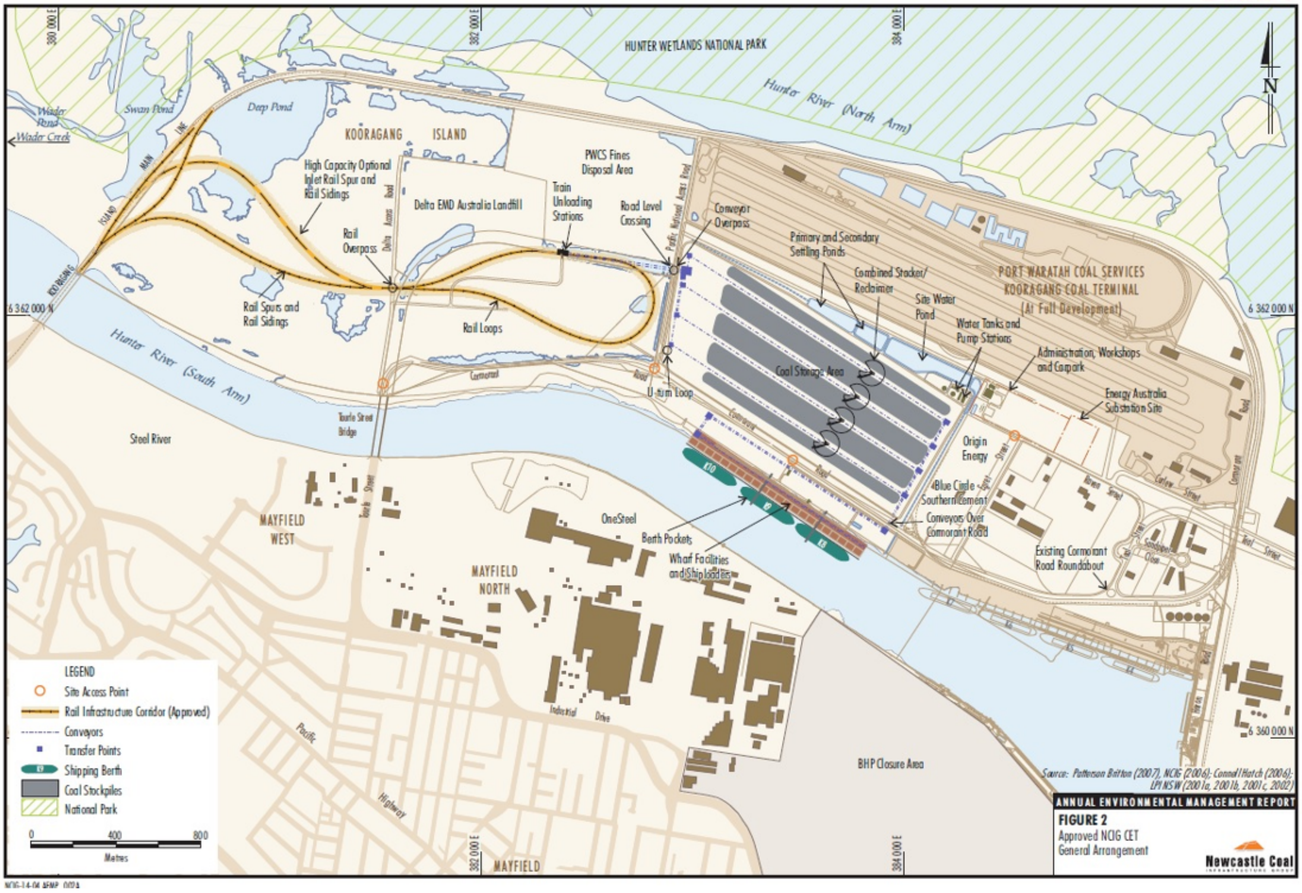


Figure 1-2: Project General Arrangement

2. OVERVIEW OF ACTIVITIES

2.1 OPERATION

The June 2017 to June 2018 reporting period included a continuation of terminal operations. All mechanical equipment was operational during the period, namely Dump Stations 1 and 2, Stacker/Reclaimers 1, 2, 3 and 4 and Ship loaders 1 and 2, along with associated inbound and outbound conveyor systems. Milestones achieved in this reporting period include:

- Provided 66 million tonnes of capacity
- Loaded 53.4 million tonnes of coal
- Record financial year average Gross Load Rate (GLR) 5,422 tph onto 544 vessels
- Financial year record Gross Unload Rate (GULR) of 8,572 tph from 7,246 trains

Operational activities are shown in **Figure 2-1** to **Figure 2-4**.

Figure 2-1: NCIG Site Overview Facing East

Figure 2-2: NCIG Site Overview Facing North

Figure 2-3: Stockyard with Stacker Reclaimers in Operation

Figure 2-4: Aerial Photograph of NCIG Terminal

3. SUSTAINABLE DEVELOPMENT POLICY

NCIG updated their Sustainable Development Policy in June 2018. NCIG's approach to environmental management is guided by this policy, which is included in **Figure 3-1**.

Newcastle Coal
INFRASTRUCTURE GROUP

Sustainable Development Policy

Creating A Sustainable Business

The Newcastle Coal Infrastructure Group (NCIG) plays an important role in the coal export industry of the Hunter Valley. In fulfilling this role, NCIG acknowledges that it is of vital importance to balance the needs of all stakeholders in our business. Through the consideration of shareholders, employees, contractors, suppliers, the community and the environment, NCIG aims to make a significant contribution to the region, ensuring a sustainable business model.

- Critical to the achievement of sustainability is our objective to maintain an environment in which we:
- **Commit** to zero harm to safety, health and the environment;
- **Identify, evaluate** and **manage** risks to employees, contractors, visitors, the environment and our local community that may arise from our activities;
- Meet all legislative requirements and seek to continuously improve safety and environmental systems on our site to meet or exceed industry and internationally recognised standards;
- **Promote** and **improve** the health of our workplace, positively contribute to the community and protect the environment in which we operate, particularly through the prevention of pollution;
- Achieve our stated vision and mission by upholding our values;
- Promote a positive, high performance culture, through the support of a work environment where all people are treated fairly and with respect and encouraged to reach their full potential;
- Respect the indigenous and non-indigenous cultural and heritage value of the people, the terminal site and its surrounds;
- Regularly review our performance, set and achieve targets that promote the achievement of our stated goals;
- Engage regularly, openly and honestly with all stakeholders and consider any views and concerns raised in decision making; and
- Develop relationships that foster the sustainable development of our local communities.

In implementing this Policy, NCIG will engage with and support our shareholders, employees, contractors, suppliers, customers, business partners and local communities in sharing responsibility for meeting our stated requirements. We will be successful when our stakeholders determine that our contribution is valued.

Philip Garling
Chairman
Revision: D | June 2018

Figure 3-1: NCIG Sustainable Development Policy

4. ENVIRONMENTAL MANAGEMENT AND PERFORMANCE

Environmental monitoring is undertaken at NCIG for meteorology, dust, surface water, groundwater and noise. The results of monitoring for the reporting period are presented and discussed in the following sections.

4.1 ENVIRONMENTAL MONITORING PROGRAM

The Environmental Monitoring Program was implemented during the reporting period to monitor the environmental performance of the Terminal operations in accordance with the PA 06_0009, environmental licences and other statutory conditions. The Environmental Representative was responsible for the implementation of the Environmental Monitoring Program and is responsible for ensuring that adequate environmental monitoring is maintained.

The details of the monitoring undertaken are provided in the following sections, however, an overview of the OEMP, is provided in **Table 4-1** All environmental monitoring sites are shown in **Figure 4-1.**

Table 4-1: Operations Environmental Monitoring Program

MONITORING FOCUS	MONITORING SITES	FREQUENCY	CRITERIA
METEOROLOGY			
Temperature, relative humidity, net solar radiation rainfall, wind speed and direction and sigma theta (rate of change of wind direction)	Project automated meteorological station[1]	Continuously monitored and the data averaged over 15-minute periods	N/A
EROSION AND SEDIMENT CONTROL			
Structural stability and effectiveness in controlling sediment migration	Drainage, erosion and sediment control infrastructure	Monthly and following significant rainfall events (i.e. greater than 20 mm in 24 hours)	N/A
NOISE			
Attended and unattended noise monitoring	Fern Bay, Stockton, Mayfield, Carrington per Section 4.2 ONMP	6 Monthly	See Section 4.7.2
Attended noise monitoring in case of complaint	Reference locations proximal to the Project[1]	At the commencement of operation	
AIR QUALITY			
Dust monitoring	DG1, DG2, DG3, DG4, DG5, DG6[1].	Monthly	See Section 4.3.2
	HVAS1, HVAS2, HVAS3, HVAS4.	Every 6 days	
	BAM1, BAM2, BAM3, BAM4.	Continuous	
	PWCS	Through regular consultation	
SURFACE WATER			
pH, electrical conductivity (EC), total dissolved solids (TDS) and total suspended solids (TSS)	Secondary settling ponds[4]	Monthly	See Section 4.4.2
	Surface water monitoring sites[4].	Monthly	
Water level	Primary and secondary settling ponds[4]	Following heavy rainfall (i.e. more than 20 mm of rainfall in a 24-hour period)	
Drainage, erosion and sediment control	All areas of NCIG	Monthly	
GROUNDWATER			

pH, EC, TDS, TSS, sulfate, polycyclic aromatic hydrocarbons (PAH), As III, Cd, Cu, Pb, Hg, Zn, Cr VI, Mn and Ni (refer Table 5)	GW1, K9/3S, K9/3N, K11/1S, K11/1^1, BH20S, BH20D, BH23S, BH23D BH21S, BH21D	6 Monthly	See Section 4.5.2
Groundwater level		6 Monthly	

1: The location of monitoring sites is shown on **Figure 4-1.**

2: Dust deposition will be analysed in accordance with AS/NZS 3580.10.1-2003 Methods for Sampling and Analysis of Ambient Air- Determination of Particulate Matter – Deposited Matter – Gravimetric Method

Figure 4-1: Environmental Monitoring Sites

4.2 METEOROLOGY

4.2.1 Environmental Management

In accordance with Condition 2.8, Schedule 2 of PA 06_0009, an onsite automated meteorological monitoring station was operated during the reporting period to monitor weather conditions representative of the site. This station was installed on the NCIG site in accordance with the requirements of the OEMP.

The automated meteorological monitoring station allows parameters such as wind direction to be used in the control of stockyard sprays. This includes activation of sprays based on evaporation of surface moisture from the coal stockpiles and deactivation of sprays under wind conditions where sprays would otherwise be ineffective in reaching coal stockpiles.

NCIG also receive additional forecast data for rainfall, with forecast data provided seven days in advance. This information is used to assist with surface water management. A screenshot of the rain forecasting is shown in **Figure 4-2.**

Area Filter: All Areas
Category Filter: All Categories
10/08/2017 14:23:48
User: NCIGpreid

SV01 eATM SV01_16 Project
Appliance Status Running
Project Status Started
Endpoint (SQL) Status Success
Endpoint (CLX) Status Success

○ Rain DL Seq OK
Last DL Date 2017-08-10
Last DL Date 13:55:04
Current Index 7

BG00XCL10: Rain Forecast Day 0 (Today)
Day Offset 0
Date 20170810
Precipitation 0.0 mm Classification OK
Age (Minutes) 25 min Age Classification OK
Precipitation 10 Percent 0.0 mm
Precipitation 25 Percent 0.0 mm
Precipitation 50 Percent 0.0 mm
Precipitation 75 Percent 0.0 mm

Figure 4-2: Rain Forecasting

4.2.2 Environmental Performance

Table 4-2 outlines the monitoring locations, meteorological parameters recorded and frequency of monitoring for the Project in accordance with the OEMP.

Table 4-2: Summary of the Meteorological Monitoring Program

Monitoring Parameter	Monitoring Sites	Frequency	Criteria
Temperature **Relative humidity** **Net solar radiation** **Rainfall** **Wind speed and direction** **Sigma theta (rate of change of wind direction).**	Project automated meteorological station [1].	Continuously monitored and the data averaged over 15 minute periods.	N/A

1 The location of the monitoring sites is shown on **Figure 4-1.**

4.2.3 Monitoring summary

The meteorological monitoring results for the reporting period are summarised below. Monthly statistical information for rainfall is detailed in **Table 4-3.**

Table 4-3: Rainfall statistics by month

Month	Total rainfall (mm)*	Daily average (mm)	Daily maximum (mm)
July 2017	31.6 (70.9)	1.0	22.0
August 2017	24.4 (72.9)	0.8	13.4
September 2017	10.4 (59.7)	0.3	10.4
October 2017	75.4 (73.0)	2.4	21.7
November 2017	75.5 (82.4)	2.5	28.5
December 2017	24.6 (79.0)	0.8	10.2
January 2018	11.4 (99.9)	0.4	6.3
February 2018	122.7 (118.2)	4.4	40.8
March 2018	122.6 (120.5)	4.0	105.9
April 2018	100.5 (111.6)	3.3	52.0
May 2018	7.4 (109.6)	0.2	4.2
June 2018	281.9 (124.7)	9.4	50.4
Annual	**888.5 (1124.9)**		

*values in brackets refer to the mean 76-year Williamtown data – sourced from the Bureau of Meteorology.

The monthly statistical information for each of the remaining meteorological monitoring parameters is detailed in **Appendix 1**.

The monthly and daily rainfall recorded at the Terminal is shown in **Figure 4-3**. A total of 888.5 mm of rain was received on the site during the reporting period with the highest rainfall recorded in June 2018. The lowest rainfall was recorded in May 2018 followed by September 2017.

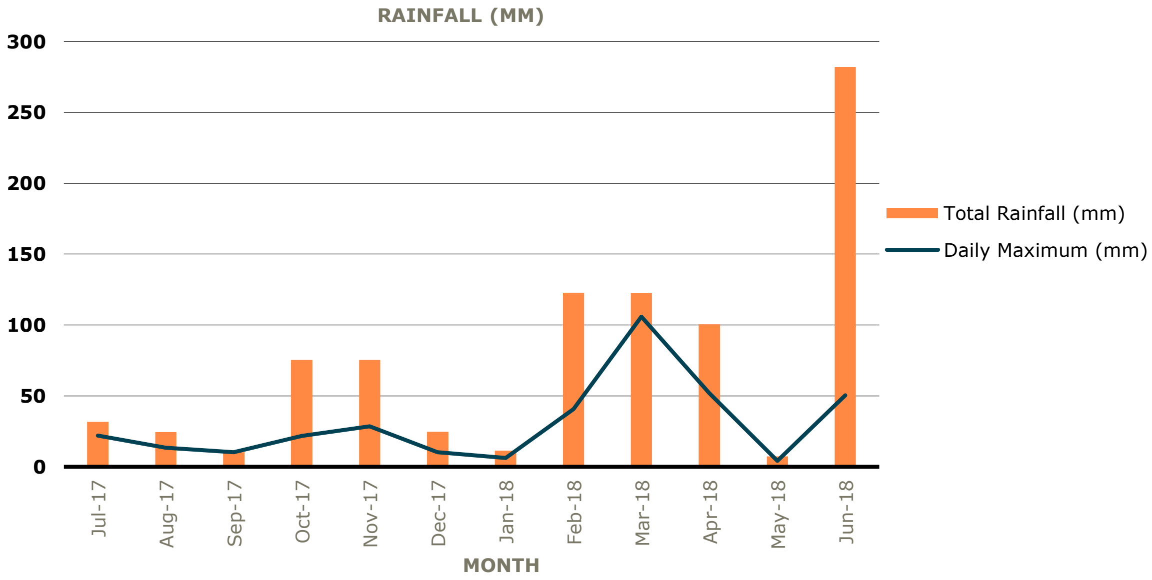


Figure 4-3: Total and Maximum Daily Rainfall by Month

Figure 4-4 illustrates the variation in average temperature during the reporting period. These variations from the winter to summer seasons are the normal expected seasonal variations. **Figure 4-5** illustrates seasonal wind conditions throughout the reporting period.

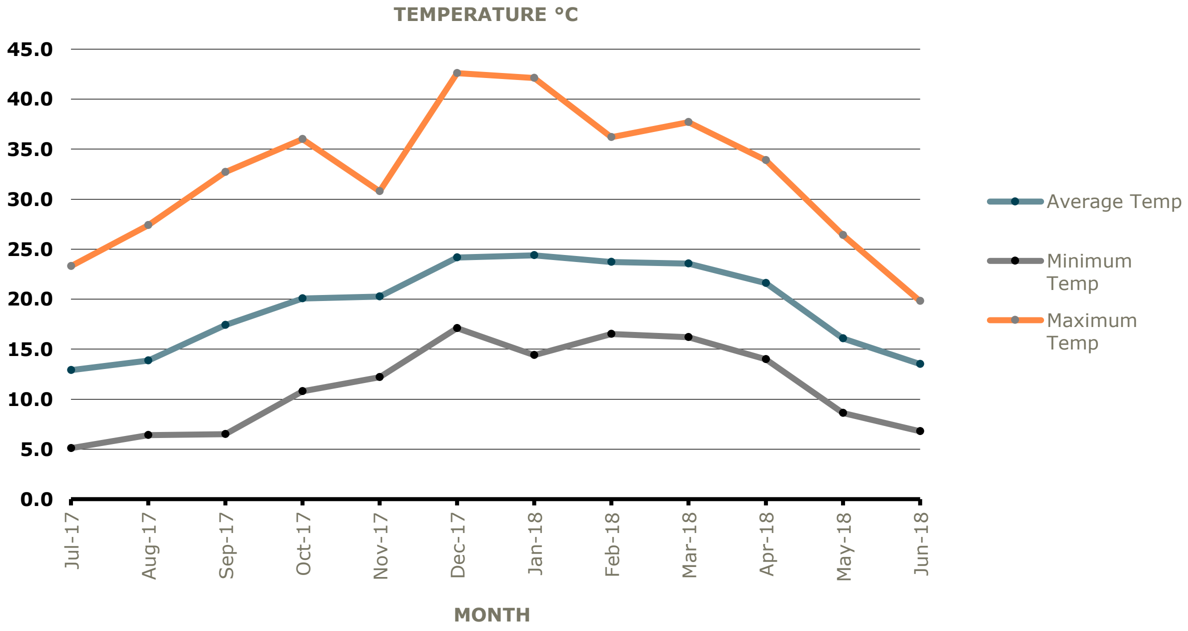
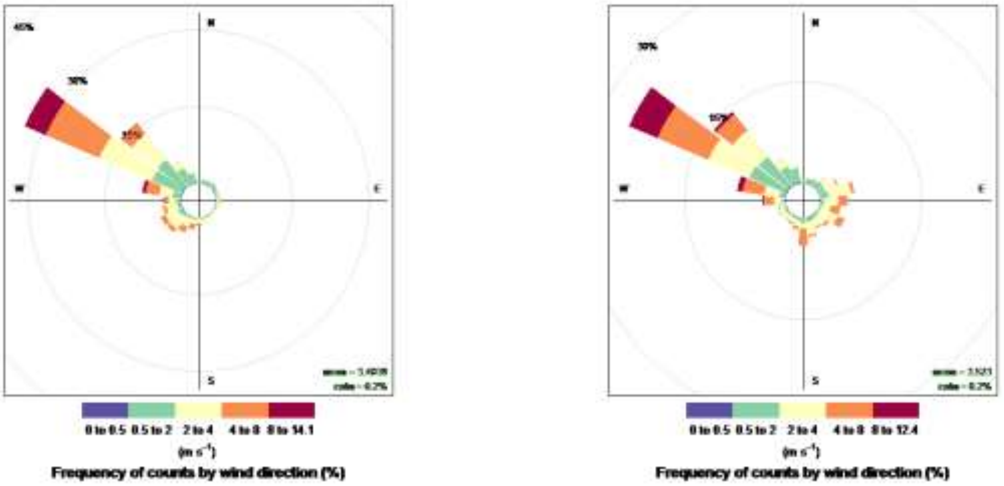
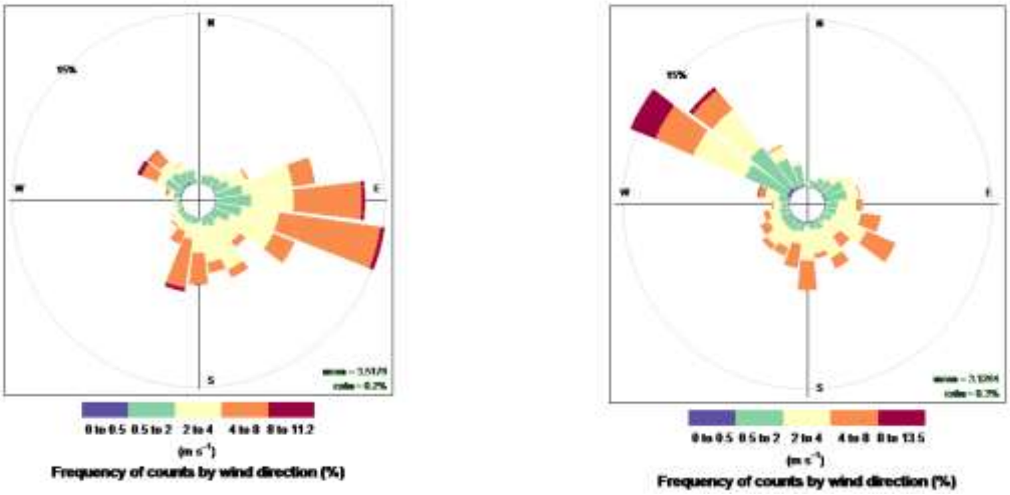


Figure 4-4: Temperature by month



Winter

Spring



Summer

Autumn

Figure 4-5: Seasonal Wind Conditions

4.2.4 Reportable incidents

No environmental incidents or complaints relating to meteorological conditions were made during the reporting period.

4.2.5 Further Improvements

No further improvements to the meteorological monitoring system are currently proposed.

4.3 AIR QUALITY

4.3.1 Environmental Management

Onsite dust management is conducted consistent with the Operations Dust and Air Quality Management Plan to achieve the following key conditions.

In accordance with Conditions 2.2 and 2.4, Schedule 2 of PA 06_0009 NCIG designed and constructed the Project in a manner that minimises or prevents the emission of visible dust beyond the boundary of the site (including windblown and traffic generated dust).

In accordance with Condition 2.5, Schedule 2 of PA 06_0009 dust emissions are being controlled on all internal roads, trafficable areas and manoeuvring areas by sealing, or otherwise treating surfaces to minimise the potential for dust generation.

In accordance with Condition 2.1, Schedule 2 of the PA 06_0009 NCIG did not permit any offensive odour, as defined under section 129 of the *Protection of the Environment Operations Act, 1997*, to be emitted beyond the boundary of the Project site.

In accordance with Condition 3.2 e) of PA 06_0009, NCIG utilises real-time monitoring data to inform environmental management decisions associated with the project. This is done through interaction with real-time Beta Attenuation Monitors (BAMs), which measure Total Suspended Particles (TSP). These are located at the boundaries of the stockyard and are used to assist the management of operation to ensure compliance with project obligations.

Dust from coal handling operations was managed primarily through suitable design of plant and machinery, including enclosures and housed areas at the dump station, conveyors, transfer houses, the buffer bin and feeders throughout the site. Additional measures include operation of dust suppression and moisture addition sprays at transfer points positioned both in transfer houses and on the machines (i.e. Stacker/Reclaimers and the Ship loader). Dust suppression spray guns have also been positioned along the stockyard berms directly adjacent the coal stockpiles. These operate on an automatic sequence, which takes into account varying weather conditions and evaporation rates of water from stockpiles. The onsite weather station is also connected to the system. This system is managed in accordance with the Operations Dust and Air Quality Management Plan (ODAQMP), including programming logic known as an Integrated Dust Management System.

Stockpiling procedures include initial stacking operations for each product are conducted at 12m to complete stockpile footprint. Subsequent stacking is then conducted at 24m. This two staged procedure results in a lower stockpile height for a significant period, resulting in a reduction in dust emissions (as PM_{10}) due to lower wind speeds.

The Newcastle Air Quality Monitoring Network was commissioned by the Office of Environment and Heritage (OEH) during the 2015-16 reporting period, including real-time air quality measurements at Mayfield, Stockton, Carrington and Newcastle. The network is collectively funded by industrial Environment Protection Licence holders operating in the Newcastle area. This includes measurements of PM_{10}, $PM_{2.5}$ and other industrial air pollutants. NCIG regularly reviews results from the monitoring network, particularly during adverse weather conditions.

4.3.2 Environmental Performance

Table 4-4 outlines the monitoring locations, air quality parameters recorded, frequency of monitoring and air quality criteria for the Project in accordance with the OEMP. Depositional Dust Monitoring results are provided in **Appendix 2**.

Table 4-4: Summary of the Air Quality Monitoring Program

MONITORING PARAMETER	UNITS	FREQUENCY	LOCATION	METHODOLOGY
DEPOSITIONAL DUST MONITORING				
Depositional Dust	g/m^2/month	Monthly	• Stockton – DG2 • Kooragang – DG3 • Mayfield – DG4 • Steel River – DG5 • Sandgate – DG6	AS/NZS 3580[1]
Depositional Dust (Integrated AQMN with PWCS)			• Fern Bay – DDG-K8 (DG1) • Stockton Prawners Club – DDG-C1 • Stockton Hospital – DDG-K1	
HIGH VOLUME AIR SAMPLING				
Total Suspended Particles (TSP)	µg/m^3	6-daily	• Steel River – HVAS1 • Mayfield – HVAS2	DEC Approved Methods[2]
Particulate Matter <10 µm (PM10)				
Total Suspended Particles (TSP) (Integrated AQMN with PWCS)			• Stockton Prawners Club – HVAS-C1 • Fern Bay – HVAS-K2 (TSP), HVAS-K3 (PM10), HVAS-K4 (Directional TSP)	
Particulate Matter <10 µm (PM10) (Integrated AQMN with PWCS)				
NEWCASTLE LOCAL AIR QUALITY MONITORING NETWORK (OPERATED BY OEH, FUNDED BY INDUSTRY)				
Particulate Matter <10 µm (PM10)	µg/m^3	Hourly (average daily values reported)	• Stockton • Carrington • Mayfield • Newcastle • Wallsend • Beresfield	DEC Approved Methods
Particulate Matter <2.5 µm (PM2.5)				
Wind Speed	ms^{-1}			AS 2922[3]
Wind Direction	Degrees			AS 2922[3]
ONSITE BETA ATTENUATION MONITORING (BAM)				
Total Suspended Particles (TSP)	µg/m^3	Continuous	• BAM E • BAM N • BAM S • BAM W	DEC Approved Methods[2]

1 Dust deposition is analysed in accordance with Australian standard AS/NZS 3580.10.1-2003 Methods for Sampling and Analysis of Ambient Air – Determination of Particulate Matter – Depositional Matter – Gravimetric Method (Standards Association of Australia 2009).

2 PM10 is monitored in accordance with the Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales (Department of Environment and Conservation NSW 2006).

3 AS 2292-1987 Ambient Air – Guide for the siting of sampling units.

The depositional dust monitoring (insoluble solids) results for the reporting period are displayed in **Figure 4-6** and **4-7** below.

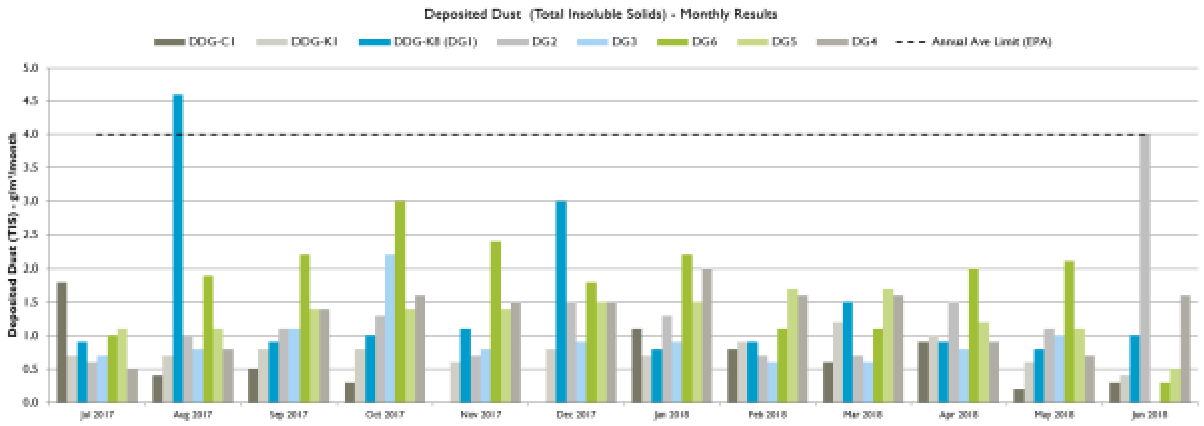


Figure 4-6: Monthly Depositional Dust

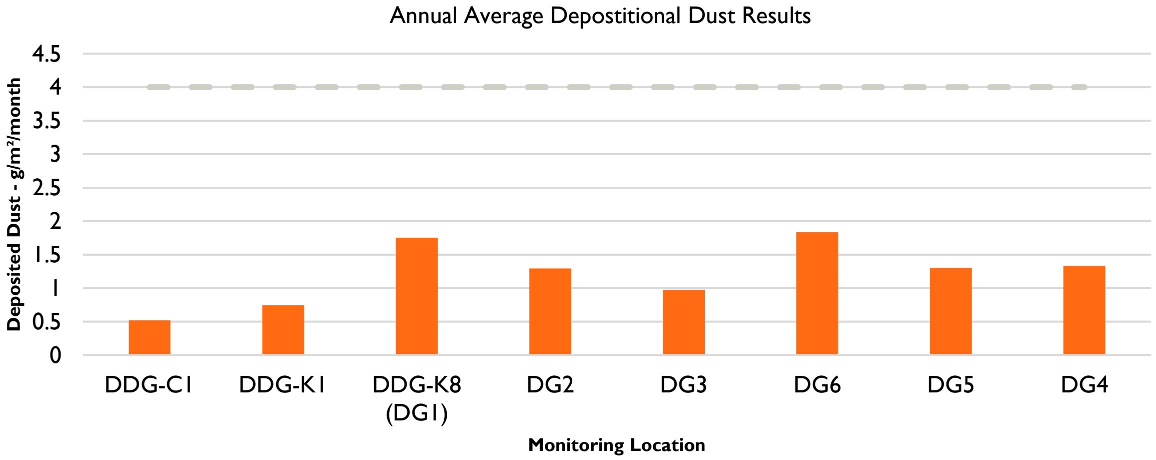


Figure 4-7: Annual Average Depositional Dust

Figure 4-6 shows that individual monthly samples from DG1 exceeded the 4g/m^2/month criteria in August 2017 and June 2018. The spike in depositional dust at DG1 in August and July was due to contamination of the gauge with a high proportion of sand and bird droppings respectively. Average depositional dust results were below the monthly criteria of 4 grams per square metre per month (g/m^2/month) at all depositional dust gauge locations **Figure 4-7.**

Air quality monitoring results from High Volume Air Sampling (HVAS), as they relate to both Total Suspended Particulate (TSP) and Particulate Matter with an equivalent aerodynamic diameter less than 10 Microns (PM$_{10}$), are displayed in **Figure 4-8, Figure 4-9** and **Figure 4-10.**

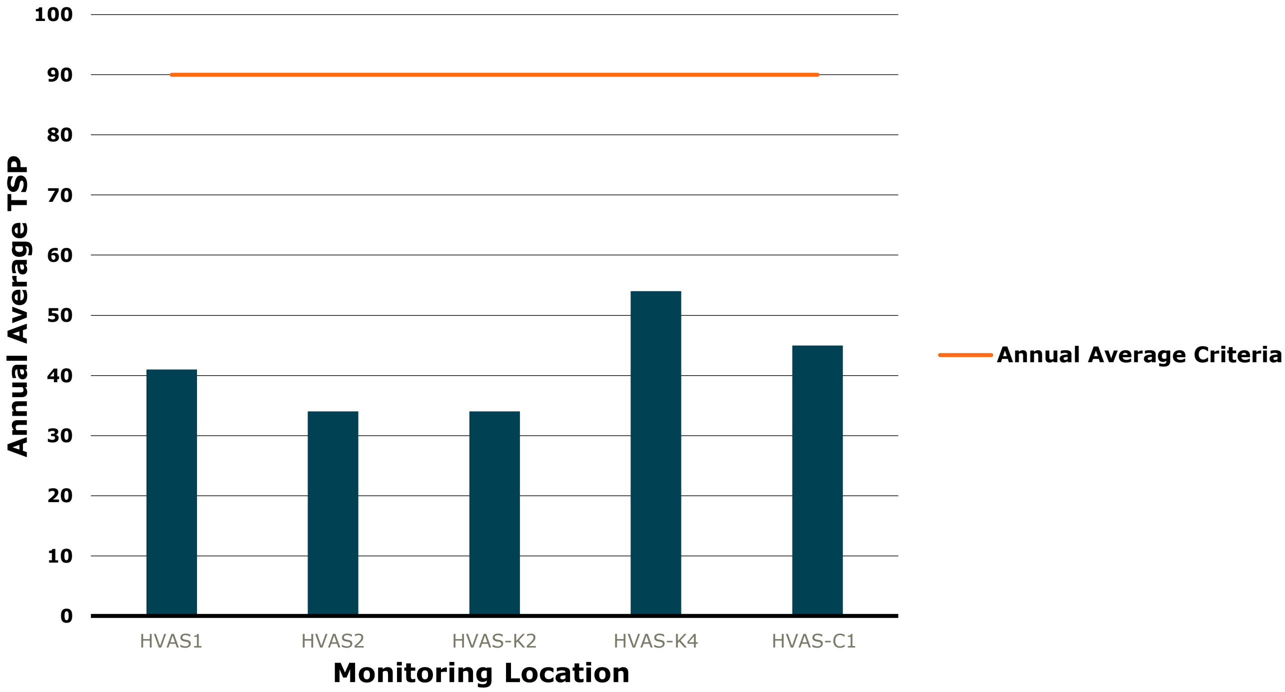


Figure 4-8: Total Suspended Particulates (TSP)

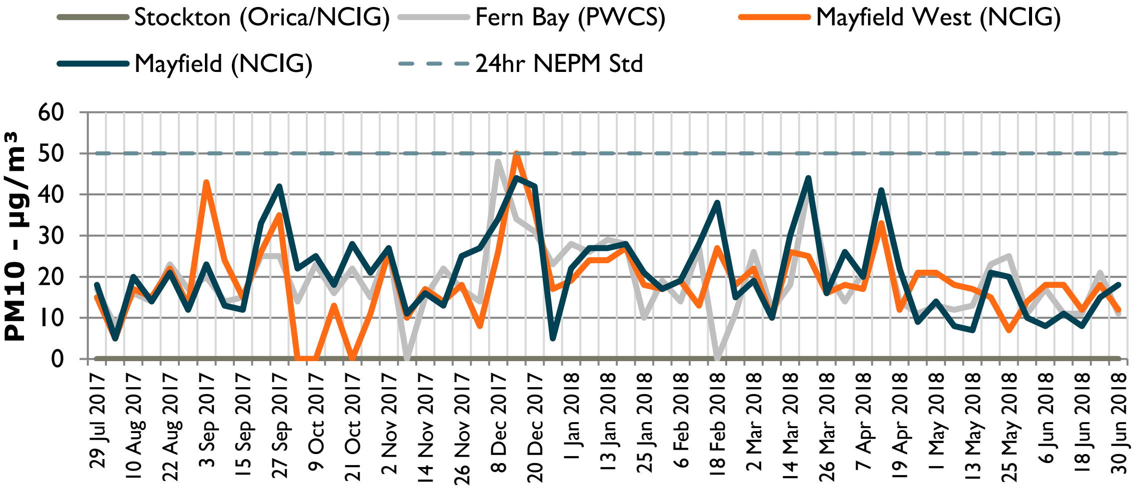


Figure 4-9: Particulate Matter <10 µm (PM_{10}) – 24 Hour Results

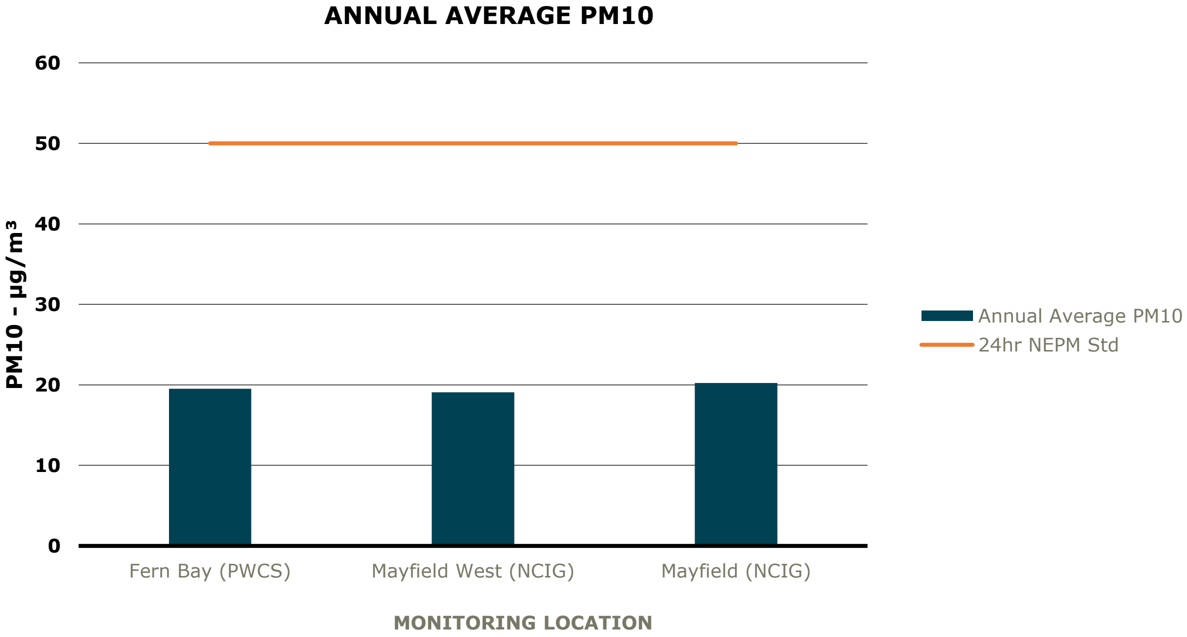


Figure 4-10: Particulate Matter <10 µm (PM_{10}) – Annual Average

The annual average TSP concentrations for the five monitoring locations were below the DEC Annual Average Limit of 90 µg/m³, as shown in **Figure 4-8.**

The annual average PM_{10} concentrations for the three monitoring locations were below the NEPM criteria. Daily concentrations of PM_{10} were below the NEPM criteria of 50µg/m³.

4.3.3 Reportable Incidents

No environmental incidents or complaints relating to meteorological conditions were made during the reporting period.

4.3.4 Further Improvements

A review of other dust management technologies and controls was undertaken during the reporting period (*Review of the Integrated Dust Management System and Options for Improvements* by Red Planet Innovations (2018)). Key recommendations from the review included included improvements to the Integrated Dust Management System to better categorise forecasted dust risk, alterations to spray sequence to better prepare for forecasted dust events, modifications to spray gun equipment to obtain a better reach over stockpiles, review the layout of stockpiles and investigate the feasibility of using treatment of the coal such as veneering.

Recommendations incorporated into the management practices for air quality since receipt of the review in early 2018 include:

1. Updates to the Integrated Dust Management System including better categorisation of dust risk and forecast events.
2. Trialling of alternate dust management technologies including veneering.

Recommendations will be further investigated and incorporated as appropriate during the next reporting period.

4.4 SURFACE WATER

4.4.1 Environmental Management

In accordance with Condition 7.6 c), Schedule 2 of PA 06_0009, an Operations Water Management Plan (OWMP) was developed which defines the surface water, stormwater and groundwater controls on the site during operation. The OWMP includes specific measures designed to avoid sediment-laden, coal-laden or hydrocarbon-impacted surface water from entering Deep Pond, wetland areas or the Hunter River. The OWMP also includes a monitoring program of surface water utilised on and around the Terminal. The OWMP identifies water management infrastructure and water requirements for activities such as dust suppression and plant washdown. A site water balance is included, which accounts for water captured onsite through rainfall and volumes of water that may be required from the local potable water system.

The OWMP identifies that surface water runoff from disturbance areas during operations could potentially contain sediments, soluble salts, fuels, oils, grease and other contaminants, in particular coal residue. The potential surface water quality impacts that relate to these contaminants from each area of the Project site are summarised in **Table 4-5.**

Table 4-5: Potential Surface Water Quality Impacts

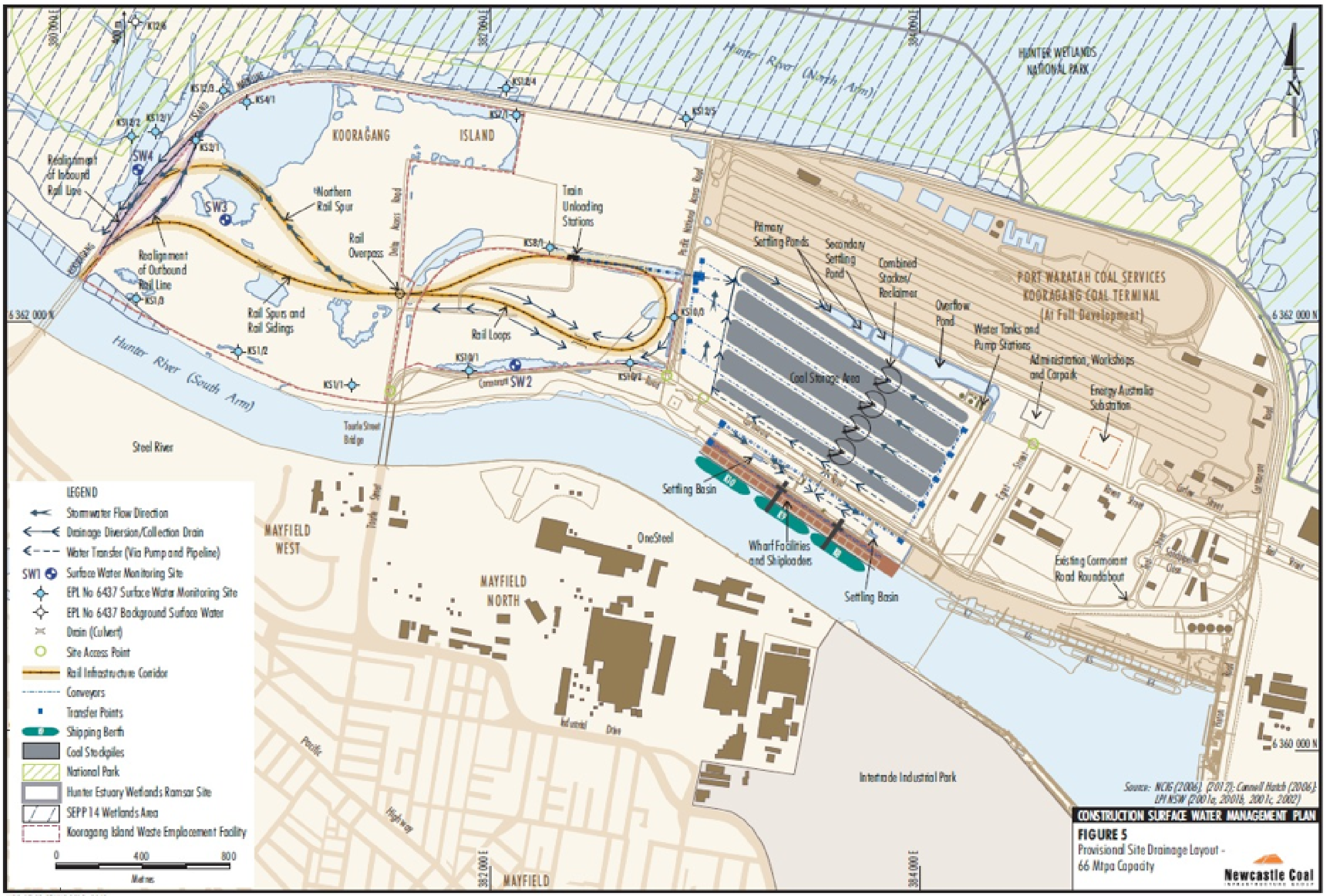
PROJECT SITE	POTENTIAL IMPACT SCENARIOS	POTENTIAL CONTAMINANT
Rail Infrastructure Corridor	Uncontrolled drainage of sediment laden runoff to downstream waterbodies within the Kooragang Island Waste Emplacement Facility (KIWEF) during construction of rail embankments.	Sediments, soluble salts, heavy metals, organic contaminants, fuels, oils and grease.
	Uncontrolled drainage of runoff from access roads and construction areas to downstream waterbodies within the KIWEF.	
	Uncontrolled drainage of runoff from exposed soils within the existing KIWEF to downstream waterbodies.	
	Potential erosion and sedimentation resulting from runoff from the rail corridor and associated drainage system.	
	Release/spill into downstream waterbodies.	Coal, diesel, lubricants and hydrocarbons.
Coal Storage Area	Uncontrolled drainage to downstream waterbodies during construction of the coal storage area.	Sediments, soluble salts, heavy metals, organic contaminants, fuels, oils, lubricants and low pH water.
	Uncontrolled drainage of runoff from access roads and construction areas to downstream waterbodies.	
	Spillage/overflow of site water to downstream waterbodies.	
	Release/spill into downstream waterbodies due to rupture of fuel tank (diesel/petrol).	Sediments, coal, diesel, lubricants and hydrocarbons.
Wharf Facilities and Ship Loader Area	Uncontrolled drainage of sediment laden runoff to the south arm of the Hunter River during construction of the berths and wharf structure, excavation on or near the banks of the South Arm of the Hunter River and during piling operations.	Sediments, soluble salts, fuels, oils and grease.
	Uncontrolled drainage of runoff to the south arm of the Hunter River from access roads and wharf construction areas including excavation on or near the banks of the South Arm of the of the Hunter River.	
	Release/spill into South Arm of the Hunter River.	Sediments, coal, diesel, lubricants, hydrocarbons.

This identification of surface water flows was utilised to develop the monitoring program defined in the OWMP which aim to ensure adjacent water bodies are not impacted by NCIG activities. The OWMP was approved by the Department of Planning (now NSW Department of Planning and Environment) as part of the OEMP.

The surface water management strategies, as detailed in the OEMP, are:

- The separation of surface water runoff generated from within the active CET and Project construction areas from that generated from surrounding areas.
- Containment and reuse of water onsite.
- The implementation of adequate water management controls to minimise the potential for impacts to offsite water resources such as adjacent wetland areas, Deep Pond and the Hunter River **Figure 4-11.**

The management of erosion and sedimentation is outlined is **Section 4.6**.



NCIG-07-02 CSWMP 2013 0048

Figure 4-11: Permanent site drainage layout

4.4.2 Environmental Performance

Table 4-6 outlines the monitoring locations, frequency of monitoring and monitoring parameters for the Project in accordance with the OEMP and OWMP. These monitoring elements form the Surface Water Monitoring Program for the Terminal.

Table 4-6: Surface Water Monitoring Program

MONITORING LOCATIONS	FREQUENCY	PARAMETERS	UNITS	REQUIRED LIMIT OF REPORTING
SW1-a, SW1-b, SW1-c, SW1-d (operational sites) SW2, SW3 (reference sites)	Monthly	pH Electrical conductivity (EC) Total Dissolved Solids (TDS) Turbidity Dissolved Oxygen (DO) Temperature Reduction/ oxidation potential (Redox)	- µS/cm-1 mg/L NTU % °C mV	0.1 10 Not specified 1 10 Not specified Not specified
SW1-d, SW6, SW7, SW8, SW9 (operational sites) **SW2, SW3, SW5, SW10, SW11 (background sites)**	6-monthly	pH Electrical conductivity (EC) Turbidity Dissolved Oxygen (DO) Aluminium Arsenic (III) Boron Cadmium Chromium (III) Cobalt Copper Iron Lead Manganese Mercury Molybdenum Nickel Selenium Zinc Total Recoverable Hydrocarbons C6-C9 Total Recoverable Hydrocarbons C10-C14 Total Recoverable Hydrocarbons C15-C28 Total Recoverable Hydrocarbons C29-C36 Anthracene Benzo(a)pyrene Fluoroanthene Naphthalene Phenanthrene Ammonia Nitrate Total Kjeldahl Nitrogen Total phosphorous Chloride	- µs/cm-1 NTU % mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L µg/L µg/L µg/L µg/L µg/L mg/L mg/L mg/L mg/L mg/L	0.1 10 1 10 0.05 0.05 0.05 0.0001 0.01 0.001 0.001 0.05 0.001 0.5 0.0001 2 0.01 0.001 0.005 0.02 0.05 0.1 0.1 0.01 0.01 0.01 0.01 0.01 0.5 0.1 0.5 0.01 Not specified
SW1-d (discharge) EPL34, SW5 (Background) EPL35	Daily during discharge	pH Turbidity Total Suspended Solids (TSS) Oil and Grease	- NTU mg/L mg/L	0.1 1 Not specified Not specified

1 The location of monitoring sites is shown in **Figure 4-1.**

Sampling of surface water ponds was undertaken during the reporting period in accordance with the OWMP. The location of the sampling undertaken is illustrated in **Figure 4-1** with the water quality results recorded detailed in **Appendix 3**. The pH values onsite ranged between 7.51 and 8.95, which is marginally (+0.95) outside the ANZG (2018) guidelines for lowland rivers which are 6.5 to 8. However the offsite water sources were more variable than onsite sampling locations (5.41 to 10.71), which are more significantly outside the ANZG (2018) guidelines. Therefore, the site is not considered to be negatively contributing to the receiving environment and further, these ranges are within the historical recording limits.

Electrical conductivity (EC) ranged from 260 to 6640µS/cm, with higher values (maximum of 8230 µS/cm) reported at offsite monitoring locations. Dissolved Oxygen (DO), while being seasonally variable, was comparable between sites. Turbidity values were variable across all sites, which is likely due to discrete weather events (i.e. rainfall) and the settlement process within onsite ponds.

Biannual surface water sampling was completed by RCA in December 2017 and June 2018, with 10 surface water samples collected for analysis and comparison of the results to the trigger levels adopted in the Surface Water Monitoring Plan. The Surface Water Monitoring Program was originally developed in 2012 as an outcome of the Independent Environmental Audit (IEA), as a precautionary measure to assess potential pollutants from the NCIG terminal, that were not investigated as part of monthly water quality monitoring measurements. Surface water samples were collected from operational locations, including the Trade Waste Pond, Wharf Sump, Hunter River Wharf, Rail Settling Basin (WT01) and Clear Water Pond; and from reference locations, including Deep Pond, Delta Pond, Pond I, Black Swan Pond and the Hunter River and compared to trigger values that were either site-specific trigger values or ANZG triggers for protection of 95% Aquatic Species. The median concentration of aluminium, boron, zinc and total phosphorus exceeded the respective ANZG (2018) freshwater trigger value (95% level of protection) at one or more monitoring locations.

In accordance with the Surface Water Monitoring Program, NCIG commissioned a review of the surface water monitoring results, which was completed by Ramboll in November 2018. The 2018 review followed on from previous reviews completed in 2016 and 2017. The 2018 review included data screening of water quality data from December 2017 and June 2018 to remove parameters with insufficient data (>60% non-detects), comparison of surface water quality against established (default) water quality triggers and calculation of site-specific trigger values for parameters that exceeded ANZG (2018) 95% freshwater trigger values (aluminium, boron, zinc, total phosphorous, electrical conductivity, dissolved oxygen, pH and turbidity). Median concentrations of each parameter were then compared to the site-specific trigger values and a trend analysis of the Hunter River reference location completed.

The surface water monitoring review recommended continuation of the six-monthly sampling regime to provide early warning of changing conditions and continued monitoring of aluminium, boron, zinc, total phosphorous, electrical conductivity, dissolved oxygen, pH and turbidity for at least another year to expand the database and strengthen reliability of the site-specific trigger values.

NCIG commissioned a review of the site water balance, surface water reuse efficiency and analysis of stormwater pond expansion, which was completed by AK Environmental in July 2017. The site water balance was developed for the period 19 May 2012 to 6 May 2017 and identified that the annual rate of captured stormwater reuse is 536 ML/year, compared to an average 502 ML/year of imported potable supply. AK Environmental identified two pathways via which surface water reuse efficiency is lost, evaporation and stormwater lost to the Hunter River during an overtopping event.

The hungry boards (weir walls) at Clearwater Pond were to be raised from 2.73 mAHD to 2.83 mAHD to increase pond system capacity by approximately 5.3 ML. AK Environmental assessed the overtopping frequency of Clearwater Pond by re-scaling capacity to 100% at 2.83 mAHD and identified that the additional capacity would have significantly reduced the volume of the January 2016 discharge event but would have only retained a minor portion of the much larger April 2015 event. AK Environmental identified that increasing the height of the hungry boards may provide an additional 7.6 ML/year of stormwater for onsite ruse.

However, as a result of further internal investigations, NCIG installed a concrete weir wall to the height of 3.05 mAHD increasing the pond capacity by a further 12 ML from the original 2.73 mAHD wall height. Further, this increased the volume of stormwater available for onsite reuse and reduced the volume of discharge events.

4.4.3 Reportable Incidents

There were no reportable incidents during the reporting period.

One discharge event occurred during the reporting period. Water quality was sampled and analysed for pH, total suspended solids and oil and grease. The results are provided in **Table 4-7.**

Table 4-7: Discharge Water Quality Monitoring

ANALYSIS	DATE SAMPLED	PH VALUE	TOTAL SUSPENDED SOLIDS	TURBIDITY	OIL & GREASE
UNITS	-	pH unit	mg/L	NTU	mg/L
SW1D (EPL 34)	20/06/18	7.6	11	15	<5
SW5 (EPL 35)	20/06/18	7.94	24	64	<5

4.4.4 Further Improvements

NCIG will continue the Discharge Water Management Project started within the previous reporting period looking to make additional improvements to management of sediment within the NCIG Surface Water Management System.

4.5 GROUNDWATER

4.5.1 Environmental Management Relating to EPL

Changes to EPL 12693 during the 2017 reporting period included expansion of the ongoing groundwater quality monitoring network to include areas adjacent to the NCIG Rail Flyover infrastructure; reduction of monitoring parameters to consolidate the ongoing groundwater monitoring program based on the review of monitoring data; and a change to the actions required to investigate contaminants of concern further based on exceedances during regular groundwater quality monitoring.

These changes to EPL 12693 groundwater monitoring requirements were implemented during the 2017 reporting period and continued throughout the 2018 reporting period.

4.5.2 Environmental Performance Relating to the EPL

Table 4-8: outlines the monitoring locations, groundwater monitoring parameters recorded, frequency of monitoring and groundwater criteria for the Project in accordance with Section M2.2 of EPL 12693.

Table 4-8: Summary of the Groundwater Monitoring Program (EPL)

MONITORING LOCATION^1	FREQUENCY	PARAMETER	UNITS
GW1 (EPL 1) **BH21S (EPL 38)** **BH21D (EPL 39)**	6-monthly	• pH • Electrical Conductivity (EC) • Aluminium • Arsenic • Bromide • Cadmium • Copper • Cyanide (free) • Cyanide (total) • Iron • Manganese • Nickel • Zinc • Total Recoverable Hydrocarbons C6-C9 • Total Recoverable Hydrocarbons C10-C14 • Total Recoverable Hydrocarbons C15-C28 • Total Recoverable Hydrocarbons C29-C36 • Total Polyaromatic Hydrocarbons (PAHs)	- µS/cm mg/L mg/L mg/L mg/L mg/L µg/L µg/L mg/L mg/L mg/L mg/L µg/L µg/L µg/L µg/L µg/L
K9/3N (EPL 20) **K9/3S (EPL 21)** **K11/1 (EPL 22)** **K11/1S (EPL 23)** **BH20S (EPL 36)** **BH20D (EPL 37)** **BH23S (EPL 40)** **BH23D (EPL 41)**	6-monthly	• pH • Electrical Conductivity (EC) • Aluminium • Arsenic • Bromide • Cadmium • Copper • Cyanide (free) • Cyanide (total) • Iron • Manganese • Nickel • Total Polyaromatic Hydrocarbons (PAHs) • Total Recoverable Hydrocarbons C6-C9 • Total Recoverable Hydrocarbons C10-C14 • Total Recoverable Hydrocarbons C15-C28 • Total Recoverable Hydrocarbons C29-C36 • Zinc	- µS/cm mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L mg/L µg/L µg/L µg/L µg/L mg/L
K11/3E (EPL 24) **K11/3W (EPL 25)** **K11/2W (EPL 26)** **K11/2E (EPL 27)** **K9/4W (EPL 28)** **K9/4E (EPL 29)** **K9/2W (EPL 30)** **K9/2E (EPL 31)** **K10/4W (EPL 32)** **DM10 (EPL 33)**	6-monthly if trigger conditions are exceeded at EPL 20, 21, 22, 23, 26, 37, 40 or 41	• pH • Electrical Conductivity (EC) • Aluminium • Arsenic • Bromide • Cadmium • Copper • Cyanide (free) • Cyanide (total) • Iron • Manganese • Nickel • Zinc • Total Recoverable Hydrocarbons C6-C9 • Total Recoverable Hydrocarbons C10-C14 • Total Recoverable Hydrocarbons C15-C28 • Total Recoverable Hydrocarbons C29-C36 • Total Polyaromatic Hydrocarbons (PAHs)	- µS/cm mg/L mg/L mg/L mg/L mg/L µg/L µg/L mg/L mg/L mg/L mg/L µg/L µg/L µg/L µg/L µg/L

1 The location of monitoring sites is shown on **Figure 4-1**

A summary of the groundwater monitoring results recorded during the reporting period is provided in **Table 4-9** with full results provided in **Appendix 4**.

Table 4-9: Summary of Groundwater Monitoring Results (EPL)

MONITORING SITES	DATES OF SAMPLING	EXCEEDANCES OF EPL REQUIREMENTS?	EXCEEDANCES OF OEMP/ OWMP	COMMENTS
GW1 (EPL 1) **BH-21S (EPL 38)** **BH-21D (EPL39)**	6/12/17 14/6/18	N/A	No	
K9/3N (EPL 20)	5/12/17 14/6/18	Yes (initial result)	No	EPL 20 (Conductivity) exceeded Trigger 2 of Condition E1 in the June 2018 monitoring round. The relevant steps in the EPL were followed and the well was re-sampled. The re-sample results fell below Trigger 2, concluding the process at Step 3 of Condition E1.1 with no further action required.
K9/3S (EPL21)	5/12/17 6/6/18	No	No	
K11/1 (EPL 22)	6/12/17 6/6/18	No	Zn	Zinc is one of nine priority analytes. On-going monitoring recommended.
K11/1S (EPL 23)	6/12/17 6/6/18	No	No	
K11/3E (EPL 24) **K11/3W (EPL 25)** **K11/2W (EPL 26)** **K11/2E (EPL 27)** **K9/4W (EPL 28)** **K9/4E (EPL 29)** **K9/2W (EPL 30)** **K9/2E (EPL 31)** **K10/4W (EPL 32)** **DM10 (EPL 33)**	Not required	N/A	N/A	Not required to be sampled as the triggers for further evaluation were not met (Section E1.1 of EPL 12693).
BH-20S (EPL 36)	6/12/17 14/6/18	No	No	
BH-20D (EPL 37)	6/12/17 14/6/18	Yes (initial result)	No	EPL 37 (Nickel) exceeded Trigger 1 of Condition E1 of the EPL in the December 2017 monitoring round. The relevant steps in the EPL were followed and the well was re-sampled. The re-sample results fell below Trigger 1, concluding the EPL process at Step 3 of Condition E1.1 with no further action required.
BH-23S (EPL 40)	6/12/17 14/6/18	Yes (initial result)	No	EPL 40 (Total PAH) exceeded Trigger 1 of Condition E1 in the June 2018 monitoring round. The relevant steps were followed, and the well was re-sampled. The re-sample results fell below Trigger 1, concluding the process at Step 3 of Condition E1.1 with no further action required.
BH-23D (EPL 41)	6/12/17 14/6/18	No	No	

An assessment of the monitoring records found the following:

- That the trigger for further evaluation (as outlined in Section E1.1 of EPL 13693) were met at EPL monitoring points 20, 37 and 40 as described in **Table 4-9**. In each case, re-sampling results were below the trigger level and no further action was required.
- That exceedance of criteria outlined in the OWMP (ANZECC (2000) trigger level for the protection of 95% of marine water species) occurred at Monitoring Point 22 for zinc.
- The zinc exceedance is the same as for the previous reporting period.

4.5.3 Reportable Incidents

No environmental incidents or complaints relating to groundwater quality conditions were made during the reporting period.

4.5.4 Further Improvements

No further improvements to the groundwater monitoring system are currently proposed.

4.6 EROSION AND SEDIMENT CONTROL

4.6.1 Environmental Management

In accordance with Condition 2.42, Schedule 2 of the PA 06_0009 NCIG has designed and constructed surface water and stormwater management infrastructure on the site to accommodate a 1 in 100 annual recurrence interval (ARI) rainfall event.

In accordance with Condition 2.49, Schedule 2 of PA 06_0009, all stormwater and surface water management infrastructure associated with the operation of the site is lined with a low-permeability material to minimise potential leakage. Stormwater is reused onsite for beneficial purposes such as the wetting of coal to reduce dust emissions from the site.

All grey wastewaters from the site are directed to sewer in accordance with a Trade Waste Licence, approved through Hunter Water Corporation, in accordance with Condition 2.51, Schedule 2 of PA 06_0009.

Erosion and sediment control measures and general surface water management measures for the Terminal are documented in the approved OWMP.

4.6.2 Environmental Performance

Table 4-10 Table outlines the monitoring locations, erosion and sediment control parameters recorded, frequency of monitoring and criteria for the Project in accordance with the OWMP. While construction of the NCIG Project was effectively completed prior to the reporting period, a number of erosion and sediment controls remained in-situ during the period.

Table 4-10: Summary of the Erosion and Sediment Control Monitoring Program

MONITORING PARAMETER	MONITORING SITES	FREQUENCY	CRITERIA
Structural stability and effectiveness in controlling sediment migration.	Drainage, erosion and sediment control infrastructure	Following significant rainfall events (i.e. greater than 20mm in 24 hours)	N/A

The management of erosion and sedimentation for the NCIG Project is detailed by the Erosion and Sediment Control Plan (ESCP), part of the OWMP. Activities that have the potential to cause or increase soil erosion at the site were identified as primarily due to exposure of soils during construction activities which are now complete.

However, the following principles continue to underpin the approach to erosion and sediment controls for the NCIG site to protect adjacent wetland areas, Deep Pond and the Hunter River:

- Minimise surface disturbance, and restrict access to undisturbed areas
- Minimise or limit construction/contractor compounds where possible
- Limit soil/material stockpiles and prevent their location within 10 metres (m) of watercourses or stormwater drains
- Separate runoff from disturbed and undisturbed areas where practicable;
- Implementation of surface drains to facilitate the efficient transport of surface runoff and utilisation of existing stormwater systems;
- Implementation of the site drainage network including perimeter bunds, internal bunds, primary settling ponds and hydraulically controlled discharge structures;
- Implementation of silt drains and diversions in areas where sediment basins are not appropriate;
- Implementation of secondary settling ponds, site water ponds and sediment dams to contain runoff from a 1 in 100-year ARI event; and
- Refuel plant and machinery within bunded areas where ever possible, or at least 50m away from waterways.

The above principles take into account the general recommendations for site drainage works presented in Managing Urban Stormwater: Soils and Construction – Volume 1 (Landcom 2004).

While the majority of the site has been stabilised post-construction of the terminal, erosion, sediment and pollution controls will be utilised where major ground disturbance occurs, in accordance with Condition 2.44, Schedule 2 of the Project Approval (06_0009).

NCIG have a network of permanent stormwater structures to manage runoff around the site and all long-term site water management structures are lined with low permeability materials (e.g. compacted clay) to minimise the potential for leakage. Water management structures are designed with sufficient capacity for a 1 in 100 year average recurrence interval (ARI) rainfall event.

4.6.3 Reportable Incidents

No environmental incidents or complaints relating to erosion or sediment control were made during the reporting period.

4.6.4 Further Improvements

NCIG intends to investigate and implement improved management of sediment within sumps and basins across the Terminal within the next reporting period with the aim of improving water quality and reducing the sediment load in the settling ponds.

4.7 NOISE

4.7.1 Environmental Management

In accordance with Condition 2.13, Schedule 2 of the PA 06_0009, Stage 1 of the NCIG Terminal has been designed, constructed, operated and maintained to ensure that the noise contributions from the plant do not exceed the maximum allowable noise contributions specified in **Table 4-11** below, at the locations and the time periods indicated.

In accordance with Condition 2.14, Schedule 2 of PA 06_0009, the monitoring of noise contributions was:

- Measured at the most affected point on or within the Site boundary at the most sensitive receiver to determine compliance with $L_{Aeq(15\ minute)}$ night noise limits.
- Measured at one metre from the dwelling façade to determine compliance with $L_{A1(1\ minute)}$ noise limits.
- Subject to the modification factors provided in Section 4 of the New South Wales Industrial Noise Policy (EPA, 2000), where applicable.

In accordance with Condition 2.15, Schedule 2 of PA 06_0009, NCIG has taken steps to ensure that trains operated on the site meet noise performance criteria established. This included construction of dedicated noise abatement berms directly adjacent the NCIG rail line and design and construction of the rail alignment to reduce noise from locomotive and wagon wheels.

Operations noise management measures are further detailed in the Operations Noise Management Plan (ONMP).

4.7.2 Environmental Performance

Table 4-11 outlines the monitoring locations, noise monitoring parameters recorded, frequency of monitoring and noise and vibration criteria for the Project in accordance with the ONMP.

Table 4-11: Summary of the Noise Monitoring Program

MONITORING PARAMETER	MONITORING SITES	FREQUENCY	CRITERIA
Attended and unattended noise monitoring	Fern Bay West, Fern Bay East, Stockton West, Stockton East, Mayfield West, Mayfield, Carrington	6-monthly	See below
Attended noise monitoring	All static and mobile elements of terminal operations	6-monthly	See ONMP

1 The location of monitoring sites is shown on **Figure 4-1.**

Noise criteria for the site operations, as defined by the Project approval and EPL12693, are provided in **Table 4-12** and **Table 4-13.** Noise monitoring was undertaken by specialist acoustic consultants on a six-monthly basis during the reporting period.

Table 4-12: Residential Noise Criteria

Location	Day/Evening/Night At all times	Night 10:00pm to 7:00am Monday to Saturday 10:00pm to 8:00am on Sundays and Public Holidays	
	$L_{Aeq(15\ minute)}$	$L_{Aeq(night)}$	$L_{A1(1\ minute)}$
Fern Bay West	41	37	57
Fern Bay East	39	36	55
Stockton West	41	37	57
Stockton East	38	35	56
Mayfield West	45	40	55
Mayfield	44	39	62
Carrington	36	33	52

The maximum allowable noise conditions apply under:

a) wind speeds of up to 3 m/s at 10 metres above ground level

b) temperature inversion conditions of up to 3 degrees (°C) pert 10 metres and 2 m/s at 10 metres above ground level.

Table 4-13: Industrial Noise Criteria

NON-RESIDENTIAL LOCATION	LAND USE	INTRUSIVE $L_{\text{AEQ(15 MINUTE)}}$ DAY/EVENING/NIGHT	ACCEPTABLE AMENITY $L_{\text{AEQ(PERIOD)}}$[1]			MAXIMUM AMENITY $LA_{\text{EQ(9 HOUR)}}$
			Day	Evening	Night	Night
Mayfield West	Commercial Steel River	Intrusive noise not applicable	65	65	65	70
Kooragang Island	Industrial	Intrusive noise not applicable	70	70	70	75
Mayfield North		Intrusive noise not applicable	70	70	70	75
Any	School	Intrusive noise not applicable	External 45 when in use	50	-	-
Any	Hospital	Intrusive noise not applicable	External 50 when in use	55	-	-

1: Daytime 7:00am to 6:00pm, Evening 6:00pm to 10:00pm, Night-time 10:00pm to 7:00am.

The monitoring undertaken principally consisted of six-monthly attended noise monitoring. Operator attended noise survey were conducted at each noise logger location to assist in defining noise sources and the character of noise in the area and therefore to qualify unattended noise logging results. All operator-attended noise measurements were conducted using a Bruel and Kjaer Type 2250L Type 1, integrating sound level meter (S/N 3004635) or Bruel and Kjaer Type 2270 Type 1, integrating sound level meter (S/N 2679354).

During the reporting period, offsite noise and onsite sound power monitoring was undertaken and reported biannually, with reports for the period ending December 2017 and June 2018. These reports concluded that offsite noise monitoring indicated compliance was achieved at both selected residential and industrial locations under prevailing conditions (SLR 2018a and SLR 2018b).

4.7.3 Reportable Incidents

No environmental incidents were reported relating to noise or vibration during the reporting period.

4.7.4 Further Improvements

No improvement to noise monitoring is required for the next period. Notwithstanding, NCIG implements a Continuous Noise Improvement Program. The program will continue to be implemented as part of ongoing NCIG operations.

4.8 HERITAGE

4.8.1 Environmental Management

The OEH advised that as the Terminal has been the subject of extensive disturbance over a period of more than 50 years, it considered that no Aboriginal heritage objects of significance would be present (DEC, pers. comm. 15 February 2007).

No items of Aboriginal cultural heritage significance were identified during construction of the Terminal. As construction of the Terminal is now complete and no further ground disturbance is required, it is unlikely that any items of potential Aboriginal cultural heritage significance would be identified in the future. However, induction training attended by all NCIG personnel continues to include information relating to aboriginal heritage and the potential identification of items of archaeological significance.

4.8.2 Environmental Performance

During the reporting period there were no items of potential Aboriginal cultural heritage significance identified.

4.8.3 Reportable Incidents

No incidents or complaints were reported relating to heritage during the reporting period.

4.8.4 Further Improvements

No improvement to heritage is required for the next period.

4.9 ECOLOGY

4.9.1 Environmental Management

The Green and Golden Bell Frog *Litoria aurea* is listed as Endangered under the *Biodiversity Conservation Act 2016* (BC Act) and Vulnerable under the EPBC Act. The Green and Golden Bell Frog is estimated to have disappeared from 90% of its former range within NSW. Known and potential Green and Golden Bell Frog habitat is located across the Terminal site and surrounds and as such NCIG has various commitments to monitoring, management and offsetting of impacts to the Green and Golden Bell Frog.

A management plan for the relocation of Green and Golden Bell Frog individuals was prepared in accordance with Condition 2.16, Schedule 2 of PA 06_0009. The Green and Golden Bell Frog Management Plan (GGBFMP) was developed in consultation with DECC (now OEH) and the Regional Land Management Corporation (now HCCDC). This plan has now been incorporated into the site Ecological and Land Management Plan.

In June 2017, a Memorandum of Understanding (MOU) on the Green and Golden Bell Frog on Kooragang Island was executed between the Office of Environment and Heritage (NSW) and NCIG, PWCS, HDC, BHP Billiton and University of Newcastle. The MOU was developed under the NSW Government's Saving our Species conservation program, which aims to maximise the number of threatened species that can survive in the wild in NSW for 100 years. Kooragang Island is one of seven management sites identified by Office of Environment and Heritage for conservation activities to protect the Green and Golden Bell Frog. The MOU was developed to assist with data sharing from Green and Golden Bell Frog population and habitat monitoring programs completed by University of Newcastle for different stakeholders.

Monitoring and characterisation of the Green and Golden Bell Frog population on Kooragang Island, in and surrounding the industrial part of the island has been completed for the eighth year by the University of Newcastle. This work is being co-funded by NCIG, PWCS and HCCDC. Monitoring continued throughout the summer season and the annual report was finalised in February 2019, including population estimates for the island. A copy of the report is included in **Appendix 5**. Monitoring of the Green and Golden Bell Frog was conducted in areas adjacent to Terminal, particularly areas surrounding the NCIG Rail Facility, as shown in **Figure 4-12**.

The objectives of the monitoring on Kooragang Island are to:

- Calculate a robust evaluation of total Green and Golden Bell Frog population size within Kooragang Island Management Zone.
- Determine the demographic composition of these populations, specifically the ratio of adults to sexually immature juveniles and the ratio of males to females.
- Define the spatial distribution of the Green and Golden Bell Frog population, including assessing where individuals are concentrated and evidence of movement between wetlands and across infrastructure barriers.

NCIG also undertakes a Compensatory Habitat and Ecological Monitoring Program (CHEMP) and reports against the results every six-months. The CHEMPs relevant to the reporting period are included at **Appendix 6** and includes:

1. Kooragang Island Green and Golden Bell Frog Population monitoring, including the quarterly reporting undertaken by the University of Newcastle (Conservation Biology Group): *Green and Golden Bell Frog Research and Monitoring Program on Ash Island*
2. NCIG Green and Golden Bell Frog Compensatory Habitat monitoring and management
3. NCIG Shorebird Compensatory Habitat monitoring and management

To reduce the likelihood of spreading potential infection, all site workers are informed through site inductions of the conservation status of the Green and Golden Bell Frog and the importance of not touching bell frogs without hygiene management training. NCIG HSEC Department representatives receive appropriate hygiene management protocol training in accordance with *Hygiene Protocol for the Control of Disease in Frogs* (NPWS, 2001).

A monitoring program was also conducted during the reporting period to survey the utilisation of Deep Pond, adjacent to the NCIG rail infrastructure area, by bird species with the primary focus on shorebirds. This Avifauna Monitoring Program was undertaken by the Hunter Bird Observers Club and the resulting information was provided to NCIG by way of agreement.

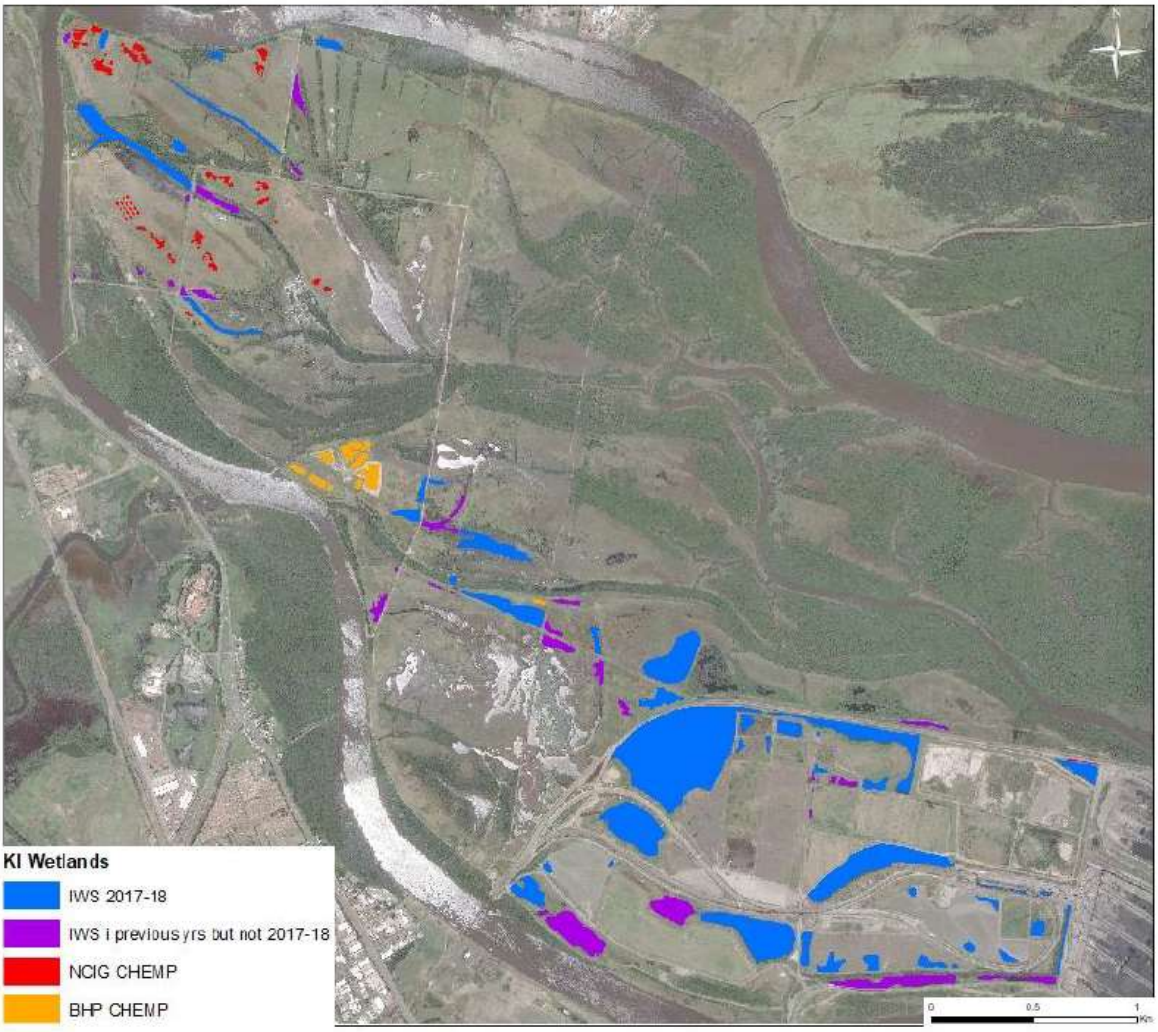


Figure 4-12: Green and Golden Bell Frog Surveyed Areas

Figure 2.1.2: Wetlands of Kooragang Island - showing the 47 wetlands surveyed in the 'island-wide' surveys of 2017-18, along with wetlands that have been surveyed in previous years that were not included in surveys in this year. The positions of NCIG and BHP CHEMP wetlands are also shown; 13 of these wetlands were surveyed as part of the island-wide surveys in 2017-18, making a total of 60 wetlands for which data is presented in this report.

4.9.2 Environmental Performance

4.9.2.1 University of Newcastle Research Program on the Green and Golden Bell Frog (*Litoria aurea*) on Kooragang Island

Two methods were used to estimate the population per surveyed pond, namely Visual Encounter Surveys and Capture-Mark-Recapture Surveys. Both these methods utilise recording of morphometrics of individuals surveyed, location and environmental conditions where individual locations were found and micro-chipping using Passive Induction Transponder (PIT) tags. Both surveys were conducted at night using survey teams of 2-6 people.

Models for population estimates were generated for each surveyed pond using established statistical designs and computer-based modelling software (eg. MARK). These estimates were correlated with results of visual encounter surveys, using a number of assumptions and limiting factors, to generate population estimates for remaining ponds. A full methodology is provided in **Appendix 5**.

A total of 60 wetlands were surveyed during the 2017/2018 breeding season, including 14 in the Northwest region of the island, 15 in the Central region and 31 in the Southern (Industrial Zone) region. Three principal rounds of surveys were completed, Round 1 in late-November to December 2017, Round 2 in January to early February 2018 and Round 3 in February to late-March 2018. The 2017-18 survey season was characterised by low levels of summer rainfall, followed by heavy rain in early and middle autumn.

A summary of the results from the 2017/2018 surveys are as follows:

- Model-estimated population size was approximately 2,000-3,000 across surveyed wetlands. This is similar to population estimates from recent years. Direct survey counts also indicate that there has been no overall decline in population levels in recent years.
- The age (determined by the snout vent length or SVL) distribution across the three main survey rounds was (note: error due to rounding):
  - 28% juvenile
  - 9% subadult female
  - 42% adult male
  - 22% adult female
- The highest number of detections were in the first round (early summer). Detections declined steadily though the second (mid-summer) and third (early autumn) survey rounds. This pattern is consistent with surveys from previous seasons.
- Due to two dry seasons in a row (2016-17 and 2017-18), *Gambusia holbrooki*, an invasive fish species that prey on amphibian tadpoles and eggs, was absent from the majority of wetlands (44/60) by March 2018.
- Successful breeding events were detected in the NCIG CHEMP, BHP CHEMP, and Industrial Zone wetlands. Surveys and demographic analysis identified four main cohorts of recruitment across the 2017-18 season:
  1. GGBF that were spawned in late autumn rain in 2017, and which overwintered as tadpoles to metamorphose in early spring 2017
  2. GGBF spawned in spring rain 2017
  3. GGBF spawned in early summer rain 2017
  4. GGBF spawned in early autumn rain 2018
- On Kooragang Island GGBF are mainly distributed within the Industrial Zone; 2/3 of frogs detected during Visual Encounter Surveys were detected there. Approximately 1/3 of detected frogs were in the Central Zone, mainly within the BHP CHEMP and these wetlands supported GGBF at high densities. Only small numbers of GGBF were detected in the Northern Zone of the island, but nearly all of these were detected at NCIG CHEMP wetlands. Very few GGBF were detected in “natural wetlands” in the Northern zone, and without the NCIG CHEMP wetlands this zone would most likely not support a population.
- Persistence (time between first and last capture of marked individuals) is similar (but not identical) to survivorship. Persistence is generally low, with less than 10% of recaptured GGBF being detected more than 1 year after initial capture, and less than 2% were recaptured after more than 2 years.

4.9.2.2 Compensatory Habitat and Ecological Monitoring Program

In accordance with Condition 2.20, Schedule 2 of PA 06_0009 NCIG developed and submitted for approval a Compensatory Habitat and Ecological Monitoring Program (CHEMP), which details how habitat and ecological values lost as a result of the project will be offset, and how ecological monitoring will be undertaken to inform on-going ecological management.

Historically the CHEMP Update Reports have been prepared quarterly however as of January 2018 reporting was undertaken 6-monthly to coincide with the Consultative Board meetings. As such attached at **Appendix 6** is quarterly reporting for July to December 2017, and 6-monthly reporting for January to June 2018.

A number of works have been undertaken in relation to the CHEMP between June 2017 and June 2018. The following points highlight the major works undertaken and milestones achieved during this reporting period.

Consultative Board –Consultative Board meetings were held on 9 August 2017 and 14 December 2017. The purpose of the Consultative Board meetings are to provide information on the Compensatory Habitat planning works completed to date and provide guidance on works to be completed, particularly in the coming 12 months. The Board consists of representatives from NSW Planning and Environment, NSW Office of Environment and Heritage (National Parks and Wildlife Service), Hunter-Central Rivers Local Land Service, the University of Newcastle, the Department of Planning and Environment Approved Ecologist for the NCIG Project, Hunter Bird Observers Club (HBOC) and NCIG. At each meeting, papers have been presented on a range of topics for the consideration and discussion of Board members. The topics discussed included updates on the Green and Golden Bell Frog and Migratory Shorebird Compensatory Habitat management and monitoring.

Green and Golden Bell Frog Compensatory Habitat Management – NCIG continued monitoring and management of compensatory habitat in accordance with the approved Green and Golden Bell Frog Compensatory Habitat Management Plan. Conservation Volunteers Australia conducted the following work during the reporting period:

- Baiting program for foxes carried out in December 2017 to January 2018 within the Green and Golden Bell Frog Compensatory Habitat and the Migratory Shorebird Habitat
- Revegetation of the Trial Ponds, planting approximately 1900 plants, comprising primarily of native grasses/ground cover in addition to shrubs and trees. This project was concluded in late December 2017, with ongoing maintenance including watering and weed removal resulting in the majority of the plants surviving through the hot and dry summer period.
- Weed control spraying: Priority weeds were targeted including Blackberry, *Juncus acutus*, Bitou Bush and Lantana. The majority of dense infestations of these weeds are now under control and maintenance will be required to control regrowth. Targeted spraying of Alligator Weed was also undertaken, predominantly throughout the eastern extent of the Licence Area. The infestation of Alligator Weed has increased since the recent fire as the ground vegetation was burnt off. Slashing of the vegetation on the interior and exterior of the Frog Fence in stage 1 was also undertaken to ensure vegetation growth does not exceed 300mm, 1m from the fence line.

The deliberately lit fire in February 2018 burnt the vegetation in Stage 1, 2 and 3, and destroyed the Frog Fence in Stage 1 (see **Figure 4-13** and **Figure 4-14**. In consultation with UoN, it was decided that the Frog Fence would be repaired as it is likely to be used in the future for release of excess GGBF spawn and further monitoring of population dynamics. The fence repair works began in June and are almost complete.

Prior to the Frog Fence repairs, bunding was able to be undertaken in Stage 1 (see **Figure 4-15**)**.** The bunding works were completed in June 2018. This bunding will help prevent water bodies connecting during periods of high rainfall, reducing the spread of *Gambusia.*

Figure 4-13: Damage to frog fencing at Stage 1 after the fire

Figure 4-14: Stage 2 after the fire

Figure 4-15: New Bunding at Stage 1

Compensatory Green and Golden Bell Frog Habitat Monitoring – The Green and Golden Bell Frog Research and Monitoring Program on Ash Island was again undertaken by the University of Newcastle (Conservation Biology Group), during January and March 2018. During this period, GGBF were found in 27 of the 42 ponds in the constructed habitats.

A total of 91 GGBF were recorded in the constructed wetlands between the months of January and March 2018. Age and sex classes of GGBF recorded were:

- 55 adult male
- 29 adult female
- 5 juvenile females
- 2 unsexed juveniles

Ponds 1.3, 4.9, 7.2, and 7.3, recorded the largest numbers of GGBF sightings, each with 7 or more observations. These four ponds were all ephemeral and *Gambusia* free at the time of surveys due to complete drying prior to the rain. The locations of these ponds are identified in **Appendix 7**. Eight instances of breeding behaviour were noted, including 7 recordings of males calling and 1 observation of amplexus.

Along with the GGBF, various other species of frogs were observed in the NCIG Compensatory Habitat wetlands. These included the Dwarf Green Tree Frog (*Litoria fallax*), Bleating Tree Frog (Litoria dentata), Emerald Spotted Tree Frog (*Litoria peronii)*, Striped Marsh Frog (*Limnodynastes peronii*), Spotted Marsh Frog (*Limnodynastes tasmaniensis*) and the Common Eastern Froglet (*Crinia signifera*).

Captive Breeding and Release Program – Following our third successful breeding event of the Green and Golden Bell frog, the Captive Breeding and Release Program has now ceased after five consecutive seasons.

Migratory Shorebird Habitat Management – UNSW Water Laboratories were commissioned to develop hydrological controls for ongoing management of the SmartGate. Based on the modelling undertaken by UNSW, two possible Design Tidal Regimes were produced. The first option was to adopt a regime where water levels exceed 0.3 m AHD 2.8% of the time (equivalent to approximately 120 tides per year exceeding 0.3 m AHD), which is equivalent to a natural elevation of 0.75 m AHD (the median level of saltmarsh). The second option was to adopt a tidal regime where water levels exceed 0.3 m AHD 0.6% of the time (equivalent to approximately 50 tides per year exceeding 0.3 m AHD), which is equivalent to the natural elevation of 0.87 m AHD (95th percentile elevation of mangroves).

With the recommendation from UNSW Water Research Laboratory, the first option was adopted. This option provides more inundation area that is suitable for saltmarsh growth. However, if observed mangrove growth is found to be excessive, the second option may need to be reconsidered.

New mangrove growth was removed in December 2017 by Conservation Volunteers Australia. The new growth was collected and counted separately by location and by growth (e.g. root shoots, seed growth or re-shoots from old mangroves), to determine the locations of highest density mangrove recruitment. These results will help to determine how the mangrove regrowth can be most effectively managed. The results can be seen in **Figure 4-16. Figure 4-17** shows the Conservation Volunteers Australia removing mangroves.

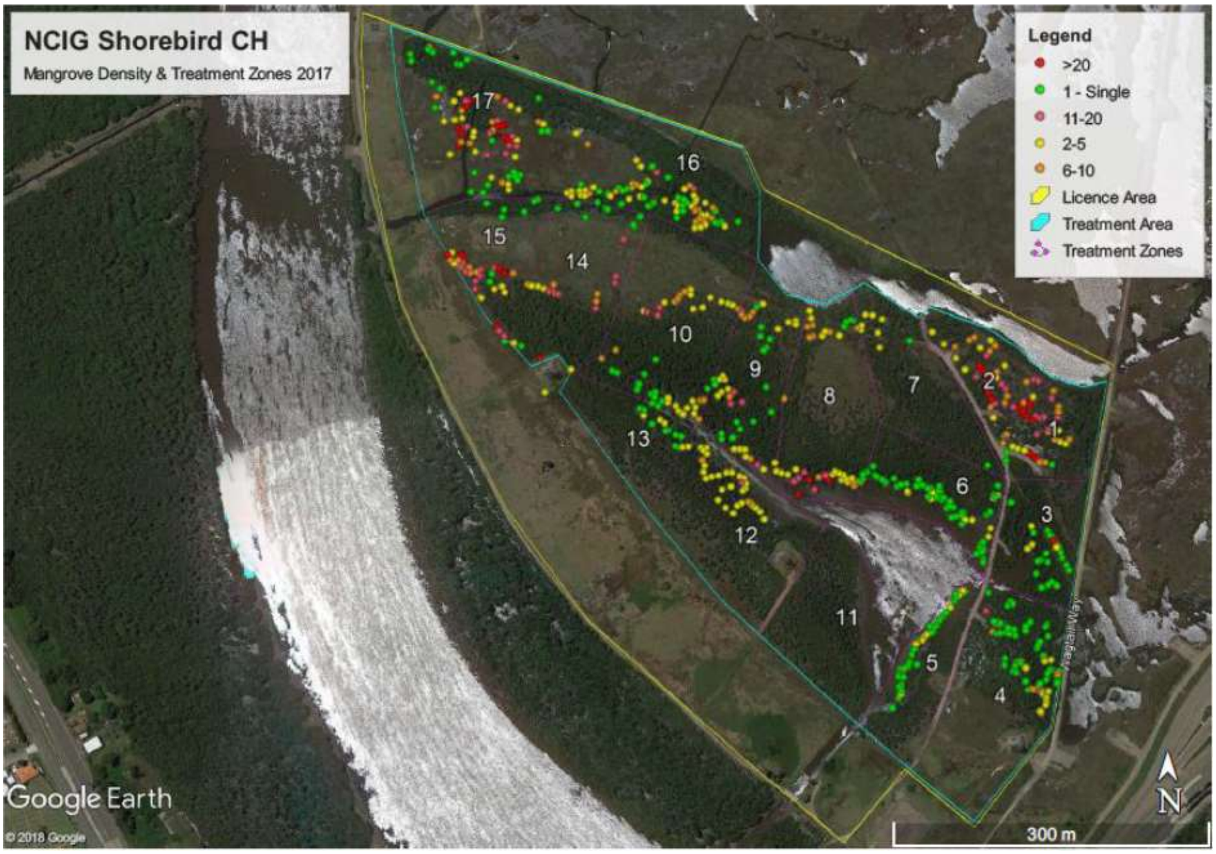


Figure 4-16: Mangroves removed from NCIG Shorebird Compensatory Habitat

Figure 4-17: Conservation Volunteers Australia removing mangroves

Migratory Shorebird Habitat Monitoring – Continuing in accordance with the Shorebird Monitoring Evaluation Reporting and Improvement Plan – fortnightly surveys are taken in September-April (high tide, low tide and nocturnal roosting), and monthly in April-September (high tide and low tide). The 2017 bird survey results (January to December 2017) show that many shorebird species have been observed across all ponds, including Fish Fry Flats as well as neighbouring ponds such as Swan Pond, Wader Pond and North-West Pond. The results show that a diverse range of birds are visiting Fish Fry Flats with 30 water/shorebird observations (including 6 migratory species) during the survey period.

The results of the monthly surveys conducted on Deep Pond North and Deep Pond South during the 2017 calendar year are illustrated by **Table 4-14** and **Table 4-15.** The aim of the monitoring program is to identify the pattern of usage of Deep Pond North and Deep Pond South by all birds over the annual cycle and determined the extent of any potential impact by the NCIG activities on this usage.

A summary of observations by Hunter Bird Observers Club is as follows:

- Two migratory shorebird species were recorded at Deep Pond North in 2017, compared to none in in 2016.
- Four species of resident shorebird were recorded at Deep Pond during 2017, being Masked Lapwing, Black-fronted Dotterel, Black-winged Stilt and Red-necked Avocet. Diversity and abundance were noted to be particularly high early in 2017
- Numerous waterfowl such as ducks, swans and grebes and other waterbirds such as herons, egrets and ibis were recorded in 2017.
- Several species listed as Vulnerable under the *Biodiversity Conservation Act 2016* were observed utilising Deep Pond North during 2017, including White-bellied Sea Eagles, and several Passerine species.

Table 4-14: Avifauna 2017 Monitoring Results – Deep Pond North

	13/01	10/02	10/03	7/04	11/05	23/06	21/07	25/08	22/09	20/10	17/11	15/12	Total
Musk Duck	1					1	1						3
Black Swan	56	5	11	23	20	14	3	4	11	2	8	17	174
Pink-eared Duck		1	86	332									419
Australasian Shoveler		12	146			27	11					2	198
Grey Teal	249	389	399	8	3			2	2			44	1096
Chestnut Teal	282	875	170	32						12		82	1453
Pacific Black Duck	274	88	7		2				4	7	3	21	406
Hardhead		19		224	2	4			19				268
Australasian Grebe				31		2	7			2		4	46
Hoary-headed Grebe		2	1		45	11		21	3	24			107
Little Pied Cormorant				1									1
Great Cormorant	3	1								2		3	9
Little Black Cormorant	26	4							7	8		11	56
Australian Pelican	33	31			2				12	10	6	41	135
Great Egret		1										1	2
Intermediate Egret		1											1
White-faced Heron		4	1										5
Australian White Ibis	7	13	1		7				1	2	2	3	36
Royal Spoonbill	11	27							1		4	11	54
White-bellied Sea-Eagle			1										1
Whistling Kite											1		1
Swamp Harrier		1		2					1		1	1	6
Nankeen Kestrel		1											1
Brown Falcon												1	1
Australian Hobby				1									1
Purple Swamphen	6	6							6				18
Baillon's Crake									1				1
Australian Spotted Crake		1											1
Eurasian Coot			1	38	12	17	35	33	30	25			191
Black-winged Stilt	4	379	32							2	2	235	654
Red-necked Avocet	1	3	124	1								168	297

Black-fronted Dotterel		3	1	22						4	7		37
Red-kneed Dotterel			1										1
Masked Lapwing	8			8	6							4	26
Black-tailed Godwit (Migratory)		89	81									4	174
Common Greenshank (Migratory)			1										1
Caspian Tern		2											2
Whiskered Tern										9			9
Silver Gull	19	1	1		300								321
Total	**980**	**1959**	**1065**	**723**	**399**	**76**	**57**	**60**	**98**	**109**	**34**	**653**	**6213**

Species in bold font are listed as threatened under the NSW Biodiversity Conservation Act 2016 and/or the Environment Protection and Biodiversity Conservation *Act* 1999

Table 4-15: Avifauna 2017 Monitoring Results – Deep Pond South

	13/01	10/02	10/03	7/04	11/05	23/06	21/07	25/08	22/09	20/10	17/11	15/12	Total
Black Swan			35	12	40	18	14	38	27	34	17	18	253
Australasian Shoveler			31					14				4	49
Grey Teal	6		4					11		16	4	18	59
Chestnut Teal			4		6					22			32
Northern Mallard (hybrid birds)			1										1
Pacific Black Duck	1		24	7	10			14		85	11	13	165
Hardhead										2			2
Australasian Grebe				23		4	4	2	2		4		39
Hoary-headed Grebe											1		1
Little Pied Cormorant				2									2
Australian Pelican											2		2
White-necked Heron									1				1
Great Egret					1				1	2	3	1	8
Intermediate Egret						1						2	3
White-faced Heron									1	1		1	3
Australian White Ibis										4	1	4	9
Royal Spoonbill										1	2	3	6
White-bellied Sea-Eagle			1										1
Swamp Harrier										2	1		3
Purple Swamphen	3			8	1	2	3	6	11	26		7	67
Dusky Moorhen										4			4
Eurasian Coot				22						10			32
Black-winged Stilt			5						6	3			14
Masked Lapwing	5		22	2				2		4		38	73
Total	**15**	**0**	**127**	**76**	**58**	**25**	**21**	**87**	**49**	**216**	**46**	**109**	**829**

Species in bold font are listed as threatened under the NSW Biodiversity Conservation Act 2016 and/or the Environment Protection and Biodiversity Conservation *Act* 1999

4.9.3 Reportable Incidents

No incidents or complaints were reported relating to flora and fauna management during the reporting period.

4.9.4 Further Improvements

Works for 2018/ 2019 will include the following:

- Revision of the NCIG Green and Golden Bell Frog Compensatory Habitat Management Plan.
- Continued fox baiting program in collaboration with BHP including NCIG Green and Golden Bell Frog habitat, BHP Green and Golden Bell Frog habitat and NCIG shorebird habitat.
- Mangrove propagule removal to be completed in spring 2018.
- Construction of bunding around Stage 2 of the GGBF habitat ponds.
- Initial review of the Shorebird Habitat Monitoring, Evaluation, Reporting and Improvement Program comparing the results so far against the outcomes, aims and evaluation questions contained in the Evaluation, Reporting and Improvement (MERI) Plan.
- Continued emergent vegetation removal in ponds to promote preferred GGBF habitat.

4.10 WASTE MANAGEMENT

4.10.1 Environmental Management

In accordance with Conditions 2.54 and 2.56, Schedule 2 of the PA 06_0009, waste materials removed from the site were directed to a waste management facility lawfully permitted to accept the materials (waste contractor invoices sighted).

NCIG advised that a target was set for recycling of 65% of the total waste generated onsite. To facilitate this NCIG implemented a soft plastics recycling initiative during the reporting period.

In accordance with Condition 2.57, Schedule 2 of the PA 06_0009, waste was not received at the site during the reporting period.

4.10.2 Environmental Performance

The principles of waste management, being waste avoidance, material reuse and recycling have been adopted by NCIG and all contractors on the site during the reporting period. The focus of this process has been the avoidance of waste, however the recycling of waste products was also actively pursued with paper, aluminium, steel, plastics (hard and soft), timber and glass being the primary materials collected.

A 12,000 litre (L) waste oil tank was installed prior to operations to enable the collection and storage of waste hydrocarbons during Terminal operations, before being removed by licensed waste transporters on a periodic basis. A purpose built oil/water separator system is also operated at the workshop and truck washdown areas, which is inspected and maintained on a regular basis.

A Waste Management Plan has been developed and incorporated into the environmental management system for the operations of the Terminal. Waste volumes are tracked on a monthly basis, with the assistance of NCIG's waste management contractor.

During the preceding reporting period, NCIG completed a waste management review of the Waste Management Plan. Following the review, NCIG implemented additional co-mingled recycling bins, implemented a soft plastics recycling program on site and ran education programs to educate on using the new recycling facilities. As a result of the changes to waste management more than 90,000 kg of waste has been diverted from landfill since July 2017. **Figure 4-18** presents the recycling statistics for the reporting period.

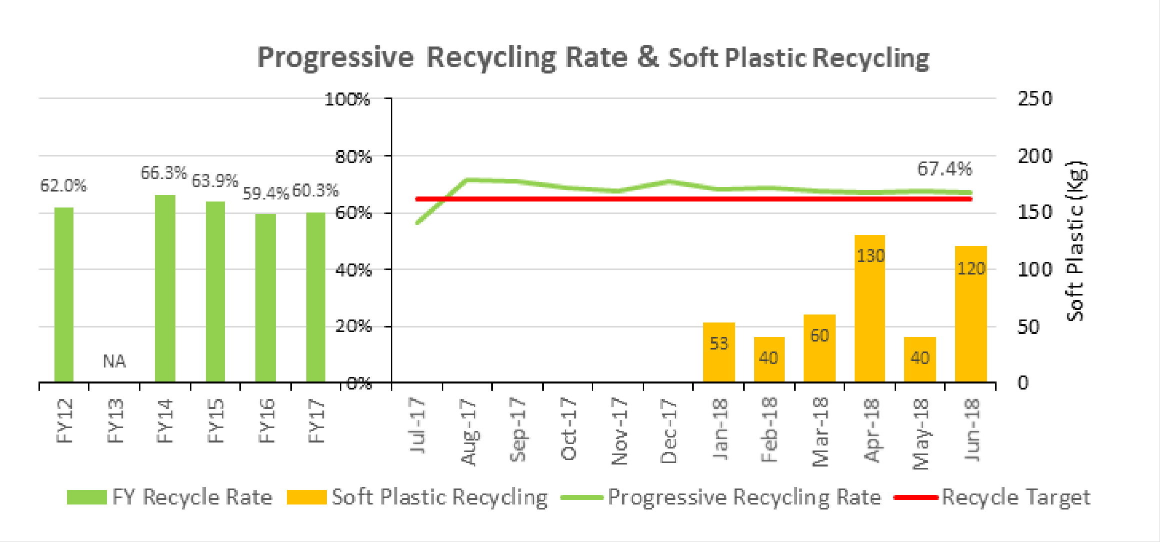


Figure 4-18: Progressive Recycling Rate and Soft Plastics Recycling

4.10.3 Reportable Incidents

No incidents or complaints were reported relating to waste management during the reporting period.

4.10.4 Further Improvements

No further improvements are proposed for the next reporting period.

4.11 COMMUNITY RELATIONS

4.11.1 Environmental Management

The following complaints handling system was maintained during the reporting period implemented:

- In accordance with Conditions 6.2, Schedule 2 of the PA 06_0009, NCIG operates a telephone number, postal address and email address for community complaints and enquiries. Current details are provided below:
  - 24-hour complaints telephone hotline: 1800 016 304
  - Postal address for written complaints: PO Box 644 Newcastle NSW 2300
  - Email address for electronic complaints: enquiries@ncig.com.au
- The community can access these details via the NCIG website (www.ncig.com.au), newsletters and signage from the NCIG site.
- In accordance with Conditions 6.3, Schedule 2 of PA 06_0009, NCIG recorded all complaints received in a Complaints Register.
- In accordance with Condition 6.4 of PA 06_0009, NCIG established and maintains a website for the provision of electronic information associated with the Terminal including all relevant Management Plans.

Upon receiving a complaint all details relating to the issue of concern are recorded in the Complaints Register including:

- The date and time, where relevant, of the complaint
- The means by which the complaint was made (telephone, mail or email)
- Any personal details of the complainant that were provided, or if no details were provided, a note to that effect
- The nature of the complaint
- A record of any operational or meteorological conditions that may have potentially contributed to the complaint

Within seven working days of a complaint being registered, an initial response was provided to the complainant and a preliminary assessment commenced to determine likely causes of the complaint using relevant available information (i.e. climatic conditions, environmental monitoring results and current construction activities).

4.11.2 Environmental Performance

Table 4-16 provides a summary of the complaints received during the reporting period. The outcome of the complaints handling process was recorded in the Complaints Register, including:

- Action taken by NCIG in relation to the complaint, including all follow-up contact with the complainant.
- Details of the finding of the investigation and the reason(s) why no action was taken.

Every effort was made to ensure that the concerns of the complainant were addressed in a manner that resulted in a mutually acceptable outcome.

Table 4-16: Community Complaints Register Summary

DATE OF COMPLAINT	ENVIRONMENTAL CONCERN RAISED	ISSUE	DATE OF FOLLOW UP	ACTION TAKEN
8 August 2017	Stockpile sprays	The Manager HSEC received a call from the Site Manager of a neighbouring business regarding incidences of water landing on their employees' private vehicles. It was alleged that this water was from the NCIG stockyard dust suppression sprays.	8 August 2017	Inspection identified that water and dust landing on the private vehicles was from the NCIG site. Investigation into air quality crossing eastern boundary was to be undertaken. NCIG engaged a consultant to undertake air quality monitoring at Boral in September and October 2017. NCIG then engaged another consultant to undertake a review of the Dust Management System and options for Improvement. A number of options for improvement have been implemented including the introduction of seasonal programming into the algorithm for westerly winds, modification of the dust risk matrix to include high temperatures as new factors in determining dust risk and trialling of stockpile veneering. A number of other recommendations will be introduced and trialled in the near future.
15 November 2017	Coal dust	DPE Officer called the NCIG Manager HSEC regarding an enquiry made by a Fern Bay resident about coal dust.	15 November 2018	NCIG Manager HSEC advised that the dust management system was currently operating as required and no dust issues had been observed. Offered to make contact direct with Fern Bay resident, to which the DPE Officer declined.
23 December 2017	Potential fuel leak	A member of the public was travelling along Cormorant Rd identified and reported a potential leaking fuel pipe near the Coal Loader.	23 December	Investigation by NCIG Process Leader (PL) found no defect on the NCIG site, as reported in the External Enquiry. Suspected water from CV21 sump into BN01 Buffer Bin Sump, which can be seen from Cormorant Rd. Discussed with the crew in the outbound stream, a Technician reported just seeing a defect on a neighbouring business wharf sump pump and water leaking from the discharge of the pump. PL contacted neighbouring business Supervisor and reported the observation and the External Enquiry. The neighbouring business Supervisor later informed the PL, a defect was found on a sump pump, where the discharge line had come free from the pump. All water had been contained within the pond, no leakage to surrounding area.
12 January 2018	Dust on water at K5	Port Authority contacted NCIG regarding dust on the water surface at K5. VTIC pilot was on his way to depart vessel at K6 when he noticed discolouration. Photos taken and sample obtained	12 January	Incident was investigated to determine whether NCIG was a possible source of the dust on the water. The Port Authority referred the issue to the EPA. As there was no evidence of the source of the dust on the water, the EPA did not pursue the incident.
6 February 2018 **(however information only became available to NCIG 12 February 2018)**	Dust	A neighbouring business contacted NCIG regarding a community enquiry they received about dust coming off coal stockpile in the south-west area of the stockyard (adjacent to Windmill and Cormorant road). The neighbouring business passed on the NCIG enquires number to the enquirer.	13 February 2018	The details surrounding the enquiry were investigated. At approximately 5pm (when the enquiry was made) there was an easterly wind of approximately 6 m/s and the western BAM (TH02) had a TSP reading of 64 µg/m3. Although stacking and reclaiming were occurring in the area at this time, there was no excessive spray usage, deducing that the coal being stacked was not dusty. Potential that visible dust may have been generated from the adjacent road works.

NCIG conducted another two rounds of the Community Support Program in the 2018 financial year. This process involved engagement with local community groups and providing support to community-based events and projects. The Program seeks applications on a six-monthly basis from community groups that are seeking support for their endeavours. NCIG undertakes an assessment process and provides primarily financial support to these community events and projects. NCIG participated with the community groups in these project and events wherever possible.

Through this process groups within the Fern Bay, Stockton, Mayfield and greater Newcastle area were assisted by NCIG. A total of $197,980 was contributed through the Community Support Program to groups within the four NCIG community investment focus areas (community, environment, health and education). **Figure 4-19** provides a breakdown of the contributions made to each of the focus areas. A full list of recipients is provided in **Appendix 8**.

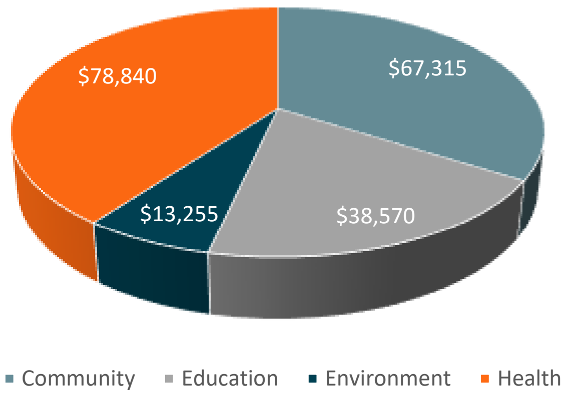


Figure 4-19: Focus area breakdown of contributions through the Community Support Program

The NCIG website answers commonly asked questions and provides opportunities for interested community members to get in contact with NCIG staff.

NCIG prepared a Sustainability Report for the 2018 financial year and this report is available on the NCIG website. The Sustainability Report highlights key achievements consistent with NCIG's Sustainability Development Policy in regard to people, critical infrastructure, the environment and contribution and engagement.

The chronology of community liaison held during the reporting period is outlined in **Table 4-17** below.

Table 4-17: Community Liaison Summary

DATE	TYPE
Spring 2017	Community Newsletter
September 2017	Community Support Program – submissions called, 20 successful applicants.
Summer 2018	Community Newsletter
March 2018	Community Support Program – submissions called, 26 successful applicants.
Autumn 2018	Community Newsletter

4.11.3 Reportable Incidents

No incidents were reported relating to community relations during the reporting period. Complaints received during the period are detailed in the section above.

4.11.4 Further Improvements

During the next reporting period NCIG will include a Community Partnership Program which will extend on the Community Support Program which aims to increase community engagement. The Community Partnership Program is a three year program designed to develop a close association with an organisation or group who is seeking to implement a grassroots project of significance that benefits the wider community.

A strong emphasis will be placed on projects or programs that fall under one of the NCIG community investment focus areas of community, environment, health and education – with applicants assessed on how well they align to these values and how they translate into a project that benefits the broader community.

5. COMPLIANCE AUDITS

Audits were undertaken in relation to NCIG activities which considered the compliance status of the Project for the reporting period. These reviews were conducted to meet the requirements of Condition 5.1 of development Approval 06-009 a) as outlined below:

5.1 The Proponent shall develop and implement a Compliance Tracking Program to track compliance with the requirements of this approval. The Program shall include, but not necessarily limited to:

a) provisions for periodic review of the compliance status of the project against the requirements of this approval;

c) a program for independent auditing at least annually, or as otherwise agreed by the Director-General, in accordance with ISO19011:2002, Guidelines for Quality and/or Environmental Management Systems Auditing.

The details and outcomes of the audits conducted are illustrated below.

Compliance Tracking Program Updated April 2017

A Compliance Tracking Program was set up for the NCIG CET in accordance with Condition 5.1, Schedule 2 of PA 06_009. The Compliance Tracking Program was updated in April 2018. The Compliance Tracking Program indicated that project compliance has been achieved for each condition of the Project Approval with the exception of those items included in **Table 5-1.**

Independent Environmental Audit

An Independent Environmental Audit will be conducted on a 3-yearly basis (as agreed by the Director-General's delegate in a letter dated 14 July 2016) in accordance with Conditions 5.1(c), Schedule 2 of PA06_009. The Independent Environmental Audit will be conducted by a suitability qualified independent person and in accordance with *ISO 19001:2002 Guidelines for Quality and/or Environmental Management Systems Auditing*.

The first Independent Environmental Audit was conducted within 12 months of the commencement of construction. This has been conducted annually until 2015, with the most recent Independent Environmental Audit conducted in November/ December 2015. The next Independent Environmental Audit will be conducted in November 2018 and be reported against in the next AEMR.

Table 5-1: Compliance Status Summary

APPROVAL/LICENCE CONDITION	CONDITION	COMPLIANCE DETAILS	COMPLIANCE STATUS
2.50	In the event that stormwater runoff collection cannot meet the water demand of the Site, treated wastewater, if available from the relevant water authority, shall be used preferentially over potable water for the purposes of dust control, unless otherwise agreed by the Director-General.	**Partial Compliance**. Discussions were held with the Hunter Water Corporation in relation to utilising treated wastewater as a part of the NCIG operations during the early stages of construction. While wastewater is currently available for utlisation, cost and supply management make it an unviable option. Liaison with Hunter Water Corporation is ongoing in relation to this matter.	Cost and supply management make the utilisation of wastewater an unviable option. Liaison with Hunter Water Corporation is ongoing in relation to this matter.
6.2	Prior to the commencement of construction of the project, the Proponent shall ensure that the following are available for community complaints and enquiries for the life of the project (including construction and operation): a) a telephone number on which complaints and enquiries about construction and operational activities at the Site may be registered. b) a postal address to which written complaints and enquires may be sent. c) an email address to which electronic complaints and enquiries may be transmitted. The telephone number, the postal address and the email address shall be displayed on a sign near the entrance to the Site, in a position that is clearly visible to the public, and which clearly indicates the purposes of the sign. This information is also to be provided on the Proponent's website.	**Partial Compliance**. NCIG has established a complaints telephone number (1800 016 304); postal address (PO Box 644 Newcastle 2300) and email address (enquiries@ncig.com.au). The required details are displayed on the NCIG website (www.ncig.com.au). Although, NCIG does not currently have a sign displayed near the entrance with the required details. This has now been rectified.	NCIG complaints facilities have been maintained, including a 24-hour complaints telephone number (1800 016 304); postal address (PO Box 644 Newcastle 2300), email address (enquiries@ncig.com.au) and NCIG website (www.ncig.com.au). All complaints that have been received are managed through these facilities. NCIG have re-installed signage with relevant contact details.

6. STANDARDS

Accreditation of the NCIG Environmental Management System (EMS) against the ISO14001 standard was maintained in March 2018. This included an onsite audit. Evidence was viewed by Ramboll personnel as part of this AEMR.

7. ACTIVITIES PROPOSED IN NEXT AEMR PERIOD

The principal elements of activities proposed within the next reporting period are:

- Continued operation and maintenance of the full 66 Mtpa capacity Coal Export Terminal.
- Further development and continuous improvement of the NCIG Environmental Management System.
- Ongoing incorporation of dust management technologies and controls recommended under the Review of the Integrated Dust Management System and Options for Improvements (Red Planet Innovations 2018) to continue to improve the management practices for air quality.
- Improvements to sediment management within onsite water management infrastructure.
- NCIG intend to update their community strategy to include Community Partnerships and further community engagement.
- Undertake the 2018 Independent Environmental Audit in accordance with Conditions 5.1(c), Schedule 2 of PA06_009.

8. REFERENCES

AK Environmental (July 2017) Review of Site Surface Water Reuse Efficiency and Cost-benefit Analysis of Stormwater System Pond Expansion

Hunter Bird Observers Club (March 2018) Deep Pond (Kooragang Island) Avifauna Data Summary 2017

NCIG (2016) Corporate Sustainability Report

NCIG (2018) Compliance Tracking Program

NCIG (December 2016) Compensatory Habitat and Ecological Monitoring Program – Half-yearly Report (January – June 2018)

NSW Planning and Environment (June 2017) Newcastle Coal Infrastructure Group (NCIG) Coal Export Terminal (MP06_0009) Compensatory Habitat Program (Condition 2.20)

Ramboll (December 2018) Draft NCIG Surface Water Monitoring Data Review 2018

Red Planet Innovations (2018) Review of the Integrated Dust Management System and Options for Improvements

SLR (2018a) Newcastle Coal Export Terminal, Biannual Off-site Noise and On-site Sound Power Monitoring, July to December 2017

SLR (2018b) Newcastle Coal Export Terminal, Biannual Off-site Noise and On-site Sound Power Monitoring, January 2018 to June 2018

University of Newcastle (February 2019) Research Program on the Green and Gold Bell Frog (Litoria aurea) on Kooragang Island Annual Report (2017-2018)

9. LIMITATIONS

Ramboll Australia Pty Ltd (Ramboll) prepared this report in accordance with the scope of work as outlined in our proposal to NCIG dated August 2018 and in accordance with our understanding and interpretation of current regulatory standards.

The conclusions presented in this report represent Ramboll's professional judgment based on information made available during the course of this assignment and are true and correct to the best of Ramboll's knowledge as at the date of the assessment.

Ramboll did not independently verify all of the written or oral information provided to Ramboll during the course of this investigation. While Ramboll has no reason to doubt the accuracy of the information provided to it, the report is complete and accurate only to the extent that the information provided to Ramboll was itself complete and accurate.

This report does not purport to give legal advice. This advice can only be given by qualified legal advisors.

9.1 USER RELIANCE

This report has been prepared exclusively for NCIG and may not be relied upon by any other person or entity without Ramboll Australia's express written permission.

APPENDIX 1

METEOROLOGICAL (OTHER THAN RAINFALL) SUMMARY

TABLE A1.1 METEOROLOGICAL STATISTICS BY MONTH

MONTH	WIND SPEED			SIGMA THETA			SOLAR RADIATION		
	Monthly average m/s	Hourly min m/s	Hourly max m/s	Monthly average	Hourly min	Hourly max	Monthly average W/m²	Hourly min W/m²	Hourly max W/m²
July 2017	3.2	0.2	10.8	14.7	2.8	93.6	14.7	0.0	662
August 2017	3.8	0.2	13.9	15.9	3.2	98.6	155	0.0	836
September 2017	3.8	0.2	12.28	16.4	3.5	85.6	210.2	0.0	805
October 2017	3.9	0.3	7.4	6.9	0.1	87.6	170.5	0.0	902
November 2017	4.4*	4.4*	4.4*	0.1*	0.1*	0.1*	170*	170*	170*
December 2017	3.4	0.1	9.9	19.2	0.1	94.3	252.9	0.0	1235
January 2018	3.7	0.3	10.9	18.2	4.6	87	275.5	0.0	1272
February 2018	3.4	0.2	8.6	17.8	5.4	93.8	247.7	0.0	1190
March 2018	3.3	0.1	9.3	18.2	5.6	93.8	203.5	0.0	1083
April 2018	3	0.1	13.1	19.3	2.8	84.2	166.7	0.0	855
May 2018	3	0.3	12.4	16.6	3.4	93.4	124.9	0.0	656
June 2018	3.1	0.3	11.8	18.6	3.6	95.7	86	0.0	694

*Equipment malfunction

TABLE A1.2 METEOROLOGICAL STATISTICS BY MONTH

MONTH	TEMPERATURE AT 2M ELEVATION (T2)			TEMPERATURE AT 10 M ELEVATION (T10)				
	Monthly average °C	Hourly min °C	Hourly max °C	Monthly average °C	Hourly min °C	Hourly max °C	Number of hours when $T_{10}>T_2$. Hours	% of month
July 2017	12.9	5.1	23.3	12.9	5.1	23.3	156	21
August 2017	13.9	6.4	27.4	13.9	6.4	27.4	169	23
September 2017	17.4	6.5	32.7	17.4	6.5	32.7	165	23
October 2017	20.1	10.8	36.0	20.1	10.8	36.0	331	45
November 2017	20.3	12.2	30.8	20.3	12.2	30.8	430	61
December 2017	24.1	17.1	42.6	24.1	17.1	42.6	41	6
January 2018	24.4	14.4	42.1	24.4	14.4	42.1	33	4
February 2018	23.7	16.5	36.2	23.7	16.5	36.2	48	7
March 2018	23.6	16.2	37.7	23.6	16.2	37.7	38	5
April 2018	21.6	14.0	33.9	21.6	14.0	33.9	65	9
May 2018	16.1	8.6	26.4	16.1	8.6	26.4	71	10
June 2018	13.5	6.8	19.8	13.5	6.8	19.8	57	8

APPENDIX 2

DUST DEPOSITION MONITORING RESULTS

TABLE A2.2 DUST DEPOSITION BY MONTH

Month	Limit	DDG-CI (Stockton)	DDG-KI (Stockton)	DDG K8 (Fern Bay)	DG3 (KI)	DG4 (Mayfield)	DG5 (Mayfield)	DG6 (Sandgate)
Jul-17	4	1.8	0.7	0.9	0.7	0.5	1.1	1.0
Aug-17	4	0.4	0.7	**4.6***	0.8	0.8	1.1	1.9
Sep-17	4	0.5	0.8	0.9	1.1	1.4	1.4	2.2
Oct-17	4	0.3	0.8	1.0	2.2	1.6	1.4	3.0
Nov-17	4	**3.4****	0.6	1.1	0.8	1.5	1.4	2.4
Dec-17	4	**6.9****	0.8	3.0	0.9	1.5	1.5	1.8
Jan-18	4	1.1	0.7	0.8	0.9	2.0	1.5	2.2
Feb-18	4	0.8	0.9	0.9	0.6	1.6	1.7	1.1
Mar-18	4	0.6	1.2	1.5	0.6	1.6	1.7	1.1
Apr-18	4	0.9	1.0	0.9	0.8	0.9	1.2	2.0
May-18	4	0.2	0.6	0.8	1.0	0.7	1.1	2.1
Jun-18	4	0.3	0.4	1.0	**15.2****	1.6	0.5	0.3

Bold = exceeding criteria

*Sand

**Insect and bird droppings

***NS – No Sample

APPENDIX 3

SURFACE WATER MONITORING RESULTS

TABLE A3.1 SURFACE WATER RESULTS FOR PH

	pH	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18
SW1(a)	Pond 1	8.39	8.28	8.37	8.58	8.14	8.11	8.71	7.9	8.02	7.51	7.98	7.85
SW1(b)	Pond 2	8.45	8.37	8.38	8.51	8.34	8.26	8.68	7.81	8.13	7.63	8	7.55
SW1(c)	Pond 3	8.39	8.36	8.31	8.55	8.59	8.35	8.68	7.63	8.18	7.67	8.08	7.55
SW1(d)	Clearwater	8.18	8.33	8.33	7.93	8.95	8.06	DRY	7.57	8.21	7.94	8.1	7.81
SW2	Black Swan Pond	8.25	8.58	9.81	5.41	9.44	9.78	9.14	DRY	9.42	8.64	8.75	9.04
SW3	Deep Pond	8.15	8.73	9.35	8.8	8.88	8.99	10.71	DRY	DRY	8.7	8.17	8.59

TABLE A3.2 SURFACE WATER RESULTS FOR ELECTRICAL CONDUCTIVITY

	EC (mS/cm)	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18
SW1(a)	Pond 1	1760	1870	1830	1610	713	1100	1410	1120	1440	284	1610	829
SW1(b)	Pond 2	1740	1910	1710	1790	791	1340	1290	781	1610	260	971	415
SW1(c)	Pond 3	1460	1730	1850	2320	1160	1770	1550	452	1470	271	1110	459
SW1(d)	Clearwater	718	1430	3070	6640	4170	4120	DRY	503	1710	674	1040	780
SW2	Black Swan Pond	1260	1500	1580	1980	2030	2030	4070	DRY	67	1220	935	802
SW3	Deep Pond	2040	1620	1610	2224	4110	4880	7470	DRY	DRY	7580	8230	7050

TABLE A3.3 SURFACE WATER RESULTS FOR TURBIDITY

	Turbidity (NTU)	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18
SW1(a)	Pond 1	178	536	327	243	794	426	190	155	741	>1000	143	476
SW1(b)	Pond 2	56	168	95	75	442	138	73	252	65	>1000	162	639
SW1(c)	Pond 3	66	275	>1000	268	150	470	175	458	360	>1000	101	574
SW1(d)	Clearwater	90	555	608	303	68	226	DRY	296	315	189	62	243
SW2	Black Swan Pond	1	1	<1	46	36	10	180	DRY	189	6	2	2
SW3	Deep Pond	19	3	3	32	42	105	398	DRY	DRY	21	10	12

TABLE A3.4 SURFACE WATER RESULTS FOR TEMPERATURE

	Water Temp (°C)	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18
SW1(a)	Pond 1	13.5	14.4	16.6	22	25.9	22.7	27.5	29.0	22.0	29.0	20.0	18.0
SW1(b)	Pond 2	13.1	14.2	16.5	22.3	26.6	23.7	27.9	29.0	22.0	29.0	19.0	18.0
SW1(c)	Pond 3	13.1	14.2	16.5	21.8	25.9	24.4	28.4	28.5	22.0	28.0	19.0	18.0
SW1(d)	Clearwater	13.4	14.8	17.7	20.1	31.9	22.5		30.0	21.0	28.0	19.0	15.0
SW2	Black Swan Pond	13.4	14.1	17.5	21.8	24.3	24.4	26.1		22.0	25.0	18.0	16.0
SW3	Deep Pond	14.0	14.6	19	21	26.4	28.1	30.1			26.0	21.0	17.0

APPENDIX 4

GROUNDWATER MONITORING RESULTS

GW1			Dec-17	Jun-18
ANALYSIS	**UNITS**	**LOR**	**GW1**	**GW1**
Sample Number			121710481003	061810481048
Date Sampled			6/12/17	14/06/18
Sampled By			LS/KH	CR/KH
Time Sampled			11:41	11:53
pH Value	pH unit		7.42	7.44
Conductivity	µS/cm		13000	13100
Temperature	°C		20.6	20.7
Bromide	mg/L	0.01	10.4	11.2
Dissolved Metals				
Aluminium	mg/L	0.01	<0.01	<0.01
Arsenic	mg/L	0.001	<0.001	<0.001
Cadmium	mg/L	0.0001	<0.0001	<0.0001
Copper	mg/L	0.001	<0.001	<0.001
Manganese	mg/L	0.001	0.203	0.203
Nickel	mg/L	0.001	<0.001	<0.001
Zinc	mg/L	0.005	0.007	0.011
Iron	mg/L	0.05	<0.05	<0.05
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	<0.004	<0.004
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	<1.0	<1.0
Acenaphthylene	µg/L	1	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0
Phenanthrene	µg/L	1	<1.0	<1.0
Anthracene	µg/L	1	<1.0	<1.0
Fluoranthene	µg/L	1	<1.0	<1.0
Pyrene	µg/L	1	<1.0	<1.0
Benz(a)anthracene	µg/L	1	<1.0	<1.0
Chrysene	µg/L	1	<1.0	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0
Sum of PAHs	µg/L	0.5	<0.5	<0.5
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	<50	<50
C15 - C28 Fraction	µg/L	100	<100	<100
C29 - C36 Fraction	µg/L	50	<50	<50
C10 - C36 Fraction (sum)	µg/L	50	<50	<50
BTEX				
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1

K9/3N			Bi-Annual Monitoring Dec-17	Bi-Annual Monitoring Jun-18
ANALYSIS	**UNITS**	**LOR**	**K9/3N**	**K9/3N**
Sample Number			121710481004	061810481049
Date Sampled			5/12/17	14/06/18
Sampled By			CR/LS	CR/KH
Time Sampled			12:49	14:00
pH Value	pH unit		7.06	6.97
Conductivity	µS/cm		26300	27400
Temperature	°C		21.4	19.8
Bromide	mg/L	0.01	20.8	24.5
Dissolved Metals				
Aluminium	mg/L	0.01	<0.01	<0.01
Arsenic	mg/L	0.001	<0.001	<0.001
Cadmium	mg/L	0.0001	<0.0001	<0.0001
Copper	mg/L	0.001	<0.001	<0.001
Manganese	mg/L	0.001	1.53	1.22
Nickel	mg/L	0.001	0.002	0.001
Zinc	mg/L	0.005	0.008	<0.005
Iron	mg/L	0.05	<0.05	0.12
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	<0.004	<0.004
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	<1.0	<1.0
Acenaphthylene	µg/L	1	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0
Phenanthrene	µg/L	1	<1.0	<1.0
Anthracene	µg/L	1	<1.0	<1.0
Fluoranthene	µg/L	1	<1.0	<1.0
Pyrene	µg/L	1	<1.0	<1.0
Benz(a)anthracene	µg/L	1	<1.0	<1.0
Chrysene	µg/L	1	<1.0	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0
Sum of PAHs	µg/L	0.5	<0.5	<0.5
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	<50	<50
C15 - C28 Fraction	µg/L	100	<100	<100
C29 - C36 Fraction	µg/L	50	<50	<50
C10 - C36 Fraction (sum)	µg/L	50	<50	<50
BTEX				
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1

K9/3S			Dec-17	Jun-18
ANALYSIS	UNITS	LOR	K9/3S	K9/3S
Sample Number			121710481005	0618104810450
Date Sampled			5/12/17	14/06/18
Sampled By			CR/LS	CR/KH
Time Sampled			11:52	14:45
pH Value	pH unit		8.1	7.94
Conductivity	µS/cm		5730	2840
Temperature	°C		22	18.7
Bromide	mg/L	0.01	4.61	2.11
Dissolved Metals				
Aluminium	mg/L	0.01	<0.01	<0.01
Arsenic	mg/L	0.001	0.003	0.004
Cadmium	mg/L	0.0001	<0.0001	<0.0001
Copper	mg/L	0.001	<0.001	<0.001
Manganese	mg/L	0.001	0.238	0.052
Nickel	mg/L	0.001	0.001	<0.001
Zinc	mg/L	0.005	<0.005	<0.005
Iron	mg/L	0.05	<0.05	0.06
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	<0.004	<0.004
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	<1.0	<1.0
Acenaphthylene	µg/L	1	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0
Phenanthrene	µg/L	1	<1.0	<1.0
Anthracene	µg/L	1	<1.0	<1.0
Fluoranthene	µg/L	1	<1.0	<1.0
Pyrene	µg/L	1	<1.0	<1.0
Benz(a)anthracene	µg/L	1	<1.0	<1.0
Chrysene	µg/L	1	<1.0	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0
Sum of PAHs	µg/L	0.5	<0.5	<0.5
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	<50	<50
C15 - C28 Fraction	µg/L	100	<100	<100
C29 - C36 Fraction	µg/L	50	<50	<50
C10 - C36 Fraction (sum)	µg/L	50	<50	<50
BTEX				
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1

K11/1			Dec-17	Jun-18
ANALYSIS	UNITS	LOR	K11/1	K11/1
Sample Number			121710481006	061810481051
Date Sampled			6/12/17	14/06/18
Sampled By			LS/MD	CR/KH
Time Sampled			15:38	13:20
pH Value	pH unit		7.12	7.32
Conductivity	µS/cm		954	1630
Temperature	°C		21	19.8
Bromide	mg/L	0.01	0.176	1.07
Dissolved Metals				
Aluminium	mg/L	0.01	<0.01	<0.01
Arsenic	mg/L	0.001	<0.001	<0.001
Cadmium	mg/L	0.0001	<0.0001	<0.0001
Copper	mg/L	0.001	<0.001	<0.001
Manganese	mg/L	0.001	0.972	0.947
Nickel	mg/L	0.001	<0.001	0.001
Zinc	mg/L	0.005	0.008	0.021
Iron	mg/L	0.05	<0.05	0.08
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	<0.004	<0.004
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	<1.0	<1.0
Acenaphthylene	µg/L	1	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0
Phenanthrene	µg/L	1	<1.0	<1.0
Anthracene	µg/L	1	<1.0	<1.0
Fluoranthene	µg/L	1	<1.0	<1.0
Pyrene	µg/L	1	<1.0	<1.0
Benz(a)anthracene	µg/L	1	<1.0	<1.0
Chrysene	µg/L	1	<1.0	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0
Sum of PAHs	µg/L	0.5	<0.5	<0.5
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	<50	<50
C15 - C28 Fraction	µg/L	100	<100	<100
C29 - C36 Fraction	µg/L	50	<50	<50
C10 - C36 Fraction (sum)	µg/L	50	<50	<50
BTEX				
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1

K11/1S			Dec-17	Jun-18
ANALYSIS	UNITS	LOR	K11/1S	K11/1S
Sample Number			121710481007	061810481052
Date Sampled			6/12/17	14/06/18
Sampled By			LS/MD	CR/KH
Time Sampled			16:18	12:32
pH Value	pH unit		7.65	7.83
Conductivity	µS/cm		13100	12600
Temperature	°C		20.3	20.2
Bromide	mg/L	0.01	11.2	12.5
Dissolved Metals				
Aluminium	mg/L	0.01	<0.01	<0.01
Arsenic	mg/L	0.001	<0.001	<0.001
Cadmium	mg/L	0.0001	<0.0001	<0.0001
Copper	mg/L	0.001	<0.001	<0.001
Manganese	mg/L	0.001	0.191	0.149
Nickel	mg/L	0.001	0.003	<0.001
Zinc	mg/L	0.005	<0.005	<0.005
Iron	mg/L	0.05	0.06	0.06
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	0.006	0.007
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	<1.0	<1.0
Acenaphthylene	µg/L	1	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0
Phenanthrene	µg/L	1	<1.0	<1.0
Anthracene	µg/L	1	<1.0	<1.0
Fluoranthene	µg/L	1	<1.0	<1.0
Pyrene	µg/L	1	<1.0	<1.0
Benz(a)anthracene	µg/L	1	<1.0	<1.0
Chrysene	µg/L	1	<1.0	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0
Sum of PAHs	µg/L	0.5	<0.5	<0.5
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	<50	<50
C15 - C28 Fraction	µg/L	100	<100	<100
C29 - C36 Fraction	µg/L	50	<50	<50
C10 - C36 Fraction (sum)	µg/L	50	<50	<50
BTEX				
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1

BH20S			Dec-17	Jun-18
ANALYSIS	**UNITS**	**LOR**	**BH20S**	**BH20S**
Sample Number			121710481008	061810481053
Date Sampled			6/12/17	14/06/18
Sampled By			LS/KH	CR/KH
Time Sampled			13:56	13:10
pH Value	pH unit		7.18	6.79
Conductivity	µS/cm		3440	1500
Temperature	°C		19.3	19.2
Bromide	mg/L	0.01	0.687	0.278
Dissolved Metals				
Aluminium	mg/L	0.01	<0.01	<0.01
Arsenic	mg/L	0.001	0.003	0.002
Cadmium	mg/L	0.0001	<0.0001	0.0002
Copper	mg/L	0.001	<0.001	0.003
Manganese	mg/L	0.001	7.17	2.34
Nickel	mg/L	0.001	0.004	0.006
Zinc	mg/L	0.005	0.015	0.068
Iron	mg/L	0.05	0.61	<0.05
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	<0.004	<0.004
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	<1.0	<1.0
Acenaphthylene	µg/L	1	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0
Phenanthrene	µg/L	1	5.1	<1.0
Anthracene	µg/L	1	<1.0	<1.0
Fluoranthene	µg/L	1	1.9	<1.0
Pyrene	µg/L	1	2	<1.0
Benz(a)anthracene	µg/L	1	<1.0	<1.0
Chrysene	µg/L	1	<1.0	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0
Sum of PAHs	µg/L	0.5	9	<0.5
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	<50	60
C15 - C28 Fraction	µg/L	100	800	460
C29 - C36 Fraction	µg/L	50	470	100
C10 - C36 Fraction (sum)	µg/L	50	1270	620
BTEX				
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1

BH20D			Bi-Annual Monitoring Dec-17	Re-Sample Feb-17	Bi-Annual Monitoring Jun-18
ANALYSIS	**UNITS**	**LOR**	**BH20D**	**BH20D**	**BH20D**
Sample Number			121710481009	021810481001	061810481054
Date Sampled			6/12/17	5/02/18	14/06/18
Sampled By			LS/KH	KH/NH	CR/KH
Time Sampled			13:24	14:00	12:30
pH Value	pH unit		6.47	6.52	6.53
Conductivity	µS/cm		476000		49900
Temperature	°C		19.9		19.8
Bromide	mg/L	0.01	42.1		62.2
Dissolved Metals					
Aluminium	mg/L	0.01	<0.10		<0.10
Arsenic	mg/L	0.001	<0.010		<0.010
Cadmium	mg/L	0.0001	<0.0010		<0.0010
Copper	mg/L	0.001	<0.010		<0.010
Manganese	mg/L	0.001	6.73		6.58
Nickel	mg/L	0.001	0.013	0.0073	<0.010
Zinc	mg/L	0.005	<0.050		<0.050
Iron	mg/L	0.05	23		16.9
Cyanide					
Free Cyanide	mg/L	0.004	<0.004		<0.004
Total Cyanide	mg/L	0.004	<0.004		<0.004
Polynuclear Aromatic Hydrocarbons					
Naphthalene	µg/L	1	<1.0		<1.0
Acenaphthylene	µg/L	1	<1.0		<1.0
Acenaphthene	µg/L	1	<1.0		<1.0
Fluorene	µg/L	1	<1.0		<1.0
Phenanthrene	µg/L	1	<1.0		<1.0
Anthracene	µg/L	1	<1.0		<1.0
Fluoranthene	µg/L	1	<1.0		<1.0
Pyrene	µg/L	1	<1.0		<1.0
Benz(a)anthracene	µg/L	1	<1.0		<1.0
Chrysene	µg/L	1	<1.0		<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0		<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0		<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5		<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0		<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0		<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0		<1.0
Sum of PAHs	µg/L	0.5	<0.5		<0.5
Total Petroleum Hydrocarbons					
C6 - C9 Fraction	µg/L	20	<20		<20
C10 - C14 Fraction	µg/L	50	<50		<50
C15 - C28 Fraction	µg/L	100	<100		<100
C29 - C36 Fraction	µg/L	50	<50		<50
C10 - C36 Fraction (sum)	µg/L	50	<50		<50
BTEX					
Benzene	µg/L	1	<1		<1
Toluene	µg/L	2	<2		<2
Ethylbenzene	µg/L	2	<2		<2
meta- & para-Xylene	µg/L	2	<2		<2
ortho-Xylene	µg/L	2	<2		<2
Total Xylenes	µg/L	2	<2		<2
Sum of BTEX	µg/L	1	<1		<1

H21S			Dec-17	Jun-18
ANALYSIS	**UNITS**	**LOR**	**BH21S**	**BH21S**
Sample Number			121710481010	061810481055
Date Sampled			6/12/17	14/06/18
Sampled By			LS/KH	CR/KH
Time Sampled			12:19	10:35
pH Value	pH unit		11.15	10.92
Conductivity	µS/cm		1310	986
Temperature	°C		20.7	21.2
Bromide	mg/L	0.01	0.898	0.826
Dissolved Metals				
Aluminium	mg/L	0.01	0.5	0.35
Arsenic	mg/L	0.001	0.004	0.006
Cadmium	mg/L	0.0001	<0.0001	0.0001
Copper	mg/L	0.001	<0.001	<0.001
Manganese	mg/L	0.001	<0.001	0.001
Nickel	mg/L	0.001	0.004	0.003
Zinc	mg/L	0.005	<0.005	<0.005
Iron	mg/L	0.05	0.06	0.07
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	0.284	0.316
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	39.8	22.4
Acenaphthylene	µg/L	1	4.1	4.7
Acenaphthene	µg/L	1	3.3	3.2
Fluorene	µg/L	1	5.8	6.1
Phenanthrene	µg/L	1	23.6	18.7
Anthracene	µg/L	1	7.4	2.7
Fluoranthene	µg/L	1	16.6	10.6
Pyrene	µg/L	1	13.6	8.9
Benz(a)anthracene	µg/L	1	4.1	3.7
Chrysene	µg/L	1	4	2.9
Benzo(b+j)fluoranthene	µg/L	1	3.9	2.9
Benzo(k)fluoranthene	µg/L	1	1.7	1.4
Benzo(a)pyrene	µg/L	0.5	2.7	2.7
Indeno(1.2.3.cd)pyrene	µg/L	1	2	2.3
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	2.4	2.5
Sum of PAHs	µg/L	0.5	135	95.7
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	190	370
C15 - C28 Fraction	µg/L	100	470	590
C29 - C36 Fraction	µg/L	50	280	140
C10 - C36 Fraction (sum)	µg/L	50	940	1100
BTEX				
Benzene	µg/L	1	2	1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	3	2
Total Xylenes	µg/L	2	3	2
Sum of BTEX	µg/L	1	5	3

BH21D			Dec-17	Jun-18
ANALYSIS	**UNITS**	**LOR**	**BH21D**	**BH21D**
Sample Number			121710481011	061810481056
Date Sampled			6/12/17	14/06/18
Sampled By			LS/KH	CR/KH
Time Sampled			14:00	10:45
pH Value	pH unit		7.11	7.12
Conductivity	µS/cm		14900	16300
Temperature	°C		21.8	20.8
Bromide	mg/L	0.01	14	14.6
Dissolved Metals				
Aluminium	mg/L	0.01	<0.01	<0.01
Arsenic	mg/L	0.001	0.001	0.001
Cadmium	mg/L	0.0001	<0.0001	<0.0001
Copper	mg/L	0.001	<0.001	<0.001
Manganese	mg/L	0.001	0.437	0.406
Nickel	mg/L	0.001	0.002	<0.001
Zinc	mg/L	0.005	<0.005	<0.005
Iron	mg/L	0.05	0.11	0.06
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	0.076	0.062
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	23.3	18.8
Acenaphthylene	µg/L	1	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0
Phenanthrene	µg/L	1	<1.0	<1.0
Anthracene	µg/L	1	<1.0	<1.0
Fluoranthene	µg/L	1	<1.0	<1.0
Pyrene	µg/L	1	<1.0	<1.0
Benz(a)anthracene	µg/L	1	<1.0	<1.0
Chrysene	µg/L	1	<1.0	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0
Sum of PAHs	µg/L	0.5	23.3	18.8
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	<50	<50
C15 - C28 Fraction	µg/L	100	<100	<100
C29 - C36 Fraction	µg/L	50	<50	<50
C10 - C36 Fraction (sum)	µg/L	50	<50	<50
BTEX				
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1

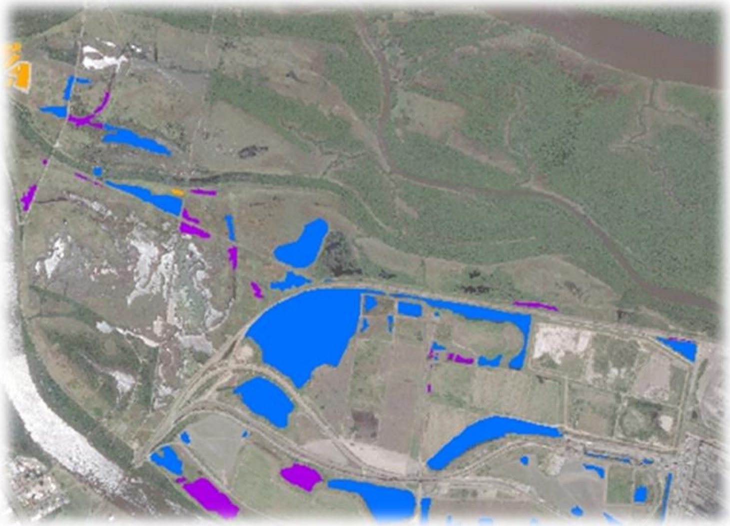
			Bi-Annual Monitoring	Bi-Annual Monitoring	Re-sample
BH23S			Dec-17	Jun-18	Aug-18
ANALYSIS	**UNITS**	**LOR**	**BH23S**	**BH23S**	**BH23S**
Sample Number			121710481012	061810481004	081810481007
Date Sampled			5/12/17	14/06/18	2/08/18
Sampled By			CR/LS	CR/KH	CR/KH
Time Sampled			14:32	9:09	12:13
pH Value	pH unit		7.37	8.09	7.50
Conductivity	µS/cm		632	630	795
Temperature	°C		21.1	19.2	19.8
Bromide	mg/L	0.01	0.306	<0.010	--
Dissolved Metals					
Aluminium	mg/L	0.01	0.03	0.05	--
Arsenic	mg/L	0.001	0.004	0.004	--
Cadmium	mg/L	0.0001	<0.0001	<0.0001	--
Copper	mg/L	0.001	<0.001	<0.001	--
Manganese	mg/L	0.001	0.463	0.269	--
Nickel	mg/L	0.001	0.002	<0.001	--
Zinc	mg/L	0.005	<0.005	<0.005	--
Iron	mg/L	0.05	0.14	0.97	--
Cyanide					
Free Cyanide	mg/L	0.004	<0.004	<0.004	--
Total Cyanide	mg/L	0.004	0.061	0.082	--
Polynuclear Aromatic Hydrocarbons					
Naphthalene	µg/L	1	<1.0	<1.0	<1.0
Acenaphthylene	µg/L	1	<1.0	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0	<1.0
Phenanthrene	µg/L	1	<1.0	1.6	<1.0
Anthracene	µg/L	1	<1.0	<1.0	<1.0
Fluoranthene	µg/L	1	<1.0	3.1	<1.0
Pyrene	µg/L	1	<1.0	3	<1.0
Benz(a)anthracene	µg/L	1	<1.0	1.3	<1.0
Chrysene	µg/L	1	<1.0	1.2	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	1.6	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	1.1	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	1	<1.0
Sum of PAHs	µg/L	0.5	<0.5	13.9	<0.5
Total Petroleum Hydrocarbons					
C6 - C9 Fraction	µg/L	20	<20	<20	--
C10 - C14 Fraction	µg/L	50	<50	<50	--
C15 - C28 Fraction	µg/L	100	<100	220	--
C29 - C36 Fraction	µg/L	50	<50	<50	--
C10 - C36 Fraction (sum)	µg/L	50	<50	220	--
BTEX					
Benzene	µg/L	1	<1	<1	--
Toluene	µg/L	2	<2	<2	--
Ethylbenzene	µg/L	2	<2	<2	--
meta- & para-Xylene	µg/L	2	<2	<2	--
ortho-Xylene	µg/L	2	<2	<2	--
Total Xylenes	µg/L	2	<2	<2	--
Sum of BTEX	µg/L	1	<1	<1	--

BH23D			Dec-17	Jun-18
ANALYSIS	**UNITS**	**LOR**	**BH23D**	**BH23D**
Sample Number			121710481013	061810481005
Date Sampled			5/12/17	14/06/18
Sampled By			CR/LS	CR/KH
Time Sampled			13:40	9:51
pH Value	pH unit		6.85	6.78
Conductivity	µS/cm		22300	25000
Temperature	°C		20.2	19.7
Bromide	mg/L	0.01	24.9	21.2
Dissolved Metals				
Aluminium	mg/L	0.01	<0.01	<0.01
Arsenic	mg/L	0.001	<0.001	<0.001
Cadmium	mg/L	0.0001	<0.0001	<0.0001
Copper	mg/L	0.001	<0.001	<0.001
Manganese	mg/L	0.001	1.14	1
Nickel	mg/L	0.001	0.003	<0.001
Zinc	mg/L	0.005	0.008	0.024
Iron	mg/L	0.05	0.78	14.5
Cyanide				
Free Cyanide	mg/L	0.004	<0.004	<0.004
Total Cyanide	mg/L	0.004	0.007	0.014
Polynuclear Aromatic Hydrocarbons				
Naphthalene	µg/L	1	<1.0	<1.0
Acenaphthylene	µg/L	1	<1.0	<1.0
Acenaphthene	µg/L	1	<1.0	<1.0
Fluorene	µg/L	1	<1.0	<1.0
Phenanthrene	µg/L	1	<1.0	<1.0
Anthracene	µg/L	1	<1.0	<1.0
Fluoranthene	µg/L	1	<1.0	<1.0
Pyrene	µg/L	1	<1.0	<1.0
Benz(a)anthracene	µg/L	1	<1.0	<1.0
Chrysene	µg/L	1	<1.0	<1.0
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0
Sum of PAHs	µg/L	0.5	<0.5	<0.5
Total Petroleum Hydrocarbons				
C6 - C9 Fraction	µg/L	20	<20	<20
C10 - C14 Fraction	µg/L	50	<50	<50
C15 - C28 Fraction	µg/L	100	<100	310
C29 - C36 Fraction	µg/L	50	<50	250
C10 - C36 Fraction (sum)	µg/L	50	<50	560
BTEX				
Benzene	µg/L	1	<1	<1
Toluene	µg/L	2	<2	<2
Ethylbenzene	µg/L	2	<2	<2
meta- & para-Xylene	µg/L	2	<2	<2
ortho-Xylene	µg/L	2	<2	<2
Total Xylenes	µg/L	2	<2	<2
Sum of BTEX	µg/L	1	<1	<1

APPENDIX 5

ANNUAL REPORT (2017/18) RESEARCH PROGRAM ON THE GREEN AND GOLDEN BELL FROG ON KOORAGANG ISLAND

Green and Golden Bell Frog (*Litoria aurea*) Research Program on Kooragang Island: Annual Report (2017-2018)



Conducted by the Amphibian Research Group, University of Newcastle, in collaboration with *Port Waratah Coal Services, Newcastle Coal Infrastructure Group,* and *Hunter Development Corporation*.

Report prepared by Colin McHenry, Cassandra Maynard, Alexandra Callan and Michael Mahony

Prepared for Port Waratah Coal Services, Newcastle Coal Infrastructure Group and Hunter and Central Coast Development Corporation.

February 2019

Executive Summary

***Note**: the structure of this report closely follows that of the previous survey season (2016-17). However, this year we have formatted data from previous seasons into a single data structure, which allows us to quantify aspects of longevity, movement, and occupancy across multiple years. We include these analyses in the current report for the first time.*

We find that the population of *Litoria aurea* on Kooragang Island is stable, with no evidence of overall decline since surveys commenced in 2010. The proportion of reproductively mature females is sufficient to constitute an effective population size adequate for persistence in the last seven years. Nevertheless, survival rates of individuals remain low, likely as a consequence of chytrid infection, and this remains a significant threat to the population. *Litoria aurea* are found to move across the landscape at greater levels than previously reported, highlighting the importance of habitat connectivity on Kooragang Island. Following several consecutive years of low rainfall in the breeding season, variation in wetland hydroperiod across the 60 surveyed wetlands has resulted in a substantial reduction in *Gambusia* densities, whilst allowing the population of *L. aurea.* to persist without apparent decline. The spatio-temporal complex of habitat connectivity and hydroperiod underpins the concept of the 'habitat mosaic', which we consider to be an important factor in determining the distribution and abundance of *L. aurea* on Kooragang Island. Reduced densities of *Gambusia,* caused by dry breeding seasons, are linked to successful *L. aurea* breeding events: this paradox stems from the breeding strategy of *L. aurea* to make use of ephermeral waterbodies. Thus, despite the observation that dry season reduces the number of wetlands for breeding, it can benefit the frog by removing the predatory fish. Recently constructed wetlands, which are *Gambusia*-free, add to the overall wetland habitat availability and provide breeding habitat, and can play a beneficial role in the management of *L. aurea*.

Conservation biology of *Litoria aurea* on Kooragang Island

1. **Population size**: In 2017-18, model-estimated population size was approximately 2,000-3,000 across surveyed wetlands. This is similar to population estimates from recent years. Direct survey counts also indicate that there has been no overall decline in population levels across that period.

2. **Demography**
   a. Age/sex class structure: for *L. aurea* age/sex class half were adults and of these 2/3 were adult males. A relatively high proportion (1/3) were adult females.

   b. Recruitment: Breeding behaviours were observed across the island. Calling and spawning are mostly linked to rain events. Surveys and demographic analysis identified four main cohorts of recruitment across the 2017-18 season: (1) *L. aurea* that were spawned in late autumn rain in 2017, and which overwintered as tadpoles to metamorphose in early spring 2017; (2) animals spawned in spring rain, 2017; (3) animals spawned in early summer rain, 2017; and (4) animals spawned in early autumn rain, 2018. Successful breeding events were detected in the NCIG CHEMP, BHP CHEMP, and Industrial Zone wetlands. Wetlands with successful breeding events spanned a range of hydroperiods and sizes, but there is a strong link between breeding and low/null densities of the invasive mosquito-fish *Gambusia*. *Litoria aurea* frequently use constructed wetlands for breeding.

   c. Gravid females: Many of the adult females captured were found to be carrying eggs (gravid), especially once SVL > 62 mm. Evidence suggests that on Kooragang Island, female *L. aurea* reach sexual maturity at smaller sizes and hence younger ages than in chytrid-free populations.

3. Longitudinal data

a. Persistence: Persistence (time between first and last capture of marked individuals) is similar (but not identical) to survivorship. Persistence is generally low, with less than 10% of recaptured *L. aurea* being detected more than 1 year after initial capture, and less than 2% were recaptured after more than 2 years.

b. Movement: Within a breeding season most recaptured *L. aurea* occur in the same wetland as their initial capture. Whilst this appears to indicate a high level of philopatry, most final recaptures are less than 6 months after initial capture, which reduces the opportunity for movement. On the longer time frame of between seasons, 22% of the frogs recaptured more than 2 years after initial capture were found in a different wetland; that proportion increased to 44% for animals that persisted for more than 3 years after initial capture. At this longer time frame, *L. aure*a move across the landscape much more than initially suspected. Most detected movements were undertaken by males, and the majority of movements were less than 500 metres. However, several movements were > 1 km, and one represented a minimum distance of 3.6 km.

4. Landscape use

a. Distribution: On Kooragang Island *L. aurea* are mainly distributed within the Industrial Zone; 2/3 of frogs detected during VES were detected there. Approximately 1/3 of detected frogs were in the Central Zone, mainly within the BHP CHEMP and these wetlands supported *L. aurea* at high densities. Only small numbers of frogs were detected in the Northern Zone of the island, but nearly all of these were detected at NCIG CHEMP wetlands. Very few *L. aurea* were detected in “natural wetlands” in the Northern zone, and without the NCIG CHEMP wetlands this zone would most likely not support a population. Within the Industrial Zone, the northern rail corridor has the highest number of *L. aurea*, but absolute numbers and densities are increasing in the southern part of that Zone.

b. Landscape factors affecting distribution, abundance, and recruitment:

i. **Habitat**: although *L. aurea* uses a range of aquatic and terrestrial habitats, two habitat requirements are highlighted with respect to managing landscape on Kooragang Island: (1) Permanent wetlands that consistently support large numbers of adult frogs, referred to herein as 'refuge' wetlands (note that we do not use this term as an equivalent concept to the ecological concept of 'refugia'); (2) wetlands that are used for successful breeding.

Refuge wetlands tend to be large, have a permanent / nearly permanent hydroperiod, and are fringed by dense stands of emergent aquatic reeds (mainly species of *Typha*, *Phragmites*, and *Schoenoplectus*). An extent of open water, and deep water close to vegetated banks may also be important components of the physiognomy of these wetlands.

Wetlands that support breeding events encompass a range of sizes and hydroperiods. Open water is a common feature. The presence of fringing reeds and flooded grass is linked to the larger events observed, but breeding will occur in the absence of these. Breeding wetlands tend to be close (< 300 m) to refuge wetlands. They are often ephemeral and semi-permanent wetlands, which *L. aurea* move to when rainfall events occur. There is a strong link with the absence of *Gambusia*, which results in many 'breeding' events having a semi-permanent or ephemeral hydroperiod (as *Gambusia* are removed from these wetlands during dry periods). However, if refuge wetlands lack

Gambusia then breeding can occur in these. In several instances, *L. aurea* bred in newly constructed wetlands.

An additional wetland type may also play an important role in the mosaic of wetland habitats that support large numbers of *L. aurea*. Small, well vegetated permanent wetlands do not support breeding but consistently support adult frogs, and data on movement indicates that they are used by frogs moving in and out of nearby refuge wetlands. These small wetlands appear to act as 'stepping stones' within the habitat mosaic, and also provide aquatic habitat during dry periods. They may be natural or constructed (i.e. the 'cluster ponds'), providing an additional opportunity for managers.

ii. ***Gambusia***: As discussed in the content of breeding habitat, there is a strong link between successful breeding and the density of *Gambusia*. In 2017-18, breeding was detected for the first time in several wetlands where consecutive dry years have removed *Gambusia*. In other instances, wetlands previously infested by *Gambusia* had much lower densities (again, a result of dry periods) and breeding by *L. aurea* was observed. *Gambusia* persist in permanent wetlands, and breeding in those appears to be minimal.

iii. **The habitat mosaic**: A spatial complex of wetlands with varying hydroperiods is required in order to provide *Gambusia*-free breeding habitat across both 'dry' and 'wet' seasons. In locations where the abundance of *L. aurea* is the greatest, these habitat mosaics incorporate large refuge wetlands and an array of smaller wetlands that may provide foraging habitat and/or increase the connectivity of the landscape; most of the wetlands within the mosaic are contained within an area no greater than 1 km across.

iv. **Northern Zone of the island**: The continued low numbers of *L. aurea* in the Northern Zone is difficult to understand and may be due to some aspect of the landscape rather than the quality of individual wetlands (e.g., the zone covers the upland areas of the estuarine drainage on the island). However, compared with the Central and Industrial Zones, the Northern Zone appears to be poorly connected to the other Zones. Additionally, in comparison with the Industrial Zone, it does not have large permanent wetlands (on the scale present in the Industrial Zone).

Specific management issues relevant to research partners

5. **Habitat corridor mitigation strategy**: Within the Industrial Zone, the density and abundance of *L. aurea* is highest in the northern part, along the area identified as the Northern rail corridor. However, numbers are steadily increasing in the southern part of the Industrial zone, in line with the overall aim of this strategy. An important component in the increase in numbers within the southern part is the provision of suitable aquatic habitat and improvement in habitat connectivity resulting from the constructed wetlands in the southern Industrial Zone (see below).

6. **Rail infrastructure mitigation strategy**: Detected movement of marked frogs indicate that *L. aurea* often cross rail infrastructure to move between wetlands around the Industrial Zone. Areas of the Industrial Zone enclosed by NCIG rail infrastructure have consistently supported adult *L. aurea* and successful breeding since 2015. Quality and connectivity of habitat has been maintained with those areas (e.g. the 'rail loop'), partly through construction of new wetlands (see below). In one instance (southern Deep Pond, K105B) the quality of habitat has been greatly improved following the construction of rail infrastructure.

7. **Constructed wetland strategy**: Over the course of this research project, wetlands have been constructed in the Northern Zone (NCIG CHEMP), Central Zone (BHP CHEMP) and Industrial Zone (PWCS 'cluster ponds' and 'HDC wetlands'). The CHEMP wetlands are the focus of separate research projects and are reported separately.

   The PWCS cluster ponds are small permanent wetlands that can be topped up in extended dry conditions. Monitoring indicates that they are used by *L. aurea* once there are larger wetlands nearby; in that context, they appear to provide an important part of the habitat mosaic.

   The HDC wetlands are nine sediment control basins in the southern part of the Industrial Zone that have been designed to provide aquatic habitat suitable for *L. aure*a. All of these now support adult *L. aurea*, and breeding has been detected in all nine. Most supported adult frogs and/or breeding within the first season following completion. They encompass a range of sizes (from small-medium to large-medium) and hydroperiods (from ephemeral to seasonal to semi-permanent), and in addition to the additional area of wetland habitat they provide across the southern Industrial Zone, they greatly improve habitat connectivity across this area. They are all free from *Gambusia* since they are hydrologically isolated. They are a key component of the apparent success of the habitat corridor and rail infrastructure mitigation strategies. They also provide most of the known breeding wetlands in the Industrial Zone.

Acknowledgements

The completion of the surveys in this project, and the analysis of data, is a complex exercise and would not occur without the assistance of various people at PWCS, NCIG, HDC, and the University of Newcastle, in addition to other colleagues and workers. We are especially grateful for assistance and support from Ben Lowder, Philip Reid, Mike Bardsley, Grant Moylan, Chad Beranek, Dean Lenga, Rose Upton, and John Clulow. Tim Jessop is thanked for his help with statistical analysis. We specifically thank the field survey team who put in hundreds of hours in the field when they could have been enjoying their summer evenings instead; Laura Bradbury, Jessica Merrick, Cormac McHenry, Lachlan Taylor, and Aaron Turner.

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1. Introduction

1.1 Background to the study: Historical context and research objectives.

The Conservation Biology Research Group at the University of Newcastle has been conducting annual surveys of the green and golden bell frog (*Litoria* aurea) on Kooragang Island since 2010. The intention has been to understand the population ecology of this amphibian to help inform best practice habitat creation and management for relevant stakeholders in order to improve ecological outcomes for this federally listed threatened species. Over the course of these surveys more than three thousand *L. aurea* individuals have been captured. This extensive data set represents one of the most comprehensive investigations of this threatened species to date. Continuous monitoring of this scale – especially of amphibian species – remains rare in an Australian context, yet necessary given that amphibian populations exhibit classic boom and bust population growth linked closely to climate and weather patterns.

The wetlands surveyed over the eight-year monitoring period have remained largely the same. However, some additional wetlands have been constructed and others have been altered, so the absolute number of wetlands surveys has increased, and the focus of each seasons' survey has sometimes shifted to track significant changes in population demographics. Nevertheless, the primary aims and methodology of consecutive surveys has remained consistent. The original project aims continue to be prioritised:

1. Providing a population size estimate for *L. aurea* on Kooragang Island;
2. Describing the demographic composition of the Kooragang Island population of *L. aurea*; specifically, the ratio of adults to juveniles and the ratio of males to females.
3. Defining the spatial distribution of the *L. aurea* across Kooragang Island, considering movement patterns and aggregations.

1.2 Background to the problem: the green and golden bell frog decline

Litoria aurea was once common and widespread along Australia's East Coast, stretching from northern New South Wales to southern Victoria, as well as into inland tablelands (Pyke et al., 2002). Rapid declines were observed from the early 1970's, leading to a dramatic reduction in both distribution and abundance (Mahony et al., 2013, Pyke and White, 1996, Pyke et al., 2002). Today, *L. aurea* persists in less than 10% of its historical distribution and occupies fewer than forty sites, most of which are geographically isolated from one another (White and Pyke, 1996, Mahony et al., 2013). Populations that were once reported on the Central Tablelands are now presumed extinct, having not been observed since the early 1970s (White and Pyke, 1999, White and Pyke, 1996). Additionally, until a recent rediscovery of a small population in Queanbeyan (Wassens and Mullins, 2001), *L. aurea* was also presumed extinct in the Southern Tablelands, having not been observed there since 1980 (Osborne et al., 1996). Many populations have also been lost along the foothills and coastal plain of the Hunter, Sydney and Shoalhaven regions where the species was once abundant (Daly, 1996, White and Pyke, 1996). *Litora aurea* was once common in the Hexham Swamp/Kooragang Island area of Newcastle (Hamer et al., 2004). The species apparently declined rapidly in the 1980s and by the 1990s the only confirmed breeding site south of the Hunter River was in small wetlands at Sandgate. This population disappeared some time prior to 2006.

As a result of this substantial range contraction, the species is now listed as endangered in NSW, and vulnerable under Commonwealth legislation. Kooragang Island is considered one of the two key extant populations in the Lower Hunter region (DECC, 2007); the other population near Maitland has only sporadic reports of observations.

Causes of the decline

(a) Disease: chytridiomicosis

Recent declines in global amphibian populations far exceed those of other vertebrate groups, with over 41% of species now extinct or threatened with extinction (MacPhee and Greenwood, 2013). Amphibians now comprise 75% of the animals listed as critically endangered as a result of disease (MacPhee and Greenwood, 2013). Significant mortalities were first reported in the 1980's, and have continued to escalate into the 21st century (Hussain, 2012). The Pandemic fungal disease 'chytridiomycosis' is heavily implicated in these declines, with conservative estimates suggesting it has driven over 200 species to, or to the edge of extinction (Skerratt et al., 2007). The chytrid fungus responsible for this disease, *Batrachochytrium dendrobatidis* (Bd) infects the skin of amphibians where it reproduces, and at high infection loads can impair osmoregulation in adult frogs, stressing the circulatory system enough to cause mortality (Voyles et al., 2007).

The NSW National Parks and Wildlife Service Draft Recovery Plan for *L. aurea* lists disease (specifically chytridiomycosis) as a threat to the persistence of the species, and several observations of infection and die-offs are referred to therein (DEC, 2005a; DEC, 2005b). In laboratory challenge experiments *L. aurea* is particularly susceptible to the chytrid fungus, with 100% of captive individuals exhibiting terminal signs of the disease following experimental exposure (Stockwell et al., 2010). Whilst it is unlikely the disease kills all infected wild individuals, the chytrid fungus clearly poses substantial threat to the persistence of wild populations of *L. aurea*, already susceptible to habitat modification and destruction and predation by introduced aquatic predators. Survival estimates of the Kooragang Island population , demonstrate significantly lower over-winter survival rates in infected individuals when compared with those individuals not infected by the pathogen (Stockwell et al, 2011) . This, in turn, is predicted to cause infected populations to decline at twice the rate of healthy ones (Stockwell et al, 2011). The chytrid fungus has also been implicated as the primary causal agent in the overwinter extinction of a reintroduced population of *L. aurea* just south of Kooragang Island (Stockwell et al., 2008). These findings suggest that large-scale seasonal die-offs are common in *L. aurea* populations during the cooler months, often remaining unobserved due to low frog detectability and reduced survey frequency. Such die-offs have serious implications for the ability of surviving populations to persist with infection, particularly given the potential for stochastic events such as drought or extreme weather events to introduce additional pressure, and extant threats such as habitat modification and invasive aquatic predators (Stockwell, 2011)

The majority of extant *L. aurea* populations are found in coastal environments. This has led to the historical assertion that the sensitivity of the chytrid fungus to salt may explain the persistence of *L. aurea* in weakly saline environments (White, 2006; Stockwell et al., 2012). Significant negative correlations have been experimentally confirmed between infection load in captive *L. aurea* and the salinity of the water bodies they are kept in (Stockwell, 2011). Wild populations of *L. aurea* inhabiting water bodies with up to 3.5 ppt salt were also found to have lower infection loads than those frogs not exposed to saline conditions (Stockwell et al., 2012). Indeed, salt concentrations above 2 ppt and below 5ppt were found to be beneficial (Stockwell et al., 2015b, Stockwell et al., 2015a). These results confirm that *L. aurea* has a survival advantage in areas with a saline influence, with this salinity offering a refuge from the effects of the chytrid fungus. The deliberate addition of salt to water bodies, both in captivity and experimental reintroduction, has been demonstrated to increase bell frog survival rates where the chytrid fungus is present (Stockwell, 2011). Thus, consideration of salinity is likely to prove a useful strategy when designing new wetland mosaics for *L. aurea* habitat.

(b) The invasive mosquito fish Gambusia holbrooki

Field observations have long recognised that *L. aurea* are less likely to breed successfully in wetlands infested with the invasive species *Gambusia holbrooki,* also known as the mosquito fish or plague minnow. Laboratory experiments have demonstrated predation of *Gambusia* upon amphibian tadpoles and eggs (Stanback, 2010, Mahony et al., 2013) even though dissection of wild caught mosquito fish shows little evidence of this consumption. More recent dietary analysis using stable isotopes has successfully confirmed both the predominately carnivorous diet of *Gambusia,* and a high rate of predation on native Australian tadpole species (Remon et al., 2016). *Litoria aurea* tadpoles do not show any avoidance or refuge seeking behaviours when introduced to *Gambusia*, further increasing their susceptibility (Hamer et al., 2002b). These findings stress the importance of designing wetland infrastructure to control for *Gambusia* infestation.

Whilst the timing of the earliest *L. aurea* declines was coincident with the expansion of *Gambusia* into NSW (White and Pyke, 1996), numerous sites exist where *L. aurea* declined despite local water bodies being free of the predatory fish (Mahony et al. 2013). Indeed, several studies - including this annual survey report - have noted the co-occurrence of *L. aurea* tadpoles and *Gambusia* in the same water body; albeit on rare occasions (Sanders et al., 2015, Hamer et al., 2002a). Thus, the introduction of *Gambusia* is unlikely to be the primary causative factor in *L. aurea* declines. Nevertheless, mosquito fish certainly place additional strains on fragile populations, and efforts should continue to mitigate their impact and prevalence on Kooragang Island, as predation by *Gambusia* is a key threatening process and a threat abatement plan exists.

The presence of mosquito fish in permanent water bodies may also have resulted in a shift in the type of habitat utilised for breeding. Bell frogs appear to have bred in permanent water bodies more frequently in the past than they do now and this may be because ephemeral water bodies that dry frequently do not sustain populations of mosquito fish (Pyke and White 1996; Hamer, Lane et al. 2002; Pyke, White et al. 2002). However, breeding in ephemeral water bodies carries the risk of wetland drying before tadpoles can metamorphose (Hamer, Lane et al. 2002).

(c) Habitat destruction and fragmentation

There are correlations between the destruction of suitable habitat and local extinction of *L. aurea.* Many habitats with historic *L. aurea* populations have been altered, particularly through infilling or drainage of wetlands for agriculture, trampling of waterways by feral horses and pigs as well as other urban and industrial development (Clancy, 1996, Daly, 1996, van de Mortel and Buttemer, 1996, Lewis and Goldingay, 1999). Habitat fragmentation reduces the probability that the smaller and disjunct populations which survive can persist through extreme events such as drought or outbreaks of disease. Furthermore, separation halts genetic exchange which would usually occur within meta-populations; resulting genetic bottle-necks can have grave implications for the long-term survival of affected species (Goldingay, 1996, White and Pyke, 1996, White and Pyke, 1999).

The creation of underpasses to facilitate the movement of wildlife across roads and infrastructure has become part of best common practice to try and reduce habitat fragmentation. Nevertheless, surprisingly little empirical data exists confirming the movement of amphibians through associated culverts and funnel fencing. Data is almost non-existent for Australian species, which do not undertake mass migrations on a seasonal basis (Koehler et al., 2014). The Growling Grass Frog (*Litoria raniformis*) is a close relative of *L. aurea* and has also undergone rapid population decline in the past 30 years. Recent research has documented the species moving through constructed culverts for the first time (Koehler et al., 2014), which implies *L. aurea* would likely do the same given suitable infrastructure.

The first four years of this research (years 2010-2014) found evidence of *L. aurea* individuals moving between the Central and Southern region of the Kooragang Island Management Zone. This suggests that the rail line and associated infrastructure are not a complete barrier to dispersal. Further observed instances of movement are discussed in Section 3.5.

1.3 Future Directions and Research Significance

Understanding habitat preference

Conservation efforts must be informed by a thorough understanding of the population demography and habitat requirements of *L. aurea.* It is an opportunistic colonising species with high dispersal ability and fecundity (Lane et al., 2007, Pyke et al., 2002) which also suggests that it should readily establish populations in all suitable habitats. This has caused confusion as to why the species fails to occupy all seemingly suitable water bodies within Kooragang Island, and furthermore why its preferences appear to change both within and between seasons. Significant research effort has been devoted to characterizing the specific habitat features which are integral to the survival of *L. aurea*, however results on important habitat variables are inconsistent across the studies (Pyke and White, 1996, White and Pyke, 1996, Christy and Dickman, 2002, Pyke et al., 2008). One study on Kooragang Island in 2002, found that *L. aurea* were more likely to be found in waterbodies which had a greater diversity of vegetation along their banks. The presence of the plant species *Juncus kraussii*, *Schoenoplectus litoralis* and *Sporobolus virginicus* were most positively correlated with *L. aurea* presence (Hamer et al 2002) . Research in this area continues on Kooragang Island, with studies underway from the University of Newcastle now focusing on the importance of specific vegetation assemblages.

It remains possible that the water bodies where *L. aurea* is regularly observed do not represent its ideal habitat. Instead, the species may be forced into sub-optimal areas by pressures such as habitat fragmentation and presence of *Gambusia holbrooki.* Nevertheless, the culmination of evidence to date implies that *L. aurea* is a habitat generalist, not a specialist, and is hence capable of persistence under a variety of environmental conditions (Hamer and Mahony, 2007).

The importance of long term monitoring

Several attempts have been made to create artificial habitat for *L. aurea*. At least 11 reintroduction or translocation programs have been reported for the species (Daly, Malolakis, Hyatt, & Pietsch, 2008; Darcovich & O'Meara, 2008; McFadden et al., 2008; Stockwell et al., 2008; White & Pyke, 2008). To date, only four of these populations have persisted beyond three years (Klop-Toker, 2016), as well as a recent population introduced to an artificial salt refuge on Kooragang Island which persisted for five years (Callen, in prep). Chytridiomycosis was implicated in the demise of the population in three of these programs (Daly et al., 2008; Stockwell et al., 2008; White, 2008). Recent habitat construction and enhancement of the extent and connectivity of wetland mosaics on Kooragang Island has proven successful, with occupancy of wetlands by adults and successful reproduction in numerous wetlands. There remains the matter of demonstrating that these successes continue, and that they have provide a strengthening of the viability of the local population.

Since 2009 there have been three studies on Kooragang Island that have monitored occupancy of created and natural wetlands as an aquatic habitat mosaic by *L. aurea* on a temporal scale of 3-5 years. However, effective ecological monitoring needs to occur on the scale of decades rather than years, especially for taxa where population size is so intrinsically linked to weather conditions (e.g. summer rains for explosive breeding events) (Lindenmayer and Likens, 2010).

1.4 Summary of Historical Findings

Population estimates of *L. aurea* on Kooragang Island exist prior commencement of the current monitoring program (2010). A survey of 32 wetlands in the years 2000 and 2001 estimated a total of 1,995 (±315) and 905 (±145) male individuals respectively (Hamer and Mahony, 2007). As can be observed in the summary table below (Table 1.4.1) these findings are largely consistent with our own population estimates, suggesting a relatively small, but nevertheless stable, population. Direct comparison of our annual dataset against earlier estimates is complicated by differences in methodology, and the fact that studies from the years 2000 and 2001 estimated male population size only.

Table 1.4.1: Summary statistics for repeat annual surveys beginning 2010 and continuing to 2016. Table highlights fluctuations in estimated population size, number of wetlands surveyed, population demographics and breeding activity from year to year. Clarification of included parameters are supplied for each column where the title is not self-explanatory.

Survey	KI Pop. Size	No. of Ponds	Sex Ratio (M/F)	Age Struct. (A/J)	Breeding Sites	Calling Sites	Most Ind.
2010/11	1153	23 (16)	1.25/1	1/3	10	5	K22
2011/12	928	55 (25)	1/1.09	1/1	unk.	11	K22
2012/13	834	55 (20)	1.4/1	4.7/1	5	11	K22/23
2013/14	1238	55 (25)	unk.	unk.	5	9	K22
2014/15	2964	58 (28)	1.43/1	1/1.3	6	4	K23
2015/16	1432	78 (42)	7.4/1	1.4/1	7	14	K104
2016/17	2580	73			8	8	K29
	* Peak population size (best estimate for month with greatest no. of individuals).	* Total no. of wetlands surveyed. (Total wetlands with *L. aurea* present in brackets)			*Number of wetlands with amplexus, tadpoles or recent metamorphs.	*Number of wetlands with calling males.	*Wetland with most captured individuals.

<u>History of migration and breeding events within the KI Management Zone</u>

The connectivity of *L. aurea* habitat on Kooragang Island is a key variable in assessing the populations stability. Several thousand wild *L.* aurea have been micro-chipped in order to track the movement of individuals across the landscape within and between survey seasons. Low recapture rates between consecutive years imply that, as predicted by previous research (Stockwell et al., 2011), many adult frogs do not survive beyond winter. Nevertheless, migrations between adjacent wetlands are commonly observed within seasons, and there has been evidence of individuals migrating more than two kilometres within a season (Hamer et al., 2008). A summary of migration is presented below for each survey period. Notable instances of mass recruitment i.e. observations of large numbers of tadpoles and/or metamorphs are also included in this summary, along with their location.

2010-11 Season

Movements between separate water bodies were observed for six individuals. The distance of these movements ranged from 70m to 581m. Five of these movements were localized within the Central region of the Management Zone, between K22/K23 and adjacent wetlands on the same side of the rail corridor. One individual was observed moving from K22 to K106C (formerly the 'small cell') which required crossing the industrial rail corridor. This data point establishes that the rail infrastructure which separates the Central and Southern Zones of the island is not a complete barrier to dispersal.

Tadpoles and/or metamorphs were found at three wetlands in the Industrial Zone, and an additional three wetlands in the Central Zone of the island. K29 ('The Cell'), was one of these wetlands, with the presence of metamorphs suggesting successful breeding even though this wetland has historically been infested with *Gambusia holbrooki.*

2011-12 Season

Movements between wetlands were detected on ten occasions with long-range movements of up to 1263m observed. Most of these movements occurred across the railway corridor, between the K22/23 complex and K29 and adjacent wetlands. Movements also occurred between wetlands in the northern half of the Southern (Industrial) region. Some of these migrations also extended west to K104 and south, to wetlands adjacent to Cormorant Road, suggesting this is the most likely migration corridor for individuals. Movement distance was found to be significantly greater for juveniles as compared to adults, though a limited data set warrants further investigation to confirm this trend.

No observations of breeding were included in this report.

2012-13 Season

Numerous movements were observed, with most of this activity occurring between K22 and K23 (approximately 80m). One long-range movement was observed between K104 (in the NW of the Industrial Zone) and K22 (within the Central Zone), a movement of more than two kilometers. This suggests that the frogs were still migrating successfully across the rail corridor.

Tadpoles were found in 5 wetlands across the island, including 3 wetlands from the Industrial Zone. Calling activity was also widespread and akin to breeding activity, was concentrated in the Industrial Zone.

2013-14 Season

Unlike previous years, no long-range movements (> 1km) were observed to occur across the island. Numerous short-range movements between wetlands K22 and K23 were observed, as were three moderate-range movements between the K22/K23 the and K29 (AKA the cell), approximately 460m as the crow flies. These movements all occurred in the period between the 2012/2013 and 2013/2014 monitoring seasons, with these moderate-range movements indicating that the industrial railway was still being crossed successfully.

Breeding and calling patterns where akin to the previous year, with the additional caveat that tadpoles found in K108 (AKA the 'rail loop wetland') may have been survivors from the previous year only.

2

014-15 Season

No long-range or medium-range movements were observed to occur in this season. As with previous years, numerous short range movements between wetlands K22 and K23 were observed. There was no movement between K22/23 and K29 (AKA the cell) as had been observed in previous years, and thus no migration observed across the industrial railway.

The artificially created cluster wetland 'C1' adjacent to K29 supported a successful breeding colony of at least three females, demonstrating its efficacy as habitat. Conversely, no *L. aurea* were detected at a second cluster wetland 'C2' located in the southern part of the Industrial Zone. A significant breeding event occurred at K104, with a total of 647 juveniles being detected through VES. Most of the juveniles were found between February and March suggesting that breeding occurred in the middle of the season.

2015-16 Season

For the second year in a row, no long or medium-range movement were observed. The only migrations seen occurred back and forth between K22 and K23. There was no evidence of movement across the rail corridor into the Southern 'Industrial' Zone.

The season was marked by very heavy rainfall in early January 2016. Following that, there was a large recruitment of metamorphs observed in K106A and K106B; on February 11 2016 we detected large densities of tadpoles and metamorphs in shallow flooded grass. We estimated density to be > 5 per square meter, i.e. >10,000 tadpoles and metamorphs across these two wetlands. Mating pairs were seen at K104A (the rail service road on the north edge of K104 that tends to form long lasting ephemeral wetland) following heavy rain in early January – but the high water levels connected this to the main body of water in K104, allowing *Gambusia* into K104A, and only a very small number of metamorphs were observed at the end of that summer). The high numbers of GGBF in the K104 area is likely due to the large breeding event observed in the previous (2014-15) season. Breeding was successful in the 'C1' cluster wetland, but there were no adults detected at the 'C2' cluster wetland; both these findings were consistent with the previous year. Recorded breeding was negatively associated with presence of *Gambusia*; but the flooding that followed heavy rainfalls in April 2015 and January 2016 meant that by the end of the 2015-2016 *Gambusia* was widely distributed across the islands, with only 19 out of 78 surveyed wetlands being free of the fish.

Several of the newly constructed HDC wetlands within the NCIG Rail Loop (K111, K113, and K114) supported at least some adult bell frogs in this season, despite having existed for less than 12 months. Breeding was recorded at one of these (K113). GGBF were not detected at the other new wetlands (K112, K117, K118), nor at the C2, a pattern that appears to be linked to connectivity across the southern part of the industrial zone. It was expected that the (positive) changes to the habitat mosaic resulting from the construction of the six new HDC wetlands would lead to dispersal to these in the following season.

The numbers of bell frogs in K29 and K108, two of the large permanent/semi-permanent 'refuge' wetlands that traditionally held large numbers of adult GGBF, were very low in this season. It appears that following the high mid-summer rainfall, adult frogs dispersed across the landscape (presumably aligned to feeding and breeding behaviours). It was noted that emergent aquatic vegetation had completely covered K108, leaving this wetland with no area of open water.

2016-17 Season

This was a much drier season than the previous year. Many of the wetlands dried out over the course of the season. Large numbers of adult frogs were detected at the large permanent//semi-permanent ‘refuge’ wetlands, especially K29, but very few frogs were detected at the ephemeral wetlands (which were mostly dry by the middle of the summer). It appears that the bell frog population, especially in the Industrial Zone, contracted to these ‘refuge’ wetlands as the system dried, leading to detectability being much higher than in the previous season where frogs were apparently widely dispersed over the landscape following very high levels of mid-summer rainfall. As a result, the population estimates for 2016-17 are notably higher than they were for 2015-16; but these should be interpreted in the context of the climatic conditions for each season.

The high rainfall in the 2015-16 season evidently led to significant recruitment, especially in K106, and the results of that could be detected by demographic analysis as a cohort of young animals in K29 during the early part of the 2016-17 season. Demographic analysis also indicated successful recruitment in K104 in the early spring of the 2016-17 season. Further large breeding events at two of the new HDC wetlands, K111 and K114, were observed in early summer 2016-17.

As expected, frogs were detected for the first time in the remaining new HDC wetlands (K112, K117, K118), and for the first time in the southern ‘cluster ponds’ (C2). This increased distribution of frogs across the southern region of the Industrial Zone correlates with improvements in connectivity and habitat mosaic following the construction of new GGBF habitat in that region. However, no frogs were detected at K108 for the first time since surveys began in 2011; that wetland was dry throughout the entire season.

Lower than average rainfall during summer and late autumn led to a large number of ephemeral and even some semi-permanent wetlands becoming completely dry; this included ‘refuge’ wetlands such as K23 and K108. As well as appearing to concentrate frogs back to the deeper wetlands (with consequent effects for detectability – see above), this drying effectively eliminated *Gambusia* from a number of wetlands (e.g. K22, K23, K46, K105B).

Mid-autumn rainfall (following Cyclone Debbie) recharged many of the wetlands and appears to have led to a late season breeding event, although this occurred after surveys had been completed and only anecdotal observations were made. It was expected that, if this late season breeding led to successful recruitment, that a cohort of small juveniles should be present in the early part of the current (2017-18) season.

1.5 Research Objectives

Research objectives for the 2017-18 season are largely consistent with previous years, and target areas of *L. aurea* biology and ecology that are relevant for management of this species and its habitat on Kooragang Island:

1. What is the estimated population size of the green and golden frog on Kooragang Island?
2. What is the demographic composition of the *L. aurea* population on Kooragang Island?
    - What are the proportions of juveniles, adult males, and adult females?
    - How much recruitment is known, and where is it occurring?
3. How do *L. aurea* utilise the landscape on Kooragang Island?
    - What is the distribution of *L. aurea* on Kooragang Island?
    - What factors affect distribution, abundance, and recruitment?
4. What information can be gained from longitudinal data?
    - What are the growth patterns of *L. aurea*?
    - How long do individual *L. aurea* persist on Kooragang island?
    - What are the movements of *L. aurea* across the island?

In addition, there are several objectives that relate to specific management issues faced by the industry research partners – Port Waratah Coal Services (PWCS), Newcastle Coal Infrastructure Group (NCIG) and Hunter Development Corporation (HDC):

5. **PWCS Habitat corridor mitigation strategy**: A long-term aim is to decrease *L. aurea* occupancy of wetlands in the north of the precinct earmarked for development (known as T4) (See Section 2: Site Context), and to increase occupancy of wetlands in the southern part of that site.

   Requires: detailed understanding of population numbers, distribution and movement in the northern and the southern parts of T4.

6. **NCIG Rail infrastructure mitigation strategy**: The construction of the NCIG 'rail loop' enclosed several wetlands that were important habitat for *L. aurea* with a high traffic rail line. It is important for NCIG to understand if the rail loop has effectively isolated the populations in those wetlands from the Kooragang Island metapopulation.

   Requires: detailed understanding of population numbers, distribution, and movement within the rail loop and at adjacent wetlands

7. **HDC Constructed wetlands strategy**: As part of capping within the rail loop in 2015, HDC constructed sedimentation ponds that were designed to provide suitable habitat for *L. aurea*. The efficacy of that design, and the location of these artificial wetlands within the landscape, is an important question for HDC as further capping works are planned and implemented.

   Requires: detailed understanding of population numbers, distribution, and movement at the HDC constructed and adjacent wetlands.

2. Methods

2.1 Site context

Kooragang Island lies at the northern boundary of the Newcastle Local Government Area, on the NSW Central Coast (Figure 2.1.1). The Island itself is estuarine in nature, and is bounded to the north and south by channels of the Hunter River. Soils are composed of deposited sand, silt and clay sediments. Several tidal channels extend onto the island, which separated the current landmass into smaller islands prior to human development. The natural hydrology of the island has been considerably altered, with agricultural development such as draining of land for pastures and industrial activity such as road construction and land reclamation altering tidal inflow. Its deltaic nature which includes low elevation, supports a diversity of wetlands ranging from saltmarsh and tidal flats to freshwater swales and large permanent freshwater wetlands.

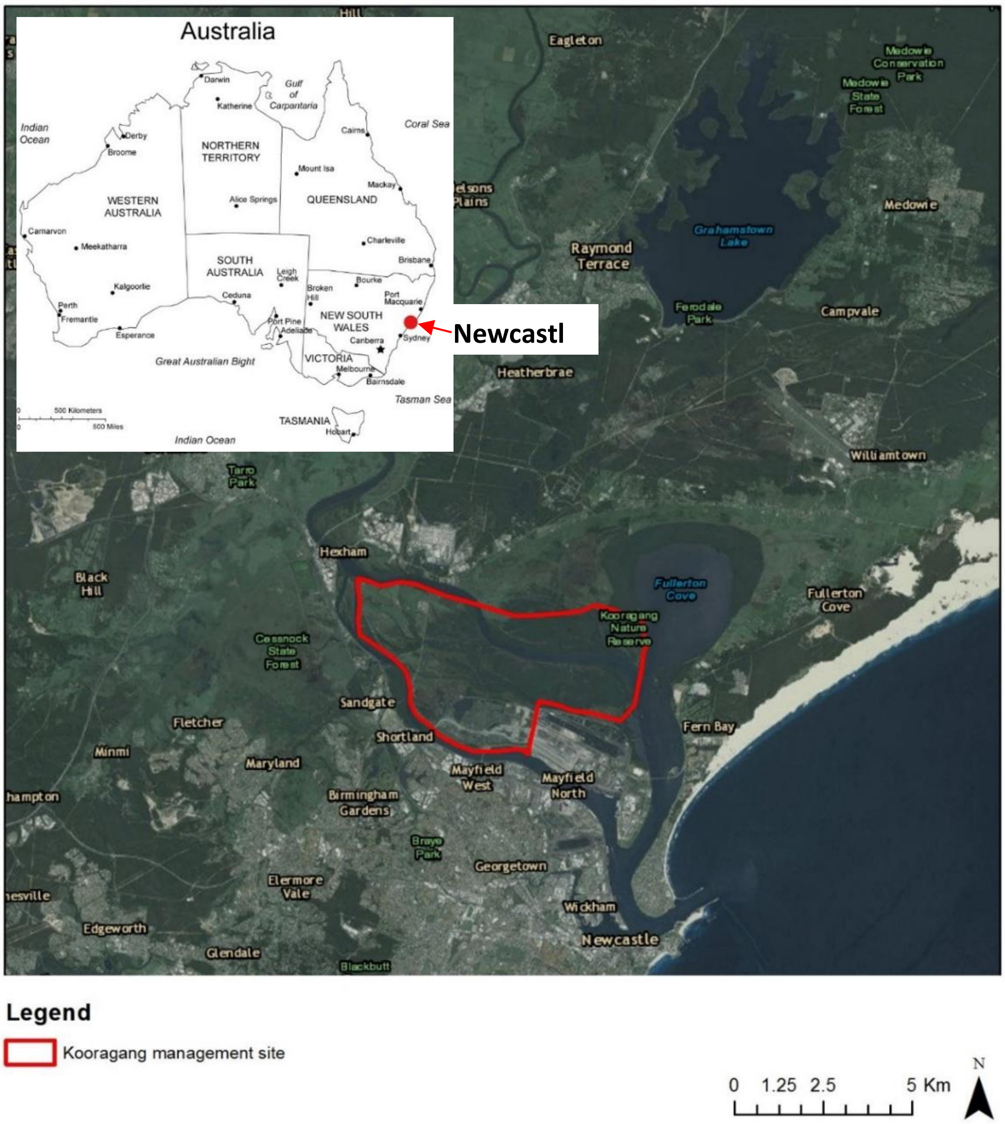

Figure 2.1.1: Contextual map depictingthe location of Kooragang Island, near Newcastle, NSW.

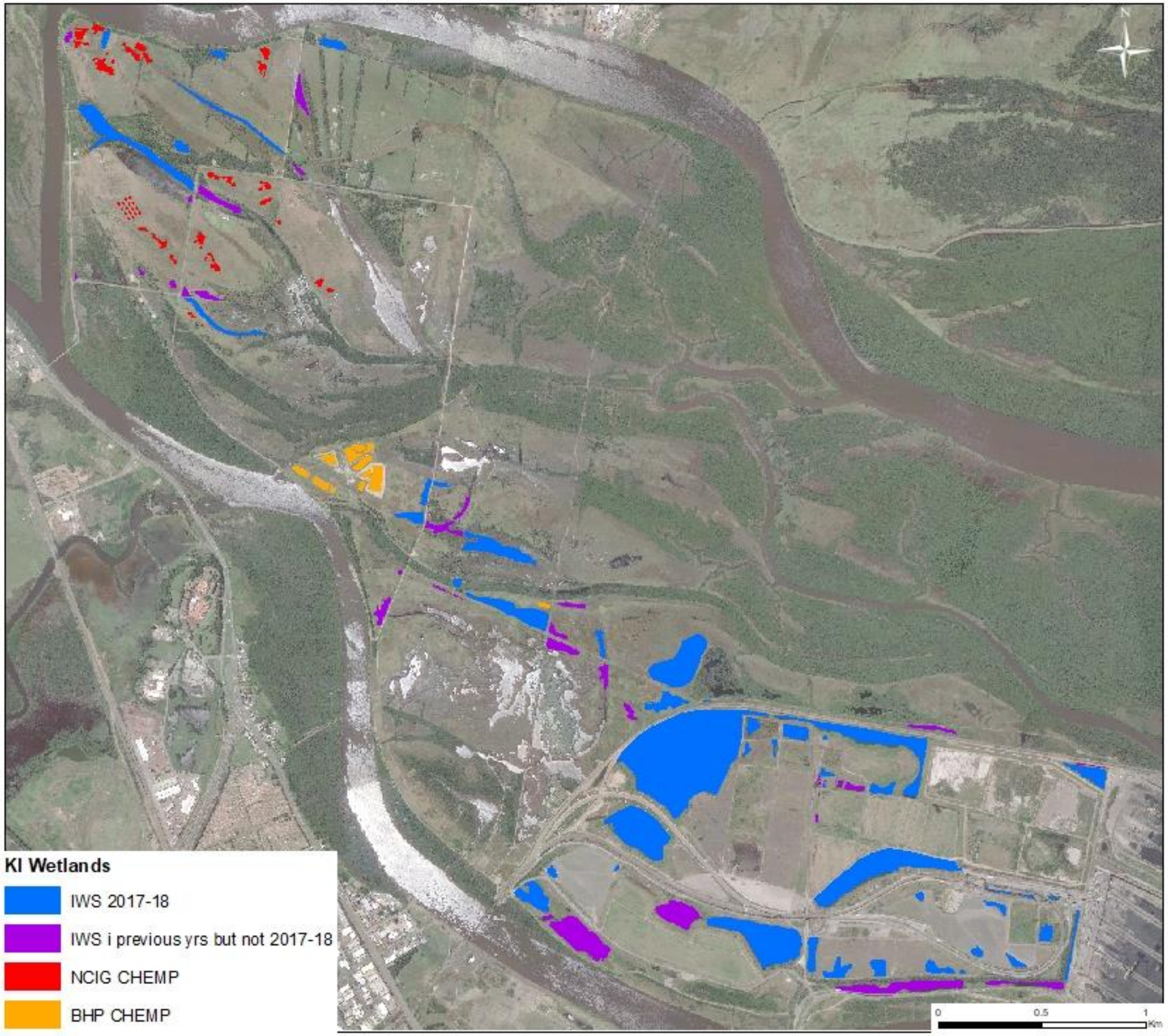

Figure 2.1.2: Wetlands of Kooragang Island - showing the 47 wetlands surveyed in the 'island-wide' surveys of 2017-18, along with wetlands that have been surveyed in previous years that were not included in surveys in this year. The positions of NCIG and BHP CHEMP wetlands are also shown; 13 of these wetlands were surveyed as part of the island-wide surveys in 2017-18, making a total of 60 wetlands for which data is presented in this report.

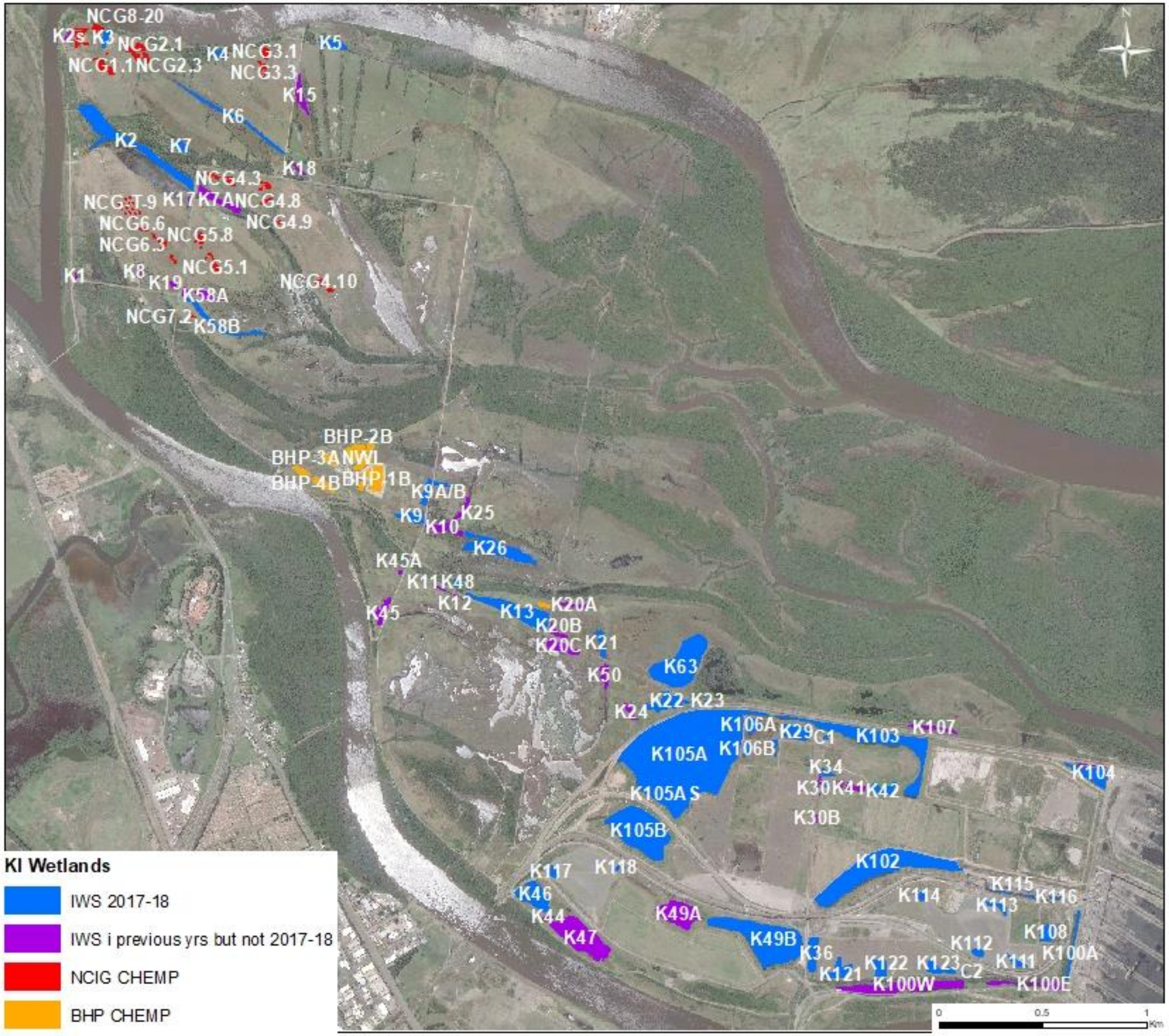

Figure 2.1.3: Wetlands on Kooragang Island that have been the focus of the annual monitoring surveys conducted by the University of Newcastle since 2010-11. The designation of wetland numbers was updated in May 2016. The 73 wetlands surveyed in the 'whole island' surveys of 2016-7 are labelled, along with several of the NCIG and BHP CHEMP wetlands.

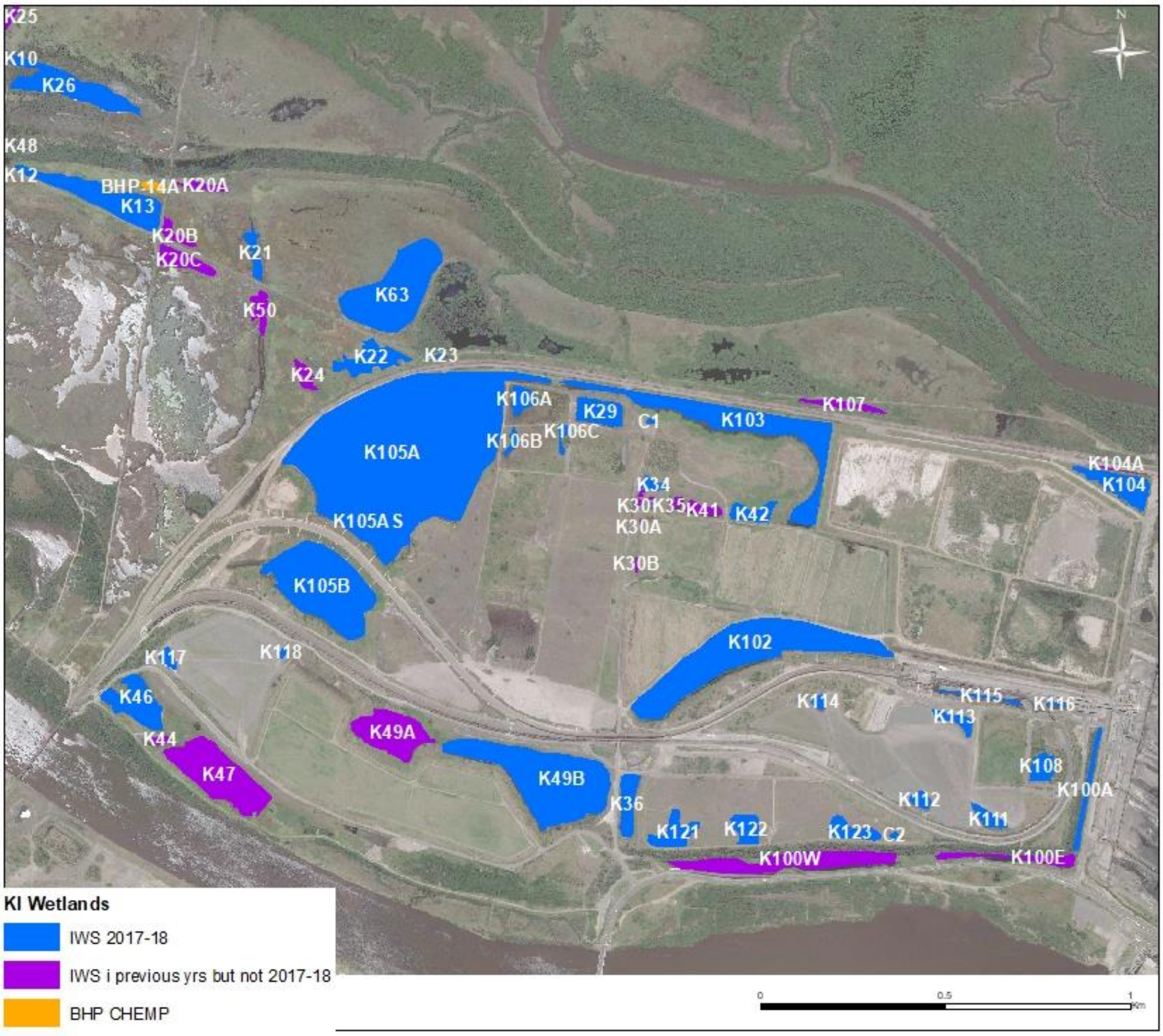

Figure 2.1.4: Surveyed wetlands in and around Terminal 4 on southern Kooragang Island for the 2017-18 season.

In the 2017-18 breeding season, 60 wetlands across the island were surveyed (Figure 2.1.2). The list of wetlands surveyed each year is consistent but with some variation between each season; a history of that variation is provided in **Appendix A** (see also Figure 2.1.2). Figures 2.1.3 and 2.1.4 show the nomenclature used by UoN to identify specific wetlands.

2.2 Groupings of wetlands: Zones, Regions, Subregions, and Jurisdictions

To assist survey logistics and analysis of spatial patterns of *L. aurea* distribution, the surveyed wetlands on Kooragang Island are organised into areas as follows:

A. **Zones**: wetlands are grouped into three geographical zones - the Northern, Central and Industrial zones.

   1. Northern Zone: this zone includes the Hunter Wetlands National Park from the Sandgate bridge in the south to Scott's Point in the north, and has an area of 377 ha. Within this zone there are 14 wetlands sampled as part of the program this year. Overall the zone has experienced a range of disturbance histories, including, grazing, clearing, draining, impounding, flood-gating and other types of human development.
   2. Central Zone: this zone also includes part of the National Park Estate. It ranges from the south from the PWCS rail line, where wetland sample sites are found adjacent to Bell Frog Track, to north at Milam Rd and terminating at the north arm of the Hunter River. Overall this zone has an area of 293 ha, of which 90% is mangrove forest community. Within this zone there are 15 wetlands sampled as part of this program this year. Compared to the Northern zone, this has been less impacted by human activity. Nonetheless, there is evidence of historic disturbance, including clearing, draining, impounding, road construction, utility easements, and flood-gating.
   3. Industrial Zone: Wetlands in this zone are located in the south-eastern part of the island, on industrial and commercial lands leased or owned by organisations undertaking a range of business activities on the site. Within this zone there are 31 wetlands sampled as part of this program this year, with a wide variety of types and sizes represented in the overall area of 346ha. As could be expected given the industrial/commercial nature of this zone it has both historically modified and continues to be a modified and disturbed part of the site. Nonetheless, the wetlands within this zone are easily delineated and in numerous cases removed from industrial activities. Compared to the rest of the site, this has undergone the greatest level of historical disturbance and continues to be impacted by human activity. It also supports the largest numbers of *L. aurea* on Kooragang Island.

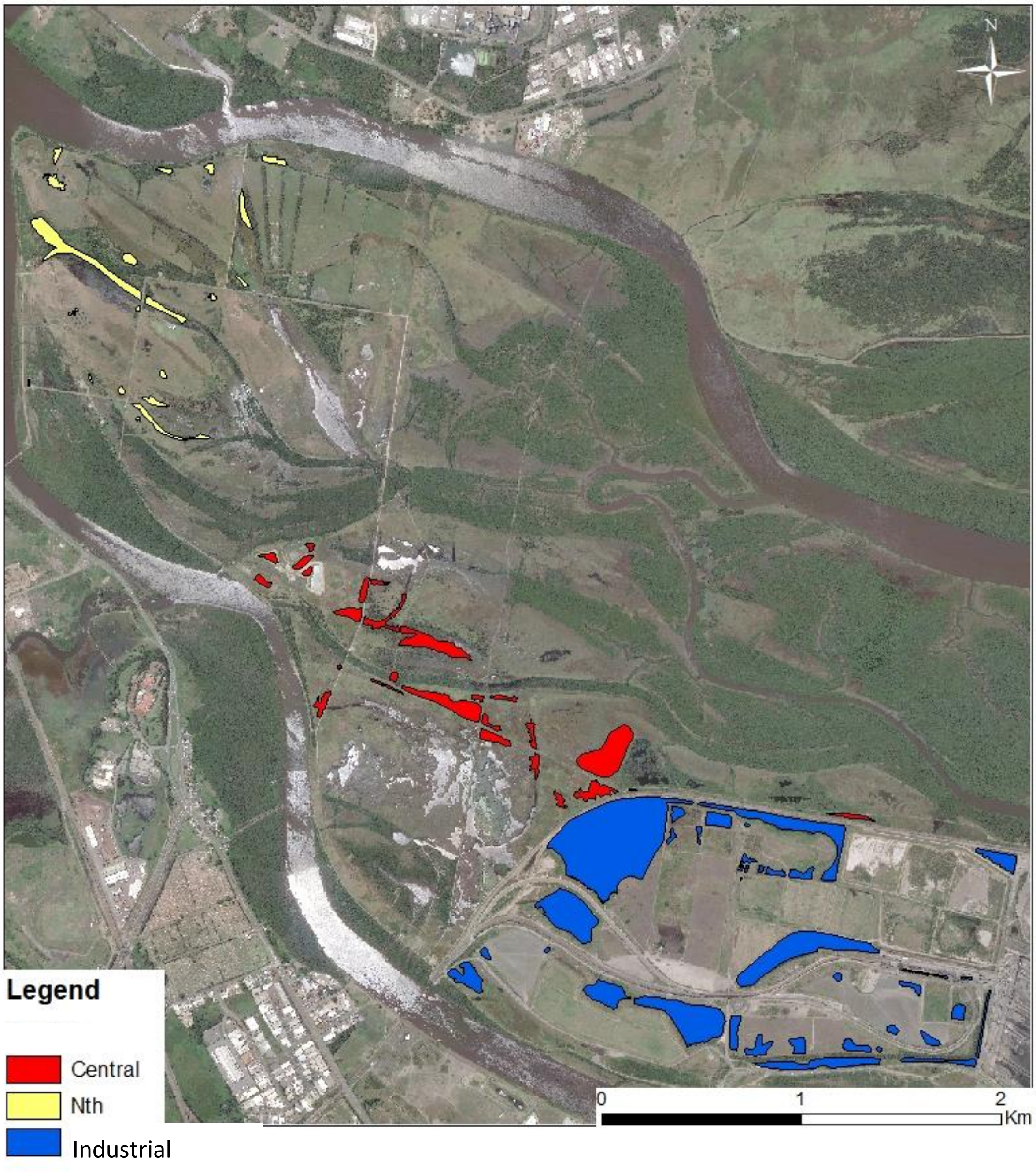

Figure 2.2.1: Allocation of surveyed wetlands on Kooragang Island to Zones; see text and Table 2.2.1 for explanation.

B. **Regions**: each zone is subdivided into two regions. This grouping of wetlands into regions allows (1) the habitat corridor mitigation strategy to be assessed (as this involves comparison of the northern vs southern parts of the Industrial Zone), and (2) equivalent subdivisions of the other two zones.

- Northern Zone:
    - i. Hunter River North
    - ii. School House
- Central Zone
    - iii. Cobban's Creek
    - iv. Bellfrog Way
- Industrial Zone
    - v. Industrial Zone North
    - vi. Industrial Zone South

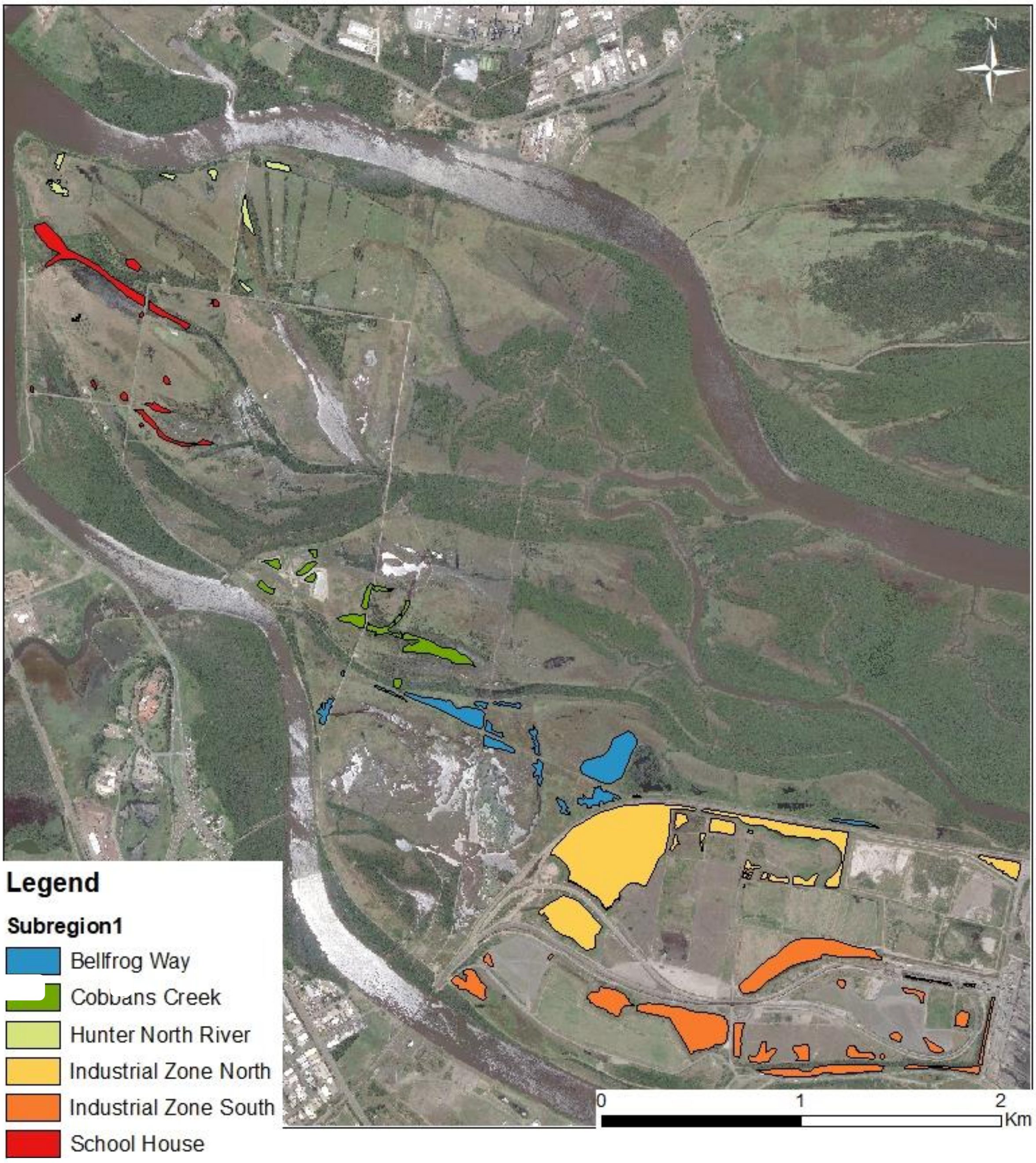

Figure 2.2.2: Allocation of surveyed wetlands to Regions. See text and **Table 2.2.1** for explanation.

C. **Subregions**: the regions are subdivided into a number of subregions, each at a consistent spatial scale (<1 km across) and determined by natural and artificial boundaries such as creeks, roads, and rail-lines. Grouping of wetlands at this scale is required for assessment of the rail infrastructure mitigation strategy and the constructed wetlands strategy:

- Hunter River North
    - a. Scott's Point
    - b. Riverside Park
- School House
    - c. Wet meadow
    - d. Millam's Pond
- Cobban's Creek
    - e. Ramsar Road West
    - f. Ramsar Road East
- Bellfrog Way
    - g. Bellfrog Way West
    - h. Bellfrog Way NE
    - i. Bellfrog Way SE
- Industrial Zone North
    - j. Delta Ponds
    - k. KIWEF *K7*
    - l. Deep Pond
- Industrial Zone South
    - j. NCIG rail central & east
    - k. Rail loop (*K10 North*)
    - l. Cormorant Road
    - m. Rail loop SW (*K10 South*)
    - n. KIWEF *K2*

Note that 'K' numbers relating to the KIWEF nomenclature of areas within the industrial zone are shown in *blue italic* font, and should not be confused with the 'K' numbers used in the UoN nomenclature for surveyed wetlands (the latter are shown in normal font).

A full list of the wetlands included in each zone, region, and subregion is included in Table 2.2.1.

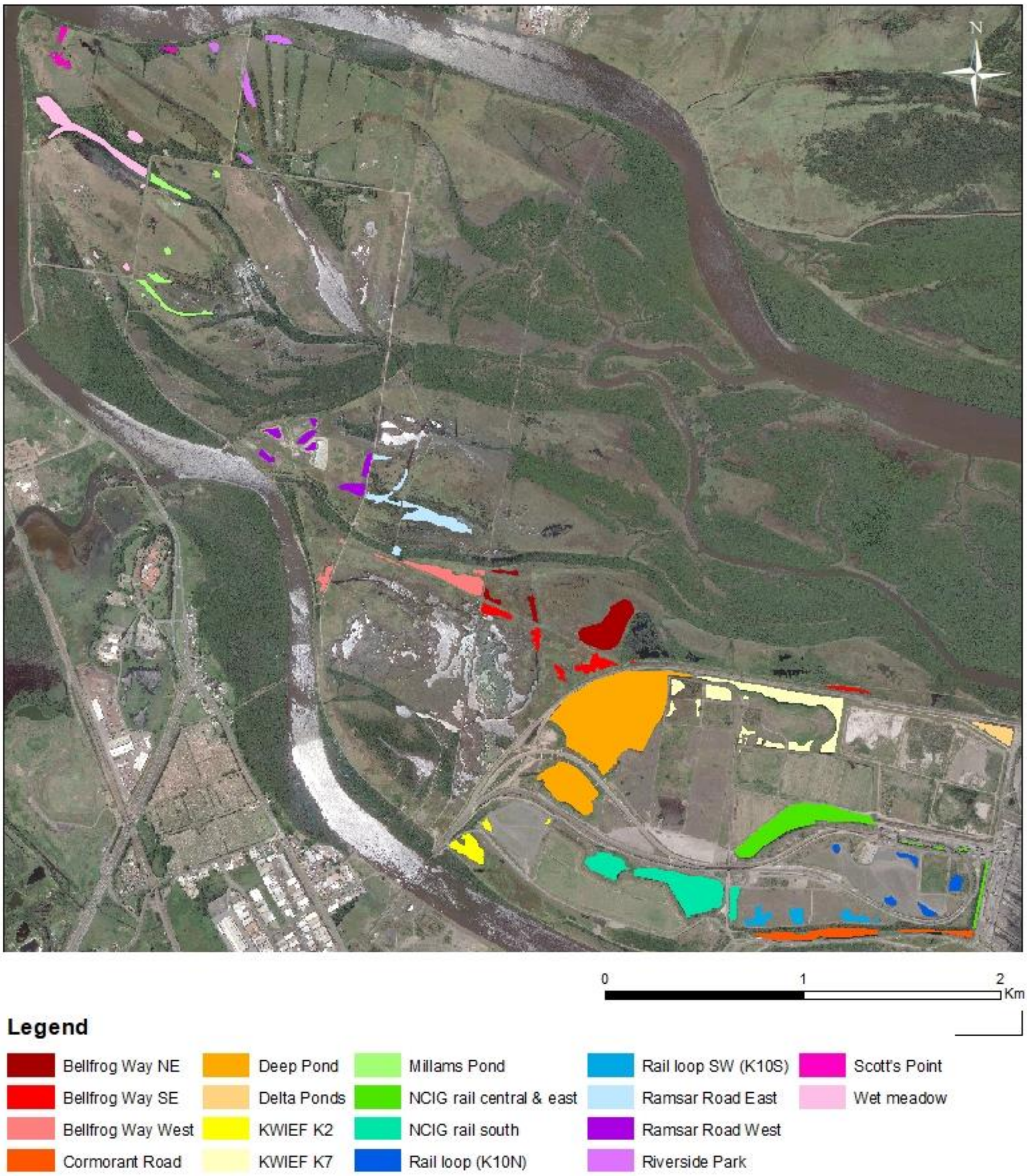

Figure 2.2.3: Allocation of surveyed wetlands to Subregions. See text and Table 2.2.1 for explanation.

Zone	Region	Subregions	Wetlands included
Nth	Hunter River North	Scott's Point	K2S, K3, K4; NCIG CHEMP stages 1 & 2
		Riverside Park	K5, K6, K15, K16, K18; NCIG CHEMP stage 3
	School House	Wet meadow	K1, K2, K7, K8, K19 K17; NCIG Trial ponds, CHEMP Stage 6
		Millam's Pond	K7A, K27, K58A, K58B; NCIG CHEMP stages 4, 5, 7
Central	Cobban's Creek	Ramsar Rd West	K9A/B, K9, NWL; BHP CHEMP stages 1-4
		Ramsar Rd East	K9C, K10, K25, K26, K48
	Bellfrog Way	Bellfrog Way West	K45, K45A, K11, K12, K13; BHP CHEMP 14A
		Bellfrog Way NE	K20A, K20B, K21, K63
		Bellfrog Way SE	K20C, K50, K24, K22, K23, K107
Industrial	Industrial Zone North	Delta Ponds	K104, K104A
		KIWEF K7	K106A, K106B, K106C, K29, K103, C1, K30A, K30B, K30, K31, K32, K33, K34, K35, K41, K42
		Deep Pond	K105A, K105AS, K105B
	Industrial Zone South	NCIG rail central & east	K102, K119, K115, K116, K100A
		Rail loop (*K10 North*)	K108, K111, K112, K113, K114, K120
		Rail loop SW (*K10 South*)	C2, K121, K122, K123
		NCIG rail south	K36, K49A, K49B
		KIWEF *K2*	K44, K46, K47, K117, K118
		Cormorant Road	K100E, K100W

Table 2.2.1: Categorisation of surveyed wetlands into Zone, Regions, and Subregions (see text for explanation; see also Figures 2.2.1 to 2.2.3). Wetlands shown in light font were not surveyed in 2017-18.

Jurisdiction

Wetlands sampled on the site for the Whole Island Monitoring Program fall under the following seven jurisdictional categories (see Figure 2.2.4).

- National Parks and Wildlife (NPWS): 14 wetlands (North and Central zones)
- CHEMP (NCIG and BHP): 13 wetlands in the North and Central zones of the National Park.
- Port of Newcastle (PoN): 2 wetlands (Central zone)
- Port Waratah Coal Services (PWCS): 16 wetlands (Industrial Zone)
- Newcastle Coal Infrastructure Group (NCIG): 3 wetlands (Industrial Zone).
- Hunter Development Corporation (HDC): 10 wetlands (Industrial Zone)
- Wetlands previously managed by BHP, but which are now managed by HDC: 2 wetlands (Industrial Zone)

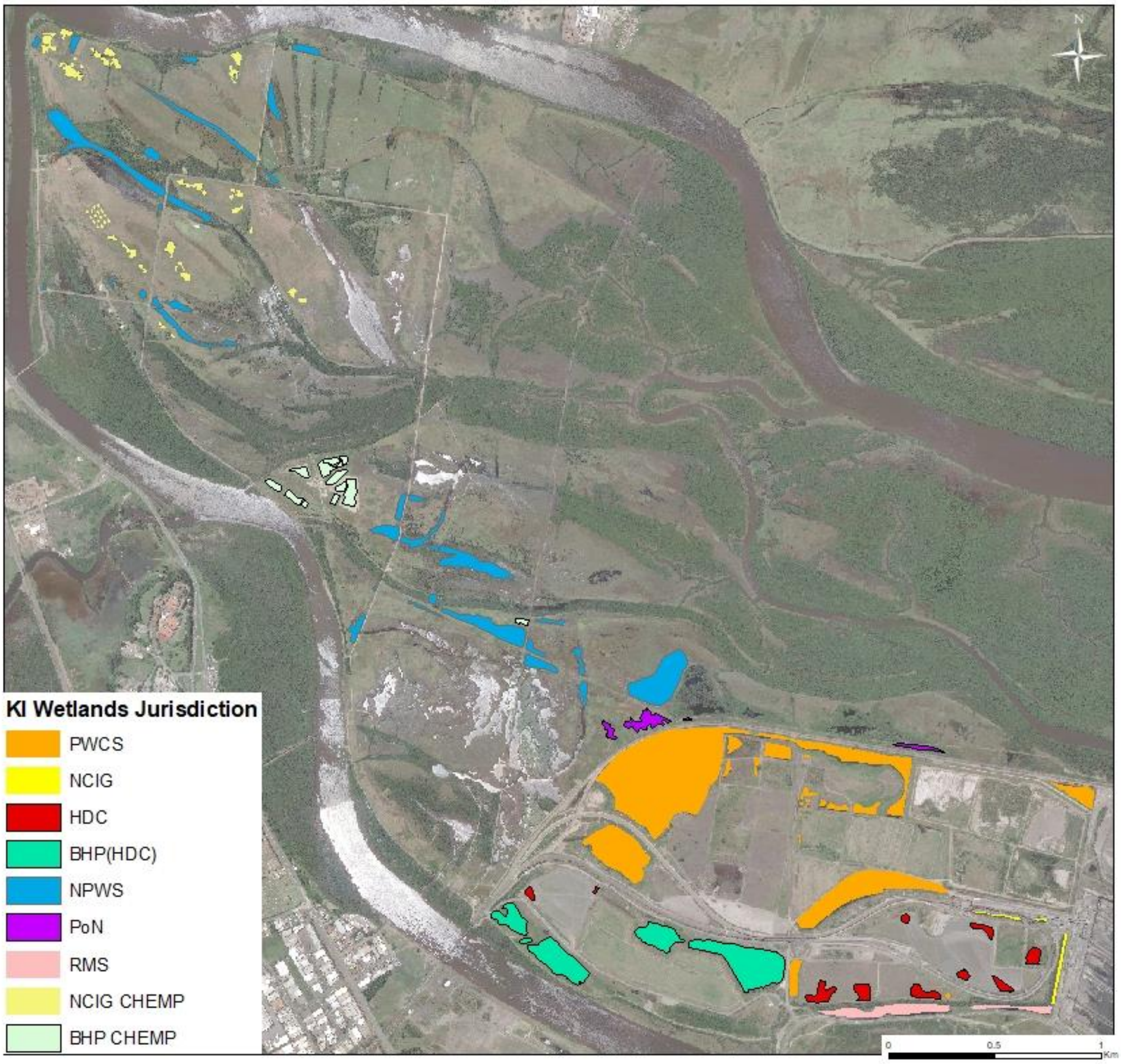

Figure 2.2.4: Named wetlands in the Kooragang Island Management Zone, summarized by jurisdiction. Note that not all of these were surveyed in the 2017-18 season (see text)

2.3 Long-term monitoring approach

The whole island monitoring program has followed a standard method for six years and was established to enable tracking of *L. aurea* distribution and abundance against time. In the past two years significant habitat creation projects and other landscape works have occurred on the site that materially should affect the distribution and abundance of the *L. aurea* population. These new wetlands must be included to enable assessment of the effectiveness of mitigation strategies in increasing distribution and abundance of the *L. aurea* population. Therefore, whilst consistency is important and we aim to monitor within a predefined set of wetlands, we must also be responsive to landscape changes (see Appendix A). Finally, several newly constructed wetlands created by HDC following capping works across the southern part of the Industrial Zone were included in surveys.

2.4 Survey techniques

There were two types of survey used:

i. Visual Encounter Survey (VES)
ii. Capture-Mark-Recapture (CMR)

Both survey types involved systematic night-time surveying by between 2-6 people, using >150 lumen LED head torches. Surveys began by listening for calling activity, before using call playback to try and elicit a response. The survey itself involves walking slowly through the wetland and surrounding terrestrial habitat, paying careful attention to vegetation as *L. aurea* tend to associate with vegetation (mainly emergent reeds). Where wetlands were too deep for wading, we used small personal watercraft (e.g. canoes).

Recording of Climatic conditions

Climatic variables were recorded at regular intervals during each night of surveying. We recorded: temperature, dew point, wet bulb temperature, barometric pressure, average wind speed, maximum wind speed, & relative humidity, using a multi-probe instrument (Kestrel).

Methodology - Adult Frogs

For each survey, each surveyor recorded

i. Start and end times of survey,
ii. Any frogs (*L. aurea* or other species) heard calling
iii. Water depth (qualitative)
iv. Presence/absence of *Gambusia*
v. Other non-target species of frog seen
vi. For each *L. aurea* encountered:
    - Time
    - Habitat structure (Tree, Reed, Grass, Rock, Ground, Aquatic)
    - Height from ground/water surface
    - Distance from water's edge (where in terrestrial habitat)
    - Size (adult/juvenile)
    - Was animal observed calling?
    - Other relevant observations

In general, we attempted to capture all *L. aurea* observed. This was done using a thin plastic bag (sandwich bags). Captured frogs were labelled with a capture code, and tied in the bag with sufficient air. If the frog was touched during capture, we washed hands with disinfectant gel (NSW NPWS Hygiene Protocol). The capture site was marked with flagging tape or on a sketch map of the wetland.

Captured frogs were processed as follows:

i. Scanned using a Passive Induction Transponder reader to see if the frog had been previously tagged.
ii. If the frog had a passive induction transponder (PIT) tag, the number was recorded.
iii. Visual inspection of frog for injuries, and nuptial pads (to identify males from females).
iv. Snout-Vent-Length was measured using callipers.
v. Body weight was measured using a 10g, 60g or 100g spring balance (Pesola). The frog was weighed in the bag, and then the bag was weighed separately.
vi. The frog was swabbed for chytrid fungus by the standard protocol used by the UoN Amphibian Research Lab (2 strokes on each side of the animal for each of: flank, inguinal region, posterior thigh, palms of hands, soles of feet).
vii. If the animal had not been previously tagged:
    ○ A small tissue samples (piece of webbing from a foot) was taken using a biopsy punch and stored in 70% ethanol.
    ○ A PIT tag was injected subcutaneously into the lower back and manipulated into the inguinal region.

Tadpoles and metamorphs

Where possible, tadpoles were collected in the field and identified in the lab, using the key in Anstis (2002). Metamorphs were identified and classified on the basis of the presence of a tail stub combined with adult colouration.

Data collection

Tissue samples and swabs were marked using the bar code from the PIT label. Processing took approximately 10 person-minutes per frog. An example of the datasheet used to record data during processing is shown. Frogs were returned to their point of capture after completion of the survey.

A single **primary** VES was performed at each wetland during each survey round; three survey rounds were performed between November 2016 and March 2017. In Visual Encounter Surveys, the entire wetland was surveyed for a maximum of 30 minutes. Care was taken not to overlap surveys by each person, or to search the same area more than once. We attempted to keep a uniform survey speed at each wetland, although that did vary between and within wetlands depending on vegetation density. Any frogs captured were processed at the end of the survey, and frogs were then released at their point of capture.

In addition to VES, Capture-Mark-Recapture (CMR) surveys were undertaken at three wetlands. The purpose of the CMR surveys is to provide a locally intense capture effort that can be used to generate an estimate of population size at that location (see Section 2.6), as well as provide large sample sets for demographic and longitudinal data (Sections 3.4, 3.5). In CMR sampling wetlands were surveyed intensively typically for 3 to 4 consecutive nights. For long-term population data comparisons wetlands were chosen for CMR sampling based on their known status as important *L. aurea* wetlands and their inclusion in previous populations estimations. To effectively capture a suitable representation of individuals from a wetland in some cases necessitated multiple surveys per night over consecutive nights. When multiple surveys were required at a wetland, frogs were processed as early as possible the next day and released that evening. As a consequence, the next survey would commence the following evening (i.e. a 2-day gap between consecutive surveys).

Effectively there is no stopping rule or constraint applied with CMR sampling, thus there was no maximum search time; rather, CMR sampling aims to survey the maximum number of *L. aurea* individuals physically possible within time and budgetary constraints. The population estimate for a CMR wetland is compared with the VES results from that wetland to enable the VES results from the whole-island survey to be converted into an estimate of population size for the whole island. To this end, each CMR survey night involved a VES survey for the first 30 minutes, where-after the following 60-90 minutes is termed 'post-VES'. Only one of these VES surveys per round is designated a primary VES; the other two are termed **secondary** VES. Only during the post-VES part of each survey was the rule against non-overlap of search effort relaxed.

2.5 Search effort

VES summary (primary VES)	2014-15	2015-16	2016-17	2017-18
Wetlands surveyed	55	75	71	60
Total wetland surveys	118	150	195	245
Nights of field surveys	38	37	41	48
Total search effort VES (person.minutes)	7,979	8,899	8,861	11,201

Table2.5.1: Survey statistics and search effort for visual encounter surveys for GGBF undertaken under the island-wide surveys across the four most recent seasons.

- In addition to the three principal survey rounds, we undertook additional rounds:
    - These were not as extensive as the principal rounds
    - One in October (Round 0) was for SOS (Save Our Species) surveys
    - One in late March (Round 3.1) targeted response of GGBF to rains in March
    - One in late April (Round 4) was to check for tadpoles and metamorphs in wetlands where breeding behaviours had been observed in March

- We intended to conduct CMR surveys at each of K23, K29, and K104 in each round
    - Drying of wetlands produced unworkable conditions in K23 and K104 during round 2.
    - CMR in K29 in round 3 was dropped in order to conduct additional VES during the autumn rain.

Round	Date	CMR
0	Oct 2017	-
1	Nov-Dec 2017	K23, K29, K104
2	Jan-Feb 2018	K29
3	Feb-Mar 2018	K23. K104
3.1	Mar 2018	-
4	Apr 2018	-

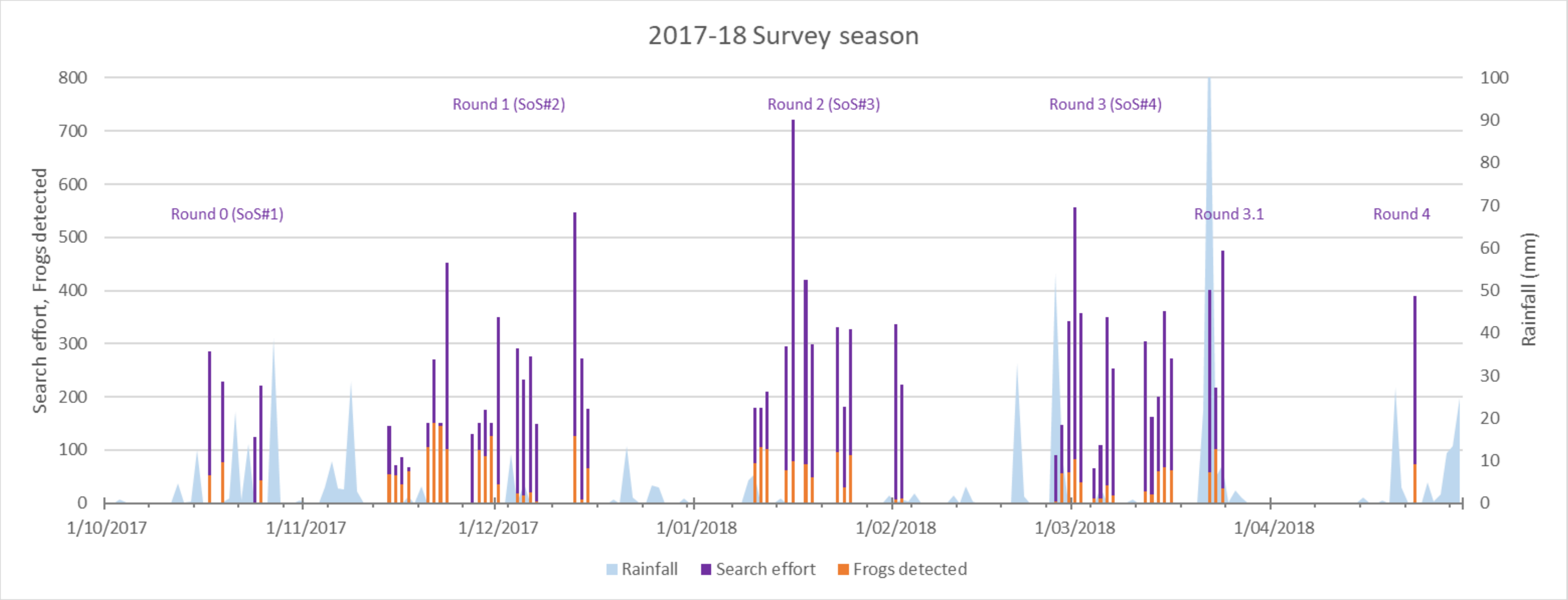

Figure 2.5.1: Search effort and *L. aurea* detections across the 2017-18 survey period, shown alongside rainfall.

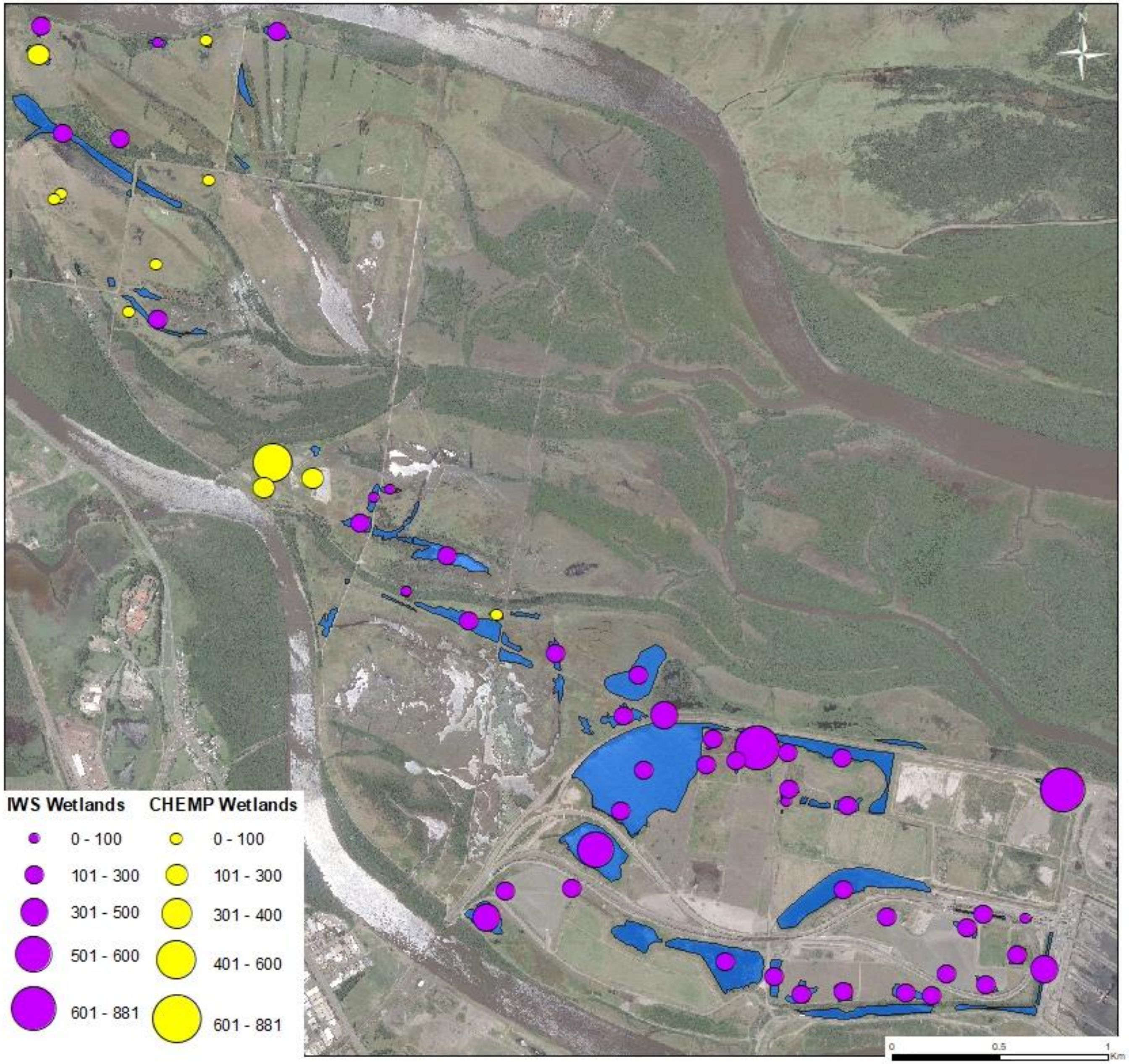

Figure 2.5.2: Search effort (person.minutes) across the 60 wetlands surveyed as part of Island-wide monitoring in 2017-8

Data is for **primary** VES surveys only.

Note that the CHEMP wetlands shown here are only those included in the Save Our Species (SOS) and Island-wide 2017-18 surveys; they do not include all CHEMP wetlands

2.6 Methodological approaches used to address objectives

Robust modelling approach (Pollock's robust design)

Robust modelling of population size is based upon data from Capture-Mark-Recapture (CMR) surveys. Repeated CMR surveys at a wetland provide data on the ratio of captured to uncaptured animals in a population, allowing an estimate of total population size (Figure 2.6.1).

In practice, there are several factors that affect the number of frogs detected at a wetland on a given night, and the total population size at a wetland is only one of these factors. Temperature, humidity, wind speed may all affect the number of frogs that are active during a survey; only active frogs are likely to be detected. An animal may also become warier after it has been captured for the first time – i.e. there is a difference between the capture probabilities of an animal on its first capture and subsequent recaptures – which can be a problem for straightforward population estimates. The statistical approaches of robust modelling can nevertheless account for the effects of these parameters, given sufficiently high quality CMR data. A more detailed overview of the Robust Modelling approach is given in Pollock (1982).

For CMR to be analysed using Robust Modelling, sets of surveys need to be conducted over multiple periods at each location. A basic survey period is termed a primary period; within each primary period, a series of surveys (secondary surveys) are conducted over a short time; these secondary surveys should ideally be no more than 48 hours apart and should continue until the recapture rate within one survey is at least 20% (and ideally up to 70%). The target recapture rate is dependent on the number of individuals captured. A higher number of captures means that a lower recapture rate is acceptable.

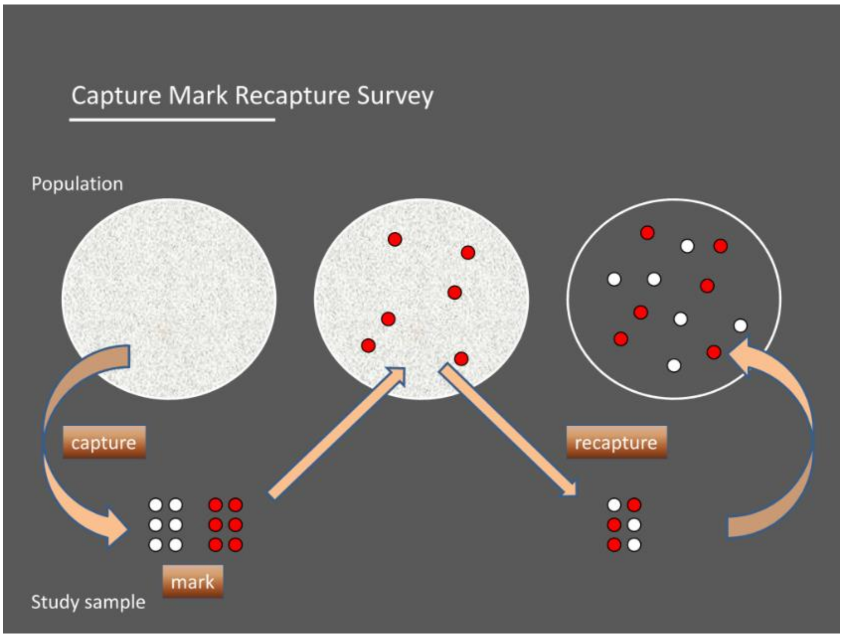

Figure 2.6.1. A simple illustration of capture-mark-recapture survey (based on two capture events only). Left circle: nothing is known about the population size, during the first capture event animals are caught, marked and released. Middle circle: the number of marked animals within the population is known. During the second capture event marked and unmarked individuals are caught. Right circle: the population size can be estimated based on the proportion of marked individuals caught during the second capture event. *Note that this is an over-simplistic depiction of current mark-recapture methods, with Robust Design allowing far more powerful modelling to be completed incorporating closed methods (as depicted here) and open methods in conjunction with one another.

Using the survey techniques outlined in Section 2.4, we compiled CMR data from three locations over two primary survey periods.

- K22/23 (the two wetlands were treated as a single population, based on data from previous years)
- K29 ('The Cell')
- K104

> *N.B. Historically, CMR surveys have occurred at K108 (the rail loop) instead of K104. However, as K108 was completely dry for the majority of this survey season, CMR efforts were necessarily moved to K104 instead.*

See Table 3.8.1 for details of survey periods at each of these.

On its own, robust modelling provides estimates for specific wetlands. In order to extrapolate these into population estimates for the whole island, we use VES survey data. This approach to population estimates relies upon a consistent survey method across all wetlands to be included in the analysis.

Data from CMR surveys were analysed using RMark, which provides an interface with the program MARK using the 'R' programming language. 'R' scripts were based upon those used by Santosatsi et al. (2016).

Assumptions applied to survey effort and population modelling

For analytical purposes we assume that survey efforts were consistent across the entire monitoring season. In reality, there are several important sources of variation:

Within and between individual observers: survey effectiveness can vary among observers. *L. aurea* are generally cryptic, and difficult to see in the different vegetation structures that they are sitting in. To overcome detection bias we used a core of experienced observers within the survey teams but this remains an important methodological limitation.

Within and between sites: *L. aurea* are cryptic and are difficult to see; moreover, they are well camouflaged in a variety of vegetation types. They are particularly difficult to spot in dense vegetation, and so wetlands with dense reeds (many of the wetlands on the northwest part of Kooragang, such as K7, K5, K4; also K13, K21, K108) are expected to have low detection rates for a given abundance of frogs. The highest probability of detection seems to be in wetlands that have a narrow band of *Juncus acutus* surrounding open water that is > 3 metres across and > 1 metre deep (e.g. K23; southern side of K104); during summer, the frogs sit on the edge of the vegetation. The constructed HDC wetlands can also contain high numbers of frogs (e.g. K111 in round 2, K114 in round 3), and the lack of mature vegetation at these sites, combined with their size, makes detection rates high. Conversely, parts of a wetland with dense *Typha* and especially *Phragmites* may hold large numbers of *L. aurea*, but have low detection rates. Weather conditions also influence detection probability; warmer nights with low wind speeds seem to be better for detecting *L. aurea* (although this is difficult to demonstrate quantitatively). Temporal variation in frog detectability can occur across one evening (frogs seem to be more detectable past 1 hour after sunset), across consecutive nights (with weather), and across the season; the evidence is that some wetlands (e.g. K23, K29, K108) are over-wintering sites, from which frogs disperse to ephemeral wetlands during the mid-summer and then return to towards autumn.

So that we could account for the inherent bias produced by habitat complexity all surveys were timed, and the survey effort calculated as part of the detection probability. Thus if a particularly complex habitat was being surveyed the entire wetland was surveyed and the time taken recorded. We also calculated wetland size and perimeter length so that we could assess frog density.

Limiting bias created by different weather patterns and seasonal conditions is more difficult to account for in analysis. To limit the effect of different weather patterns we aimed to accomplish a complete survey of all wetlands in a two to three-week period, thus limiting the impact of short term climate variations. To overcome seasonal effects, the surveys were replicated thrice, one in early summer, one in mid-summer, and a final survey round in late summer/early autumn. Despite this design the summer season of 2016 was punctuated with several large rainfall events that occurred in the middle of and before timetabled surveys. Such events do effect bell frog detection and occupancy at wetlands. Detection of bell frogs is increased when males are actively calling, and during these times they are more active around the edge of wetlands and on the water surface, making visual encounter easier. Associated with large rain events bell frogs disperse from permanent wetlands and move to ephemeral wetlands. In some situations, this may only be a matter of metres and in others it may involve distances of tens of metres. For example, at permanent wetland K104 an ephemeral wetland occurs adjacent to the permanent wetland and the frogs disperse only a short distance, whereas at K22 the frogs move over 70 metres to K63, which covers a large area.

Demographic composition and effective population size

To construct the age-class structure of the bell frog population we determined the age of individual frogs collected by using a growth curve for bell frogs developed on Kooragang Island (see Hamer et. al., 2007 for a description of the method used to construct and verify the growth curve). This approach relies on knowing the relationship between body length, measured as snout to vent length (SVL), and the age of the frog. Since bell frogs have seasonal reproduction (the summer season when reproduction occurs and tadpoles usually metamorphose) most individuals can be placed in a yearly cohort, although animals that overwinter as tadpoles and metamorphose early in the season are known and add a level of complexity to identifying cohorts. Thus, it is possible to assign all individuals to size-classes and express the population demography in age cohorts. In addition to body length the body mass of frogs can be related to age and can also be related to animal condition.

Designation of adult males, adult females, and sub-adult females.

In previous years, we categorised animals into these overall age classes by using body length (measured as SVL), based on the analysis of Hamer et al. (2008).

Adulthood is defined as the capacity to reproduce. In 2015-16, for males this was designated at a SVL of >49 mm), and for females at SVL > 68 mm). Adult bell frogs are sexually dimorphic; females reach a large body size and mass than the equivalent aged males. This provides the scheme used to interpret age/sex class data in last year's analysis:

Age-class determination:

- Nuptial pads apparent → adult male (typically > 44 mm SVL)
- Body length < 44 mm and nuptial pads not apparent → Juvenile (sex unknown)
- Body length > 44 mm, nuptial pads not apparent → juvenile females
- Body length > 68 mm, nuptial pads not apparent → adult female.

The very large number of captures in 2016-17 (see Section 3) provided the opportunity to test these categories quantitatively. Males were determined on the basis of nuptial pads. Since females are identified on the basis of the absence of these pads, there is some uncertainty as to what point a small bell frog can be considered a sub-adult female as opposed to a juvenile.

Plotting the percentage of males captured against SVL (Figure 2.6.2) indicates that, between 50 mm and 60 mm SVL adult males are consistently 60% of the population. At 48 mm, about 35% of captured animals display nuptial pads, but above 49 mm 60% do. An animal above 49 mm without nuptial pads is therefore a sub-adult female (until large enough to be considered an adult female).

Gravid females can be detected by 'candle-lighting', i.e. placing a bright light such as a head-torch against their back, and looking at the silhouetted visceral organs from the ventral surface (Figure 2.6.3). Large females were checked for gravidity ad hoc. The smallest females to be found gravid were 58 mm SVL., and by 68 mm 100% of inspected females were gravid. The onset of adulthood for females is therefore less than 68 mm (used in 2015-16); we used a length of 58 mm in this analysis. Note that this is quite different to the categories used to analyse demography last year and an accurate comparison of the 2015-16 results with the 2016-17 and 2017-18 results would require the earlier data to be reanalysed.

Figure 2.6.2: Proportion of animals that can be confirmed as reproductively mature (i.e. adults), plotted against SVL. Top, males; Bottom, females. In the lower chart, the red line represents the number of females found to be gravid, as a proportion of the animals inspected for gravidity, whilst the blue line shows that number as a proportion of all animals captured. Data from 2016-17 surveys.

Figure 2.6.3: Illustration of the 'candle-light' method of checking for gravidity in females. A large, bilateral mass in the mid to upper trunk region indicates enlarged ovaries and thus gravidity.

The categories used this year are thus:

- ○ Nuptial pads apparent → adult male (typically > 44-58 mm SVL)
- ○ Body length < 49 mm and nuptial pads not apparent → Juvenile (sex unknown)
- ○ Body length > 49 mm, nuptial pads not apparent → juvenile female
- ○ Body length > 58 mm, nuptial pads not apparent → adult female.

3. Results

3.1. Summary of survey counts

	Round 0	Round 1	Round 2	Round 3	Round 3.1	Round 4
	Total	**Total**	**Total**	**Total**	**Total**	**Total**
All Detections	175	1,309	775	527	187	74
VES Detections	169	452	405	229	146	74
Captures	9	960	563	398	111	0
Unique	5	654	393	321	108	-

Table 3.1.1: Summary data from all surveys in 2017-18 season. 'Detections' refers to total encounters (i.e. captures and non-capture observations. Because some individuals are encountered and captured multiple times, 'Detections', and 'Captures' provide overestimates of the number of unique individual frogs actually encountered ('Unique'). Note that only Rounds 1, 2, and 3 where 'full' surveys of all 60 wetlands (see Section 2.5)

The highest number of detections were in the first round (early summer) (Table 3.1.1). Detections declined steadily though the second (mid-summer) and third (early autumn) survey rounds. This pattern is consistent with surveys from previous seasons.

Zones (detections)	**Search effort (VES)**	**VES**	**Total**	**Search Sensitivity**
Northern Zone	1,040	6	11	0.01
Central Zone	2,662	457	737	0.17
Industrial Zone	6,921	978	2,232	0.14

Jurisdiction (detections)	**Search effort (VES)**	**VES**	**Total**	**Search Sensitivity**
NPWS wetlands	1,460	13	13	0.01
CHEMP wetlands	1,819	400	405	0.22
PoN wetlands	423	50	330	0.12
PWCS wetlands	4,563	712	1,927	0.16
NCIG wetlands	574	83	87	0.14
HDC wetlands	1,681	159	217	0.09
BHP (HDC) wetlands	582	58	68	0.10

Table 3.1.2: Location (summarised by Zones) and jurisdiction of *L. aurea* detected.

As with previous survey seasons, the highest number of detections were in the Industrial Zone (Table 3.1.2). The PWCS wetlands support the greatest number of *L. aurea*. A large number of frogs are present within the CHEMP wetlands.

With the additional survey rounds this year (see Section 2.5), total numbers of frogs detected were high (Table 3.1.3). The number of unique frogs detected (on the basis of PIT tags) was the highest of any year so far, but includes animals captured in the additional survey (‘0’, ‘3.1’, and ‘4’) rounds; the total number of unique individuals encountered during the three main survey rounds was 1,155 (see Figure 3.3.3B).

	Primary VES	**Total**
Frogs detected	1,499	3,047
Frogs captured	757	2,041

	Captures	**Unique**
PIT tagged frogs	1,828	1,285

Demographic summary	**Captured**		**PIT tagged**		**Unique**		**Recapture index**
	Number	%	Number	%	Number	%	
juveniles (SVL < 49.5 mm)	554	28%	354	20%	294	23%	1.20
subadult females (49.5mm<SVL<58mm, no nups)	171	9%	171	9%	114	9%	1.50
adult males (>49.5, nups)	838	42%	838	47%	568	45%	1.48
adult females (>58mm SVL, no nups)	438	22%	438	24%	282	22%	1.55
metamorphs	5		-		-		
unknown animals (not tagged)	35		28		28		
	2,041		**1,829**		**1,286**		

Table 3.1.3: Summary of demographic data. Recapture index shows the ratio of captures per unique individuals (i.e. higher values indicate a higher probability of recapture).

For unique animals, the proportion of adult females was similar to the previous year at 22%. Note, however, that this figure is dependent on accurate categorisation of females of 58 mm SVL and greater as reproductively mature adults (see Section 2.6 above and 3.6 below for discussion of this key issue); this categorisation is based upon candling and more reliable data (such as hormonal analysis) is needed to have full confidence in that size threshold. Nevertheless, 22% of tagged *L. aurea* being adult females indicates that survival of females to reproductive age is relatively high. Note that only frogs above 40 mm SVL are tagged, and smaller individuals are counted but not tagged. Thus, the actual proportion of juveniles in the population is much greater than the 23% indicated by PIT tags.

The recapture index for adult females was high (1.55); this means that the probability of recapturing an adult female was greater than for any other demographic.

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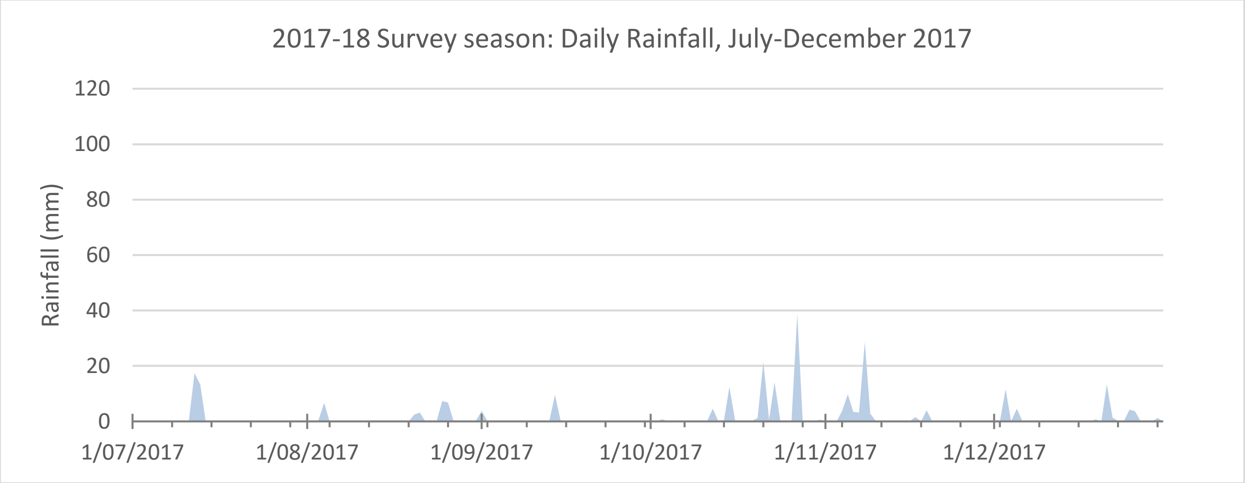
3.2. Seasonal context: environmental factors

Overview

The 2017-18 survey season was characterised by low levels of summer rainfall, followed by heavy rain in early and middle autumn. There was also heavy rain in June 2018.



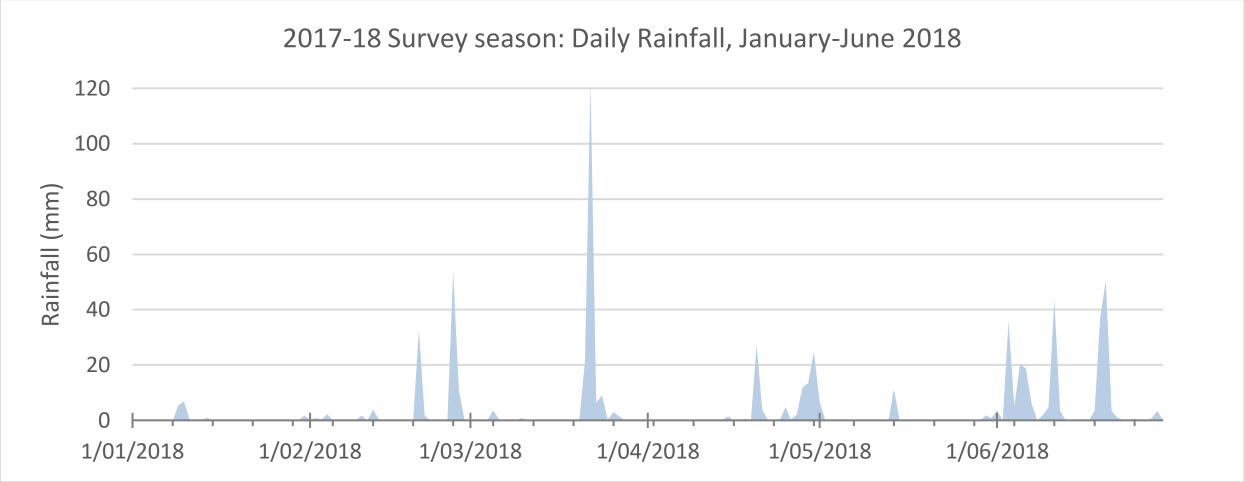


Figure 3.2.1: Weekly rainfall before, during, and after the 2017-18 survey season (October to April) on Kooragang Island, taken from BoM records for Williamtown airport.

Wetlands were reasonably (but not highly) well charged by the end of winter 2017. Low summer rainfall lead to most wetlands being dry by the end of February. Conditions where dry enough for a fire in the northern part of the island to burn out several wetlands in late February.

Most wetlands were well recharged with rain event in early March, with significant rain in late March, and 'top up rain' in late April. Heavy winter rain in early June meant that all wetlands were fully charged through the winter of 2018.

As a result of two dry seasons in a row (2016-17 and 2017-18), *Gambusia* was absent from the majority of wetlands (44/60) by March 2018. For a description of the link between *Gambusia* density and breeding by *L. aurea* see Section 3.6.

Table 3.2.1: Summary of water presence at each wetland per round, along with presence of *Gambusia* and observed breeding. 10 wetlands were dry at the start of the survey period, and 34 were dry by the end of summer. This drying, following an similar drying event in the previous year, has resulted in the removal of *Gambusia* from many wetlands. A large rainfall event in early autumn at least partially recharged the majority of wetlands.

	Hydrology			**Gambusia**	**Breeding**
Pond	Early Summer	Late summer	Early Autumn	Mar 2018	
K2	0	0	0	-2	
K3	0	0	1	2	
K4	0	0	0.5	-2	
K5	1	1	1	-2	
K7	0	0	0	-2	
K58B	1	0	0.5	1	
NCIG_1.1	1	0.5	1	2	
NCIG_3.1	0.5	0.5	0.3	1	
NCIG_4.7	1	0.5	1	2	
NCIG_5.1	0.3	0	0	-2	
NCIG_7.1	1	0.5	1	2	
NCIG_T13	1	0	1	2	
NCIG_T14	0.3	0	0.3	-2	
NCIG_T15	1	0	1	2	
BHP-1A	0.3	0.3	0.5	-2	
BHP-2C	0.5	0.3	0.5	-2	
BHP-3A	0.3	0.3	0.5	-2	
BHP-4B	0	0.3	0.3	-2	
BHP-14A	1	0.5	0.5	-2	
K9A/B	1	1	1	-2	
K9C	1	0	0.5	-2	
K9	0	0	1	-2	
K26	1	1	1	-2	
K48	1	0	1	-2	
K13	0	0	0	-2	
K21	1	0.3	1	2	
K63	1	0.3	1	1	
K22	1	0	0	-2	
K23	1	0	1	-2	
K104	1	0	1	2	tads mets
K103	1	0.3	1	0	
K105A	1	0.3	1	2	
K105AS	1	0	1	0	
K105B	1	0	1	-1	
K106A	0	0	1	-2	
K106B	0	0	1	-2	
K106C	1	0	1	-2	
K29	1	0	1	-1	mets

	Hydrology			**Gambusia**	**Breeding**
Pond	Early Summer	Late summer	Early Autumn	Mar 2018	
C1	1	1	1	-2	
K31	1	0	1	-1	
K34	1	0	1	-2	
K42	1	0	1	-1	
K102	1	0.3	1	-2	
K36	1	0.5	1	2	
C2	1	1	1	-2	
K115	1	1	1	-2	
K116	1	1	1	-2	
K100A	1	0.5	1	2	
K108	0	0	0	-2	
K111	1	0	1	-2	
K112	1	0	1	-2	tads mets
K113	1	0	1	-2	tads
K114	1	0	1	-2	tads mets
K121	1	0	1	-2	tads
K122	1	0	1	-2	tads
K123	1	0.5	1	-2	tads
K46	1	0	1	-2	
K49B	1	0	1	-1	
K117	1	0.5	1	-2	
K118	1	0.5	1	-2	tads mets

tads	tadpoles
mets	metamorphs

0	dry
0.3	low
0.5	intermediate
1	good

2	*Gambusia* present
1	*Gambusia* (re)appeared
0	unknown status
-1	*Gambusia* disappeared
-2	*Gambusia* absent

Hydrology

Figures 3.2.2 to 3.2.4 show the changing hydrology of the wetlands across the 2017-18 breeding season; in early summer, most of the wetlands in the Industrial Zone held good levels of water (Figure 3.2.1). By late February, almost all wetlands were dry, including those known to act as refug sites for large numbers of adult *L. aurea* (i.e. K23, K29, K104), and even large permanent wetlands such as K105A (Deep Pond), K103, and K102 were nearly dry (Figure 3.2.2). In Central part of the island, the only wetlands to hold water at this time were the BHP CHEMP and those 'natural' wetlands that are at least occassionally inundated by high tides (see 'Salinity' below).

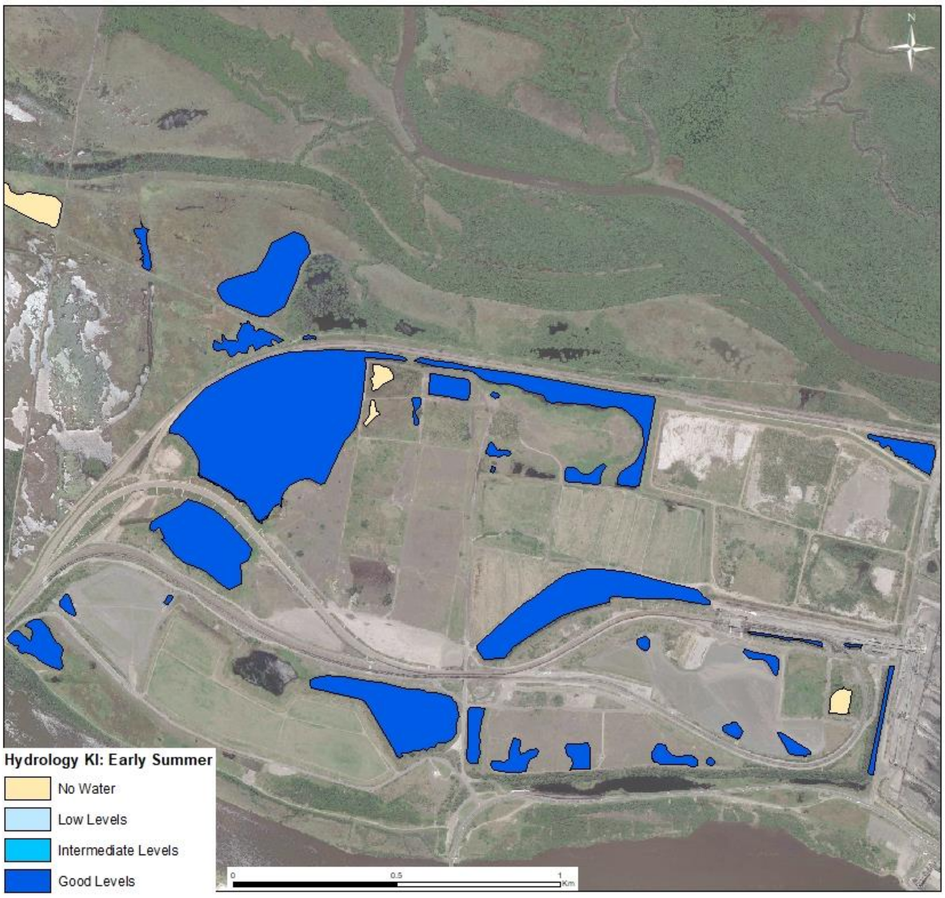


Figure 3.2.2: **Water levels across southern Kooragang Island wetlands in November-December 2017**

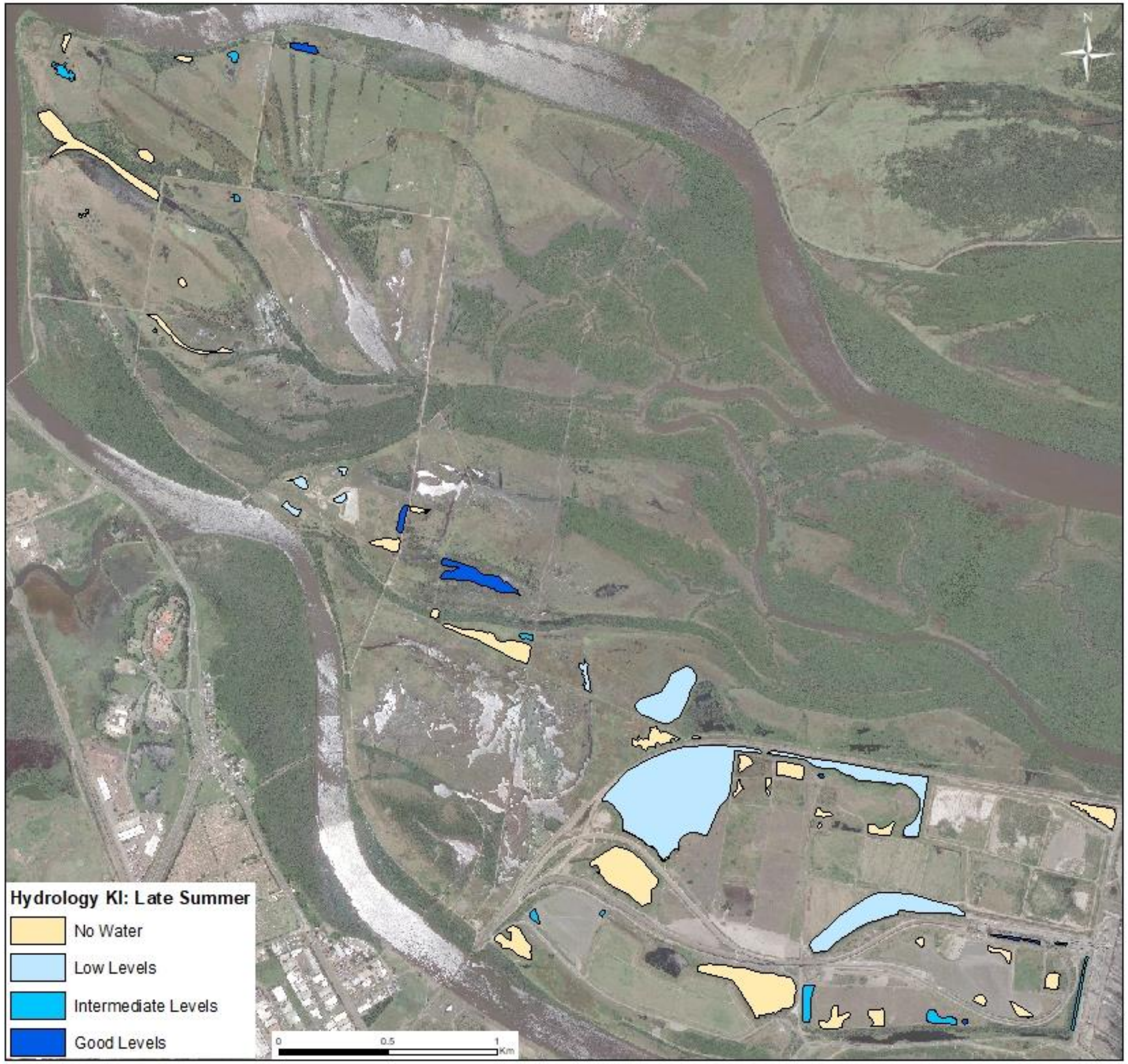


Figure 3.2.3: Water levels across surveyed wetlands in late February 2018, immediately prior to rain on 26th February.

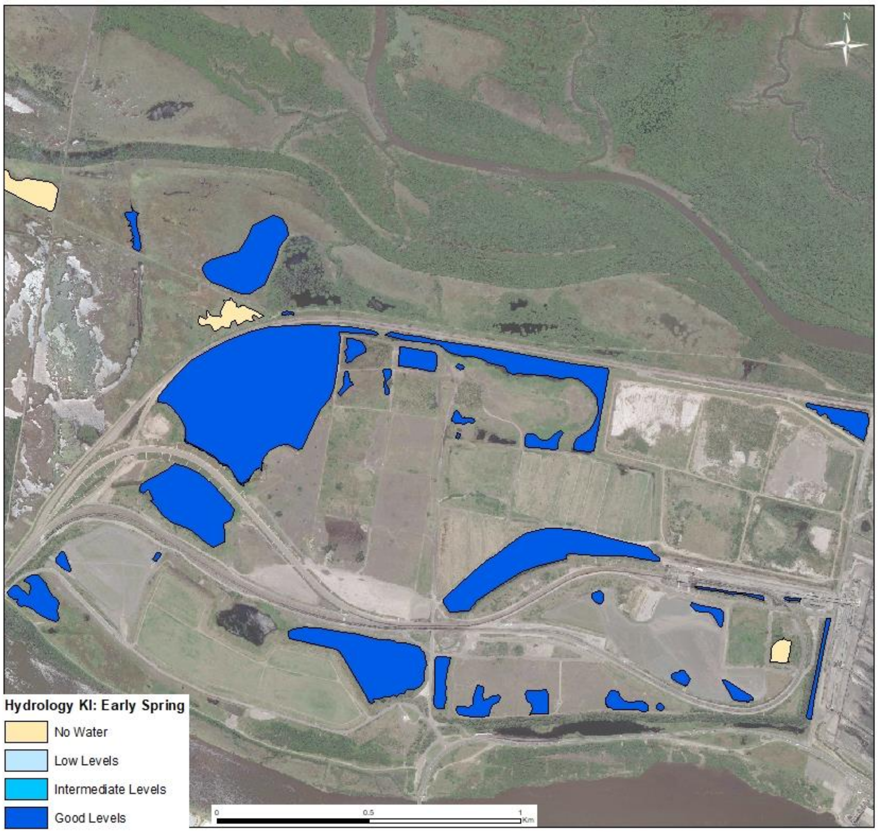


Figure 3.2.4: Water levels across southern Kooragang Island wetlands in late March 2018.

Autumn rain recharged most wetlands, with the exception of K108 and K22. This was the second full season that K108 had not held any water.

Salinity

The maximum salinity levels recorded across the breeding season are shown in Figure 3.2.5. High salinity levels in wetlands immediately north of Bell Frog lane indicate connectivity of these wetlands with estuarine water from the Hunter River. It appears that, when freshwater levels in these wetlands are low (as in drought conditions), they can be inundated by estuarine water during king tides (which did occur during the second round this season).

These wetlands may be hydraulically connected with the high levels of salinity in K48, K26, K9A/B, and K58, and this connection may help explain the consistent presence and reappearance of *Gambusia* in these wetlands (Table 3.2.1).

The wetland K5, in Riverside Park, was constantly saline. It is located very close to the Hunter River, and seems to be tidal.

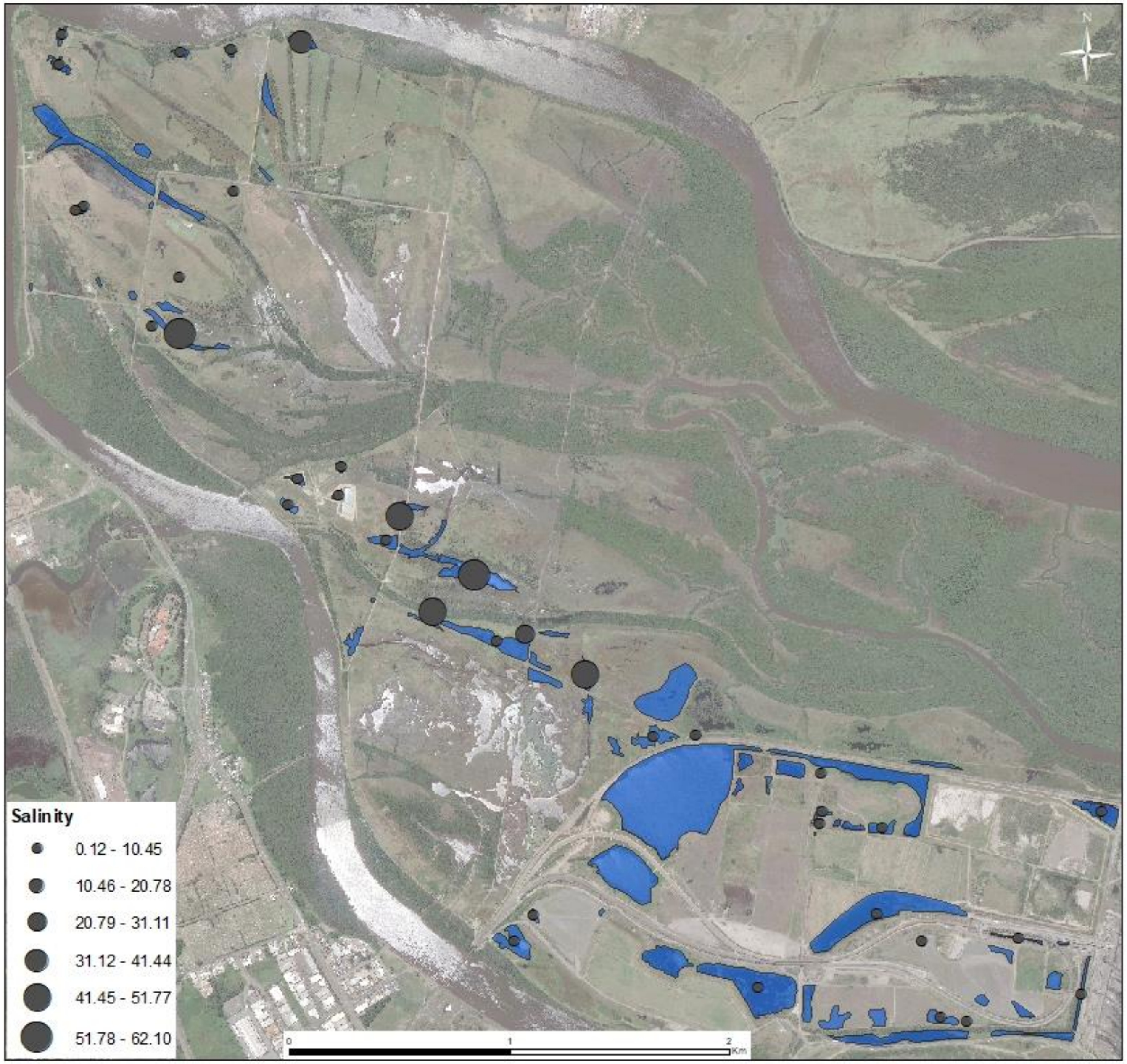


Figure 3.2.5: Maximum salinity levels (ppt) recorded across the 2017-18 survey season

Hydroperiod

Wetland hydroperiod is an important factor in determining *L. aurea* occupancy, abundance, and behaviour. The spatio-temporal mosaic of habitat that provides the requirements for a healthy *L. aurea* population is complex, but knowledge of the hydroperiod of the various wetlands on Kooragang Island allows managers to understand this key factor in that mosaic.

There are two challenges in characterising the hydroperiod of wetlands across Kooragang Island;

1. Collecting data on the hydrology (i.e. water levels and water quality) in each wetland at different times across multiple seasons, and
2. Categorising wetland hydroperiod in a way that is relevant to understanding *L. aurea* ecology.

The categories used in the current research program are refined as we gain more data on wetland hydrology in different years, under a range of weather and climatic conditions. We here present a relatively ‘fine-grained’ categorisation; the advantages of this are, for example:

- It helps explain current *Gambusia* distribution; i.e. by distinguishing between wetlands that did not dry out in a drought year (deep permanent), and those that did dry out, the categorisation system accounts for the distribution and density of *Gambusia* immediately following a drought.
- It better shows range of wetland hydroperiods in locations with good *L. aurea* numbers (e.g. around K29). This subtle variation in wetland hydroperiod within a relatively small area may be an important factor in determining habitat mosaics that support good levels of *L. aurea*.

We here update last year’s analysis with the addition of three categories (Table 3.2.2):

- Saline (regular tidal),
- Saline (irregular),
- Non-breeding ephemeral (very short hydroperiod wetlands.

Table 3.2.2: Categories of wetland hydroperiod used in the present analysis of *L. aurea* habitat on Kooragang Island

Category	Notes	Score
Managed (effectively permanent)	Artificial/operational ponds whose water levels can be regulated by deliberate removal or addition of water. (e.g. cluster ponds, NCIG conveyor ponds)	9
Saline (irregular)	Wetlands that can be influenced by large tides when their own levels of fresh water are low (i.e. a king tide during a drought). Lack of tidal flushing can produce hypersaline conditions (e.g. K26)	8
Saline (regular)	Wetlands that are close to estuarine waters and which are influenced by regular tidal cycles (e.g. K5)	7
Deep Permanent	Deep wetlands that always hold water	5
Nearly permanent	Hold water year around, except in drought (e.g. 2017-18)	4
Semi-permanent	Hold water year around in normal years but not in dry years (e.g. 2016-17)	3
Seasonal (long-term ephemeral)	Hold water for long periods after rain	2
Temporary (short-term ephemeral)	Hold water for short periods after rain (e.g. K106A, K106B), sufficient to allow breeding by *L. aurea*	1
Non-breeding ephemeral	Wetlands that even after significant rainfall only hold water for a period too short for successful breeding by *L. aurea* (e.g. K7)	0

Wetland	Score	Description
K2	1	Temporary
K3	2	Seasonal
K4	3	Semi-permanent
K5	7	Saline (regular tidal)
K7	0	Non-breeding ephemeral
K58B	8	Saline (irregular)
NCIG_1.1	5	Deep permanent
NCIG_3.1	2	Seasonal
NCIG_4.7	5	Deep permanent
NCIG_5.1	3	Semi-permanent
NCIG_7.1	5	Deep permanent
NCIG_T13	4	Nearly permanent
NCIG_T14	2	Seasonal
NCIG_T15	4	Nearly permanent
BHP-1A	3	Semi-permanent
BHP-2C	5	Deep permanent
BHP-3A	5	Deep permanent
BHP-4B	3	Semi-permanent
BHP-14A	8	Saline (irregular)
K9A/B	8	Saline (irregular)
K9C	2	Seasonal
K9	3	Semi-permanent
K26	8	Saline (irregular)
K48	8	Saline (irregular)
K13	2	Seasonal
K21	8	Saline (irregular)
K63	8	Saline (irregular)
K22	2	Seasonal
K23	4	Nearly permanent
K104	4	Nearly permanent
K103	4	Nearly permanent
K105A	4	Nearly permanent
K105AS	4	Nearly permanent
K105B	3	Semi-permanent
K106A	1	Temporary
K106B	1	Temporary
K106C	4	Nearly permanent
K29	4	Nearly permanent
C1	9	Managed
K31	3	Semi-permanent
K34	3	Semi-permanent
K42	4	Nearly permanent
K102	4	Nearly permanent
K36	5	Deep permanent
C2	9	Managed
K115	9	Managed
K116	9	Managed
K100A	5	Deep permanent
K108	1	Temporary
K111	2	Seasonal
K112	1	Temporary
K113	1	Temporary
K114	2	Seasonal
K121	2	Seasonal
K122	3	Semi-permanent
K123	3	Semi-permanent
K46	3	Semi-permanent
K49B	4	Nearly permanent
K117	5	Deep permanent
K118	5	Deep permanent

Table 3.2.3: Categorisation of wetland hydroperiod, updated from the previous year. See text for discussion

Wetlands were allocated to one of these categories, based upon hydrology data from 2015-16 (a very wet year), 2016-17 (a dry year), and 2017-18 (a drought year) (Table 3.2.3, Figure 3.2.6, Figure 3.2.7).

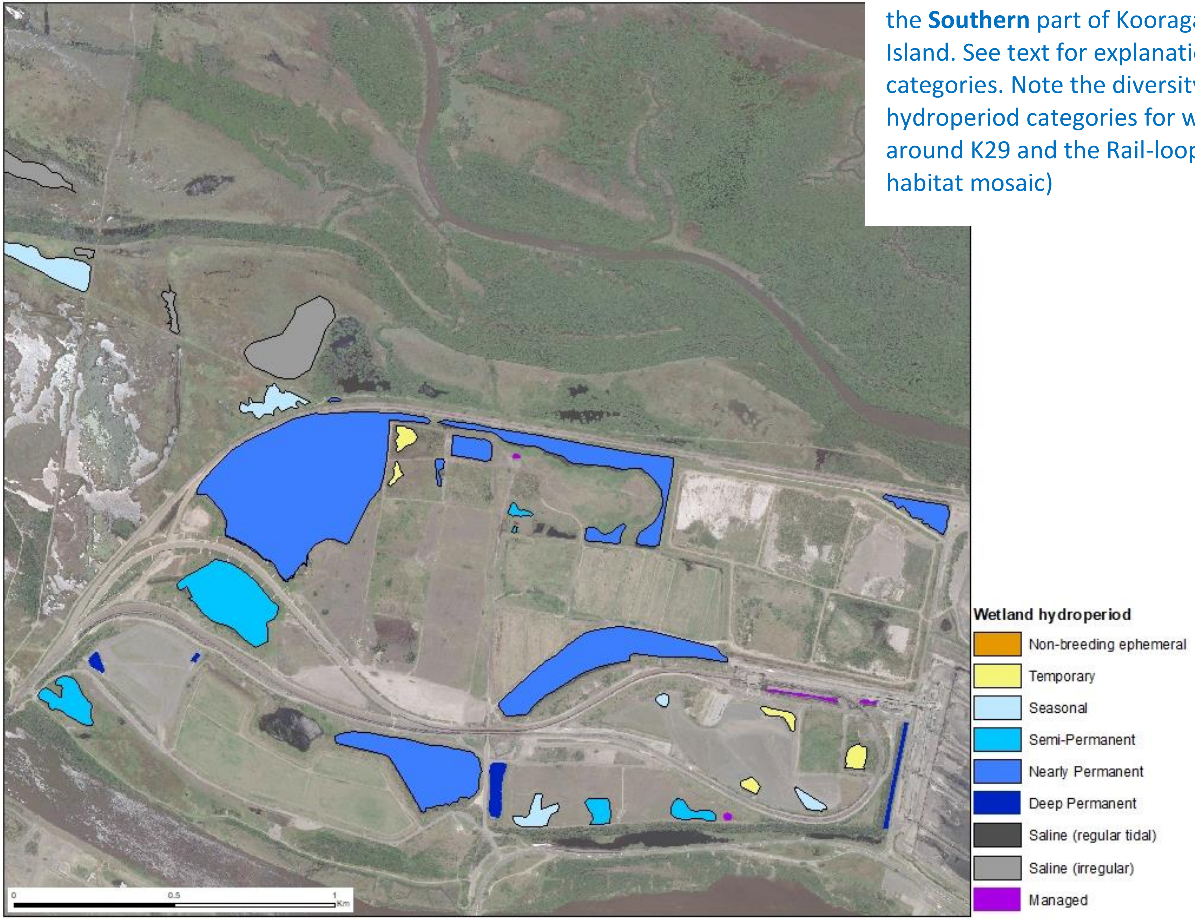


Figure 3.2.6: Wetland hydroperiod in the **Southern** part of Kooragang Island. See text for explanation of categories. Note the diversity of hydroperiod categories for wetlands around K29 and the Rail-loop (c.f. habitat mosaic)

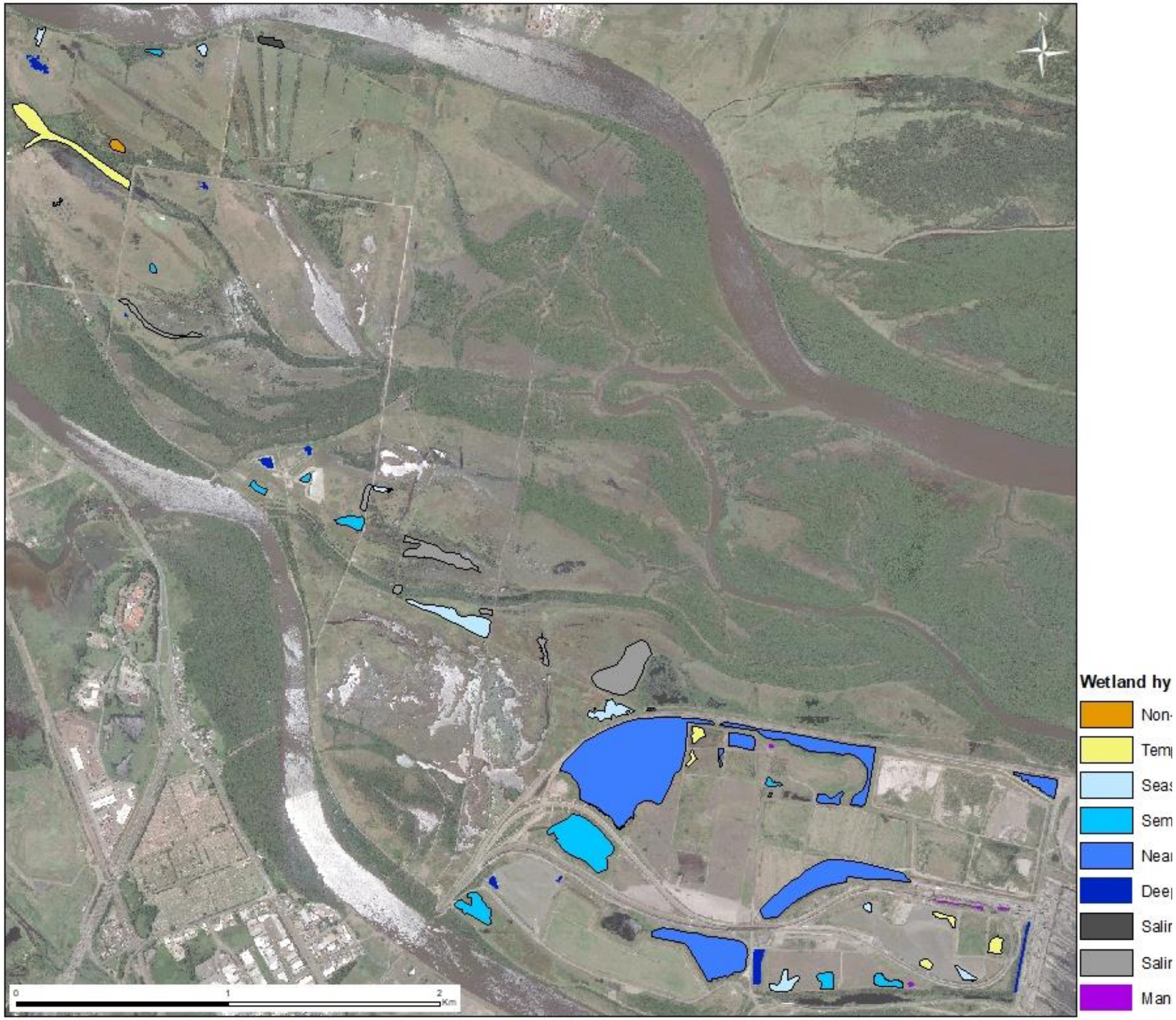
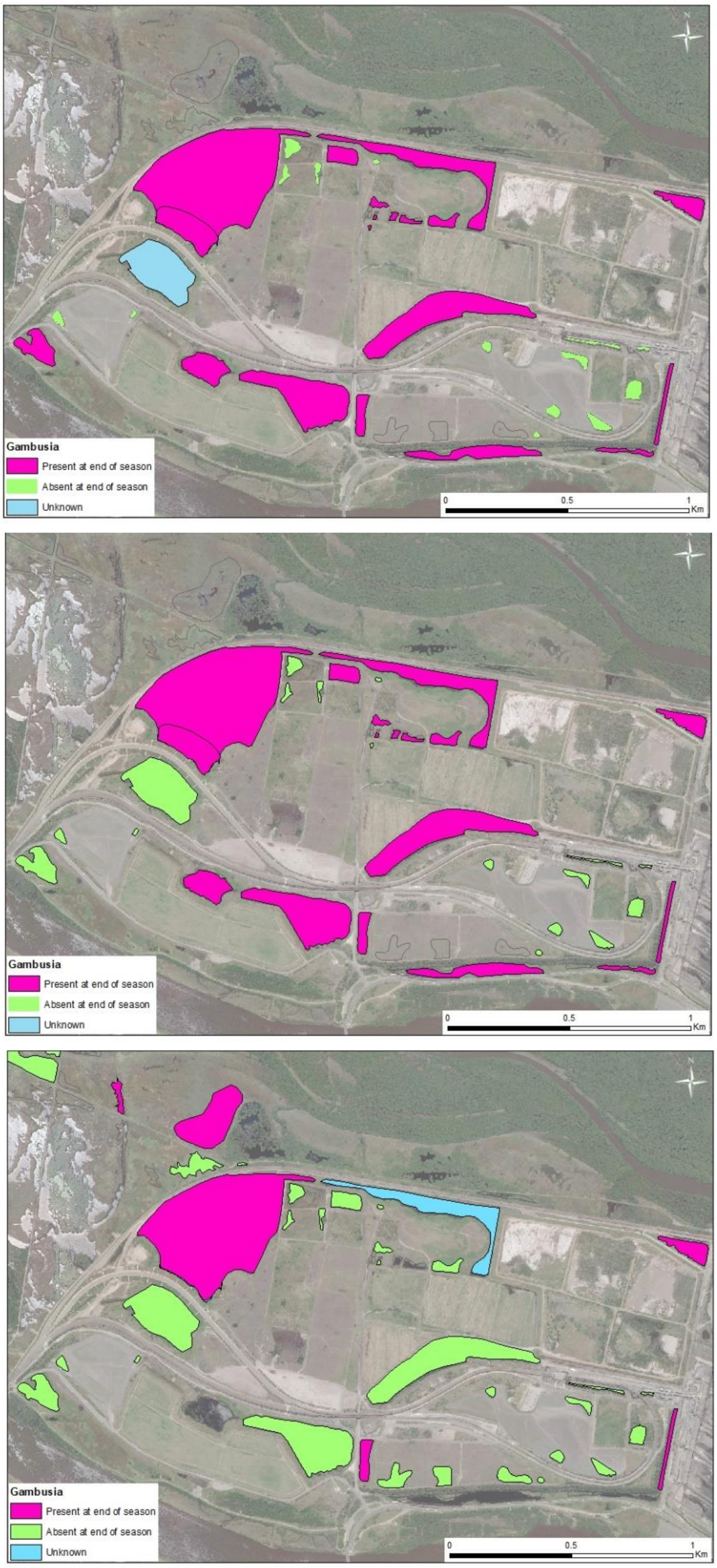


Figure 3.2.7: Hydroperiod scores for wetlands across Kooragang Island, updated using information from the 2017-18 survey season. See text for explanation of categories

Gambusia



Following two consecutive years where summer rainfall was lower than average, *Gambusia* distribution was limited to a small number of wetlands in industrial zone (Table 3.2.1) by March 2018, i.e. K104, K105A, K103(?), K36, K100A. This is a marked contrast with 2015-16 distribution, where *Gambusia* were present across most wetlands.

The dry season in 2016-17 removed *Gambusia* from some wetlands (K105B, K46), and the current season has removed the fish from even more (including K29).

Although present, numbers were low at some wetlands such as K104. This may have been a factor in the breeding event detected there in the early part of the 2017-18 season.

Note that *Gambusia* have always been absent from the constructed HDC wetlands and the cluster ponds.

Figure 3.2.8: Distribution of *Gambusia* across the **Southern** part of Kooragang Island, late summer 2016 (top), 2017 (middle), and 2018 (bottom). After extensive infestation in 2015 following heavy summer rains, two consecutive dry summers have eliminated *Gambusia* from most wetlands.

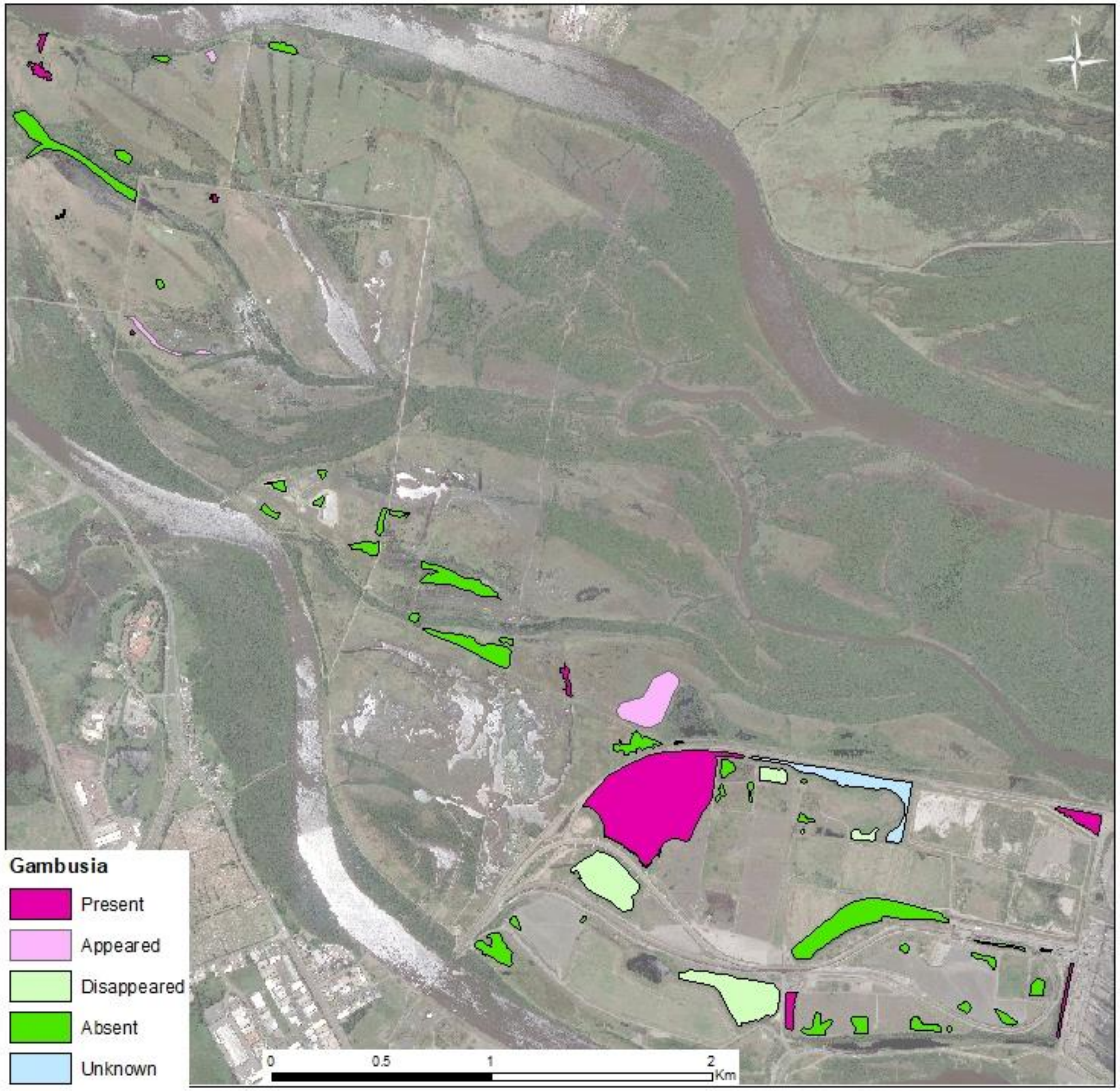


Figure 3.2.9: *Gambusia* distribution across the southern wetlands. Wetland scored as ‘disappeared’ are mostly those that dried during the season. Where scored as ‘appeared’, it is likely that *Gambusia* was always present but was not detected in the first round of surveys. The data for K105A is assumed based upon the pattern of previous years; *Gambusia* present could not be ascertained in March 2018.

3.3. Distribution of *Litoria aurea* across Kooragang Island

.

The distribution of *L. aurea* across Kooragang Island is shown using:

i. Search Sensitivity (a measure of density or relative abundance)

ii. Demographic plots showing absolute numbers detected during standardised visual encounter surveys (VES).

iii. Demographic plots showing absolute numbers detected during all surveys (i.e. VES and CMR)

i. Search sensitivity shows the number of frogs detected per unit search effort – it is thus a proxy for density (although it is also affected by detectability). Figure 3.3.1 shows Search Sensitivity calculated for primary VES for the 3 principal survey rounds. Figure 3.3.2 shows the metric pooled across the whole season.

Frogs were widely distributed across southern Kooragang (as with last year), with very low densities across the northern island. The density in Central zone was high at the BHP CHEMP wetlands.

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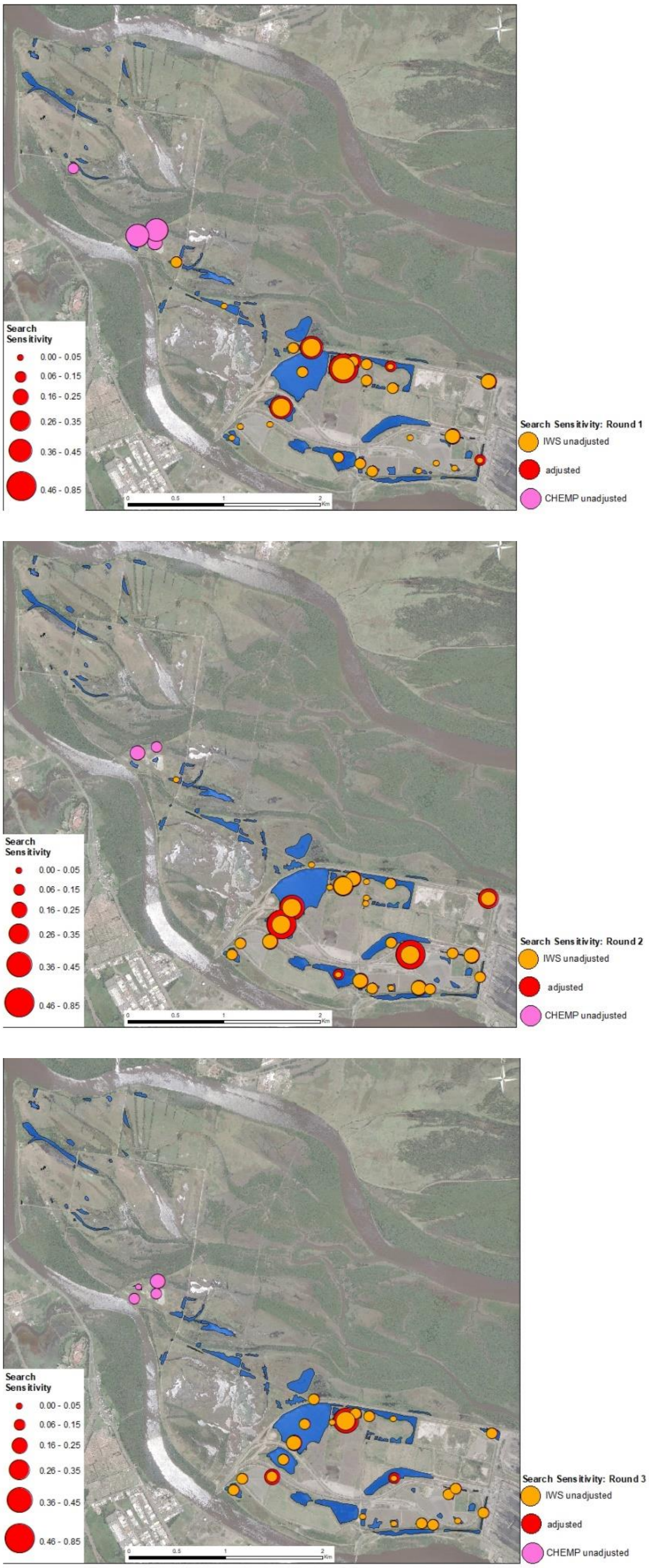


Figure 3.3.1: Search sensitivity (frogs detected per person.minute) across the 60 wetlands surveyed as part of 'whole island' monitoring in 2017-18, for each of the three principal survey rounds.

Data is for **primary** VES surveys only. See Figure 3.2.2 for explanation.

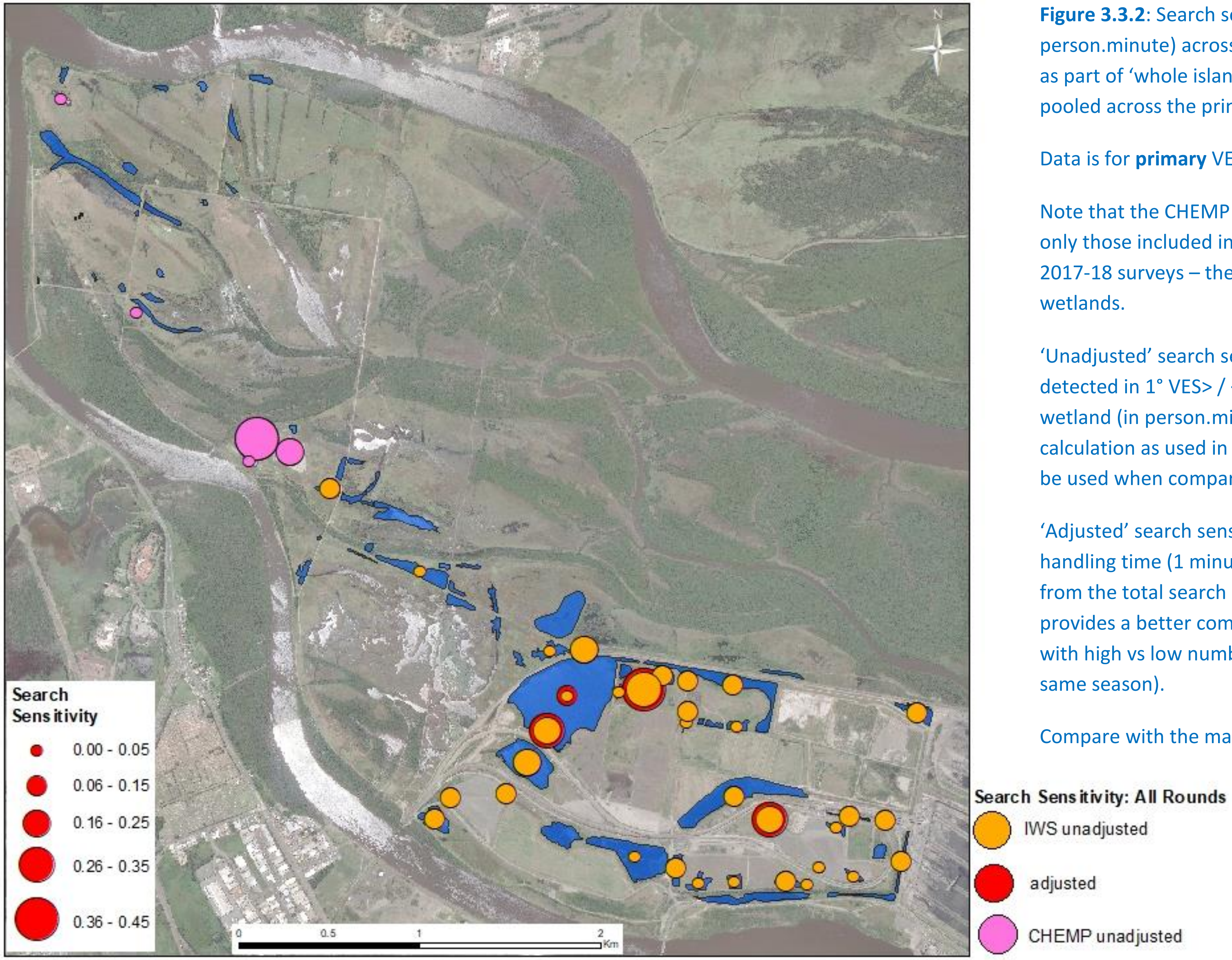


Figure 3.3.2: Search sensitivity (frogs detected per person.minute) across the 60 wetlands surveyed as part of 'whole island' monitoring in 2017-18, pooled across the principal survey rounds.

Data is for **primary** VES surveys only.

Note that the CHEMP wetlands shown here are only those included in the Save Our Species (SOS) 2017-18 surveys – they do not include all CHEMP wetlands.

'Unadjusted' search sensitivity is simply <frogs detected in 1° VES> / <search effort at each wetland (in person.minutes)>. This is the same calculation as used in previous reports (and should be used when comparing data with those).

'Adjusted' search sensitivity deducts a fixed handling time (1 minute for each frog captured) from the total search effort for each wetland. This provides a better comparison between wetlands with high vs low numbers of frogs (within the same season).

Compare with the map of Search Effort (Fig. 2.5.2)

ii. Demographic plots differ from Search Sensitivity plots in that they indicate the actual numbers of *L. aurea* detected during primary VES. They also show a demographic breakdown of those survey numbers.

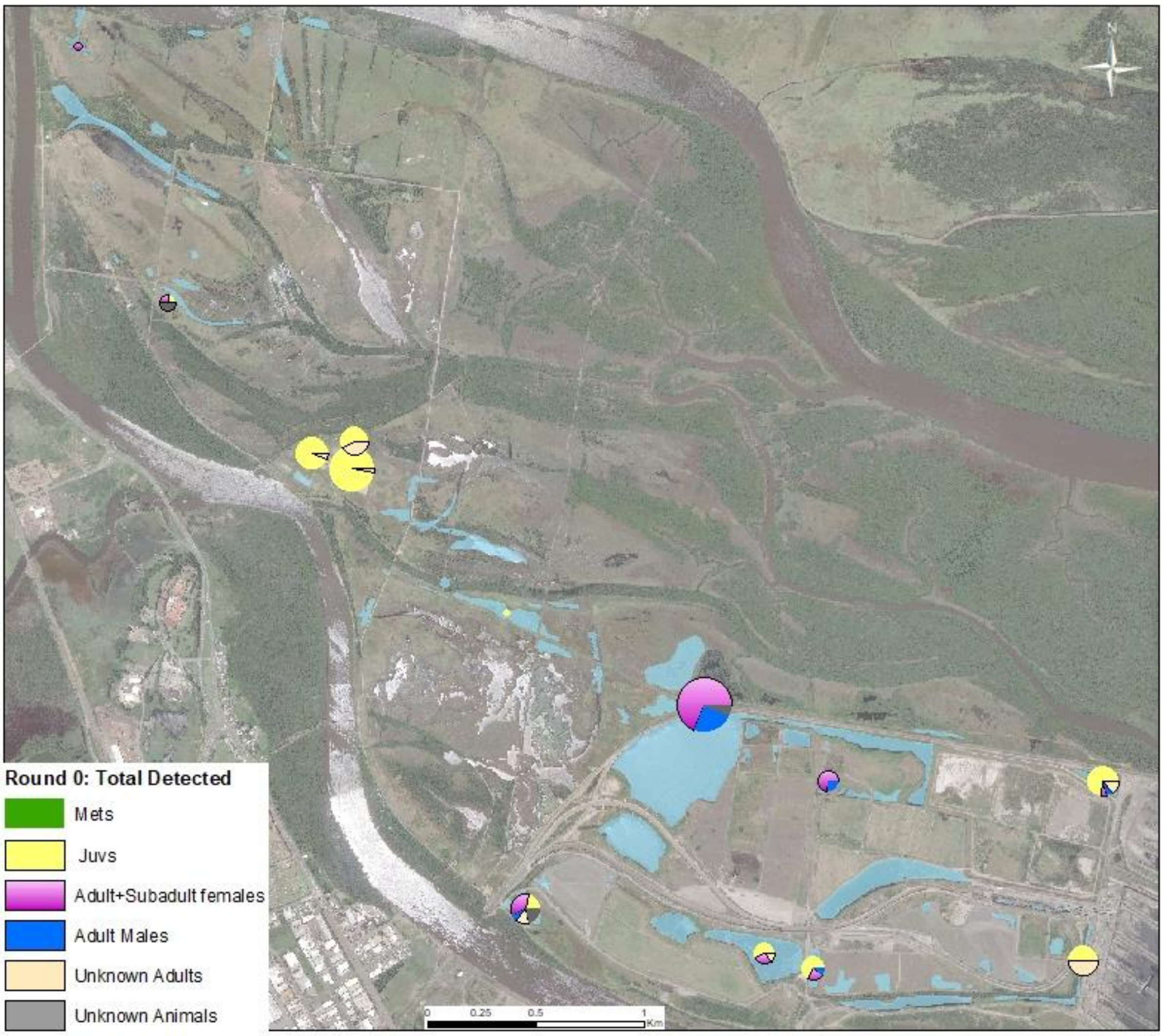


Figure 3.3.3: Demographic breakdown of frogs detected during Round 0 in October 2017. **Total Detected** is shown but only VES were conducted during this round (at a subset of at 30 wetlands across the island). Note that where surveys are primarily visual (rather than capture), it is difficult to distinguish between subadult and adult females and so these categories are grouped together.

Round 0 (mid October): This was a 'partial' survey of 30 wetlands; it provides some information on *L. aurea* activity in the first part of the season. We found large numbers of juveniles in K104, K100A, K36, and K49B, and the BHP CHEMP wetlands; these were presumably frogs that were spawned during the autumn rain event in April 2017. Presumably, these juveniles overwintered as tadpoles.

There was a high proportion of adult females at K23 and K34. Note the large numbers of adults at K46; there was chorusing at that wetland during this round.

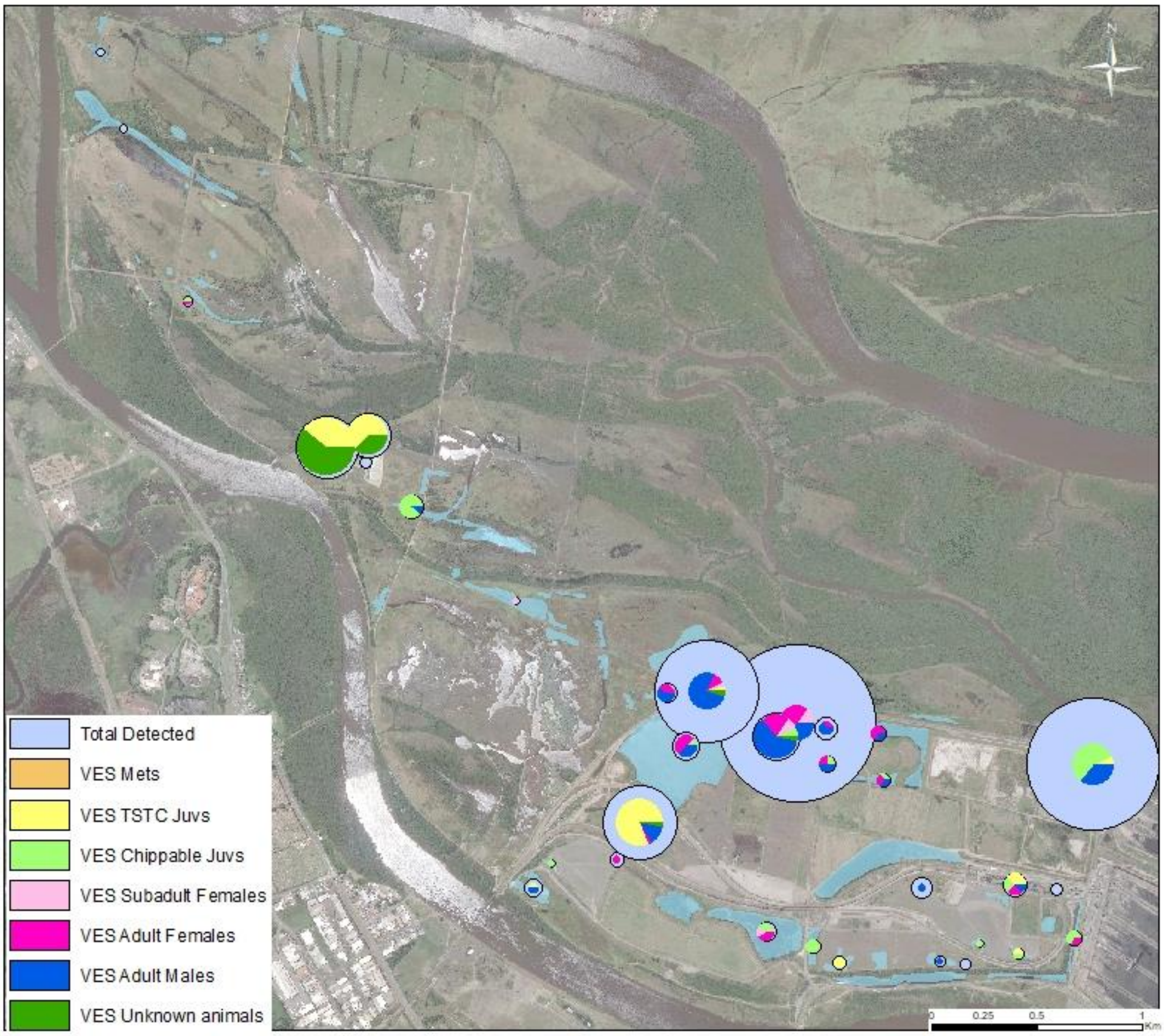


Figure 3.3.4: Demographic GIS plots Round 1. 'Total detected' denotes animals that were detected during CMR and non-primary VES surveys. Breakdown in to demographic groups is based upon data taken from frogs captured during VES surveys only. TSTC = 'Too Small to Chip', i.e. juveniles <40 mm SVL; 'Chippable Juvs' are juveniles that are >= 40 mm SVL. 'VES unknown' are animals detected during VES but not captured or readily identifiable as juveniles/adults.

Round 1 (Late November – early December 2017): This full survey round (with the exception of K102 and K105AS) resulted in the detection of large numbers of small juveniles (<40 mm) at K105B and the BHP CHEMP wetlands. Such large numbers of small frogs are suggestive of a recent breeding event (i.e. autumn 2017) at those wetlands. In addition, there were some small juveniles at K121; this observation is of interest as those wetlands had only been created a few months prior. Larger juveniles (SVL > 40 mm) were present at K9, K104, K36, K100A, and K106C.

Unlike the previous round in October, most of the adults detected were males. The CMR surveys at K23, K29, K104 are indicated by the large circles denoting Total Detected (the inner circles, containing the breakdown of demographic data, show the VES detections).

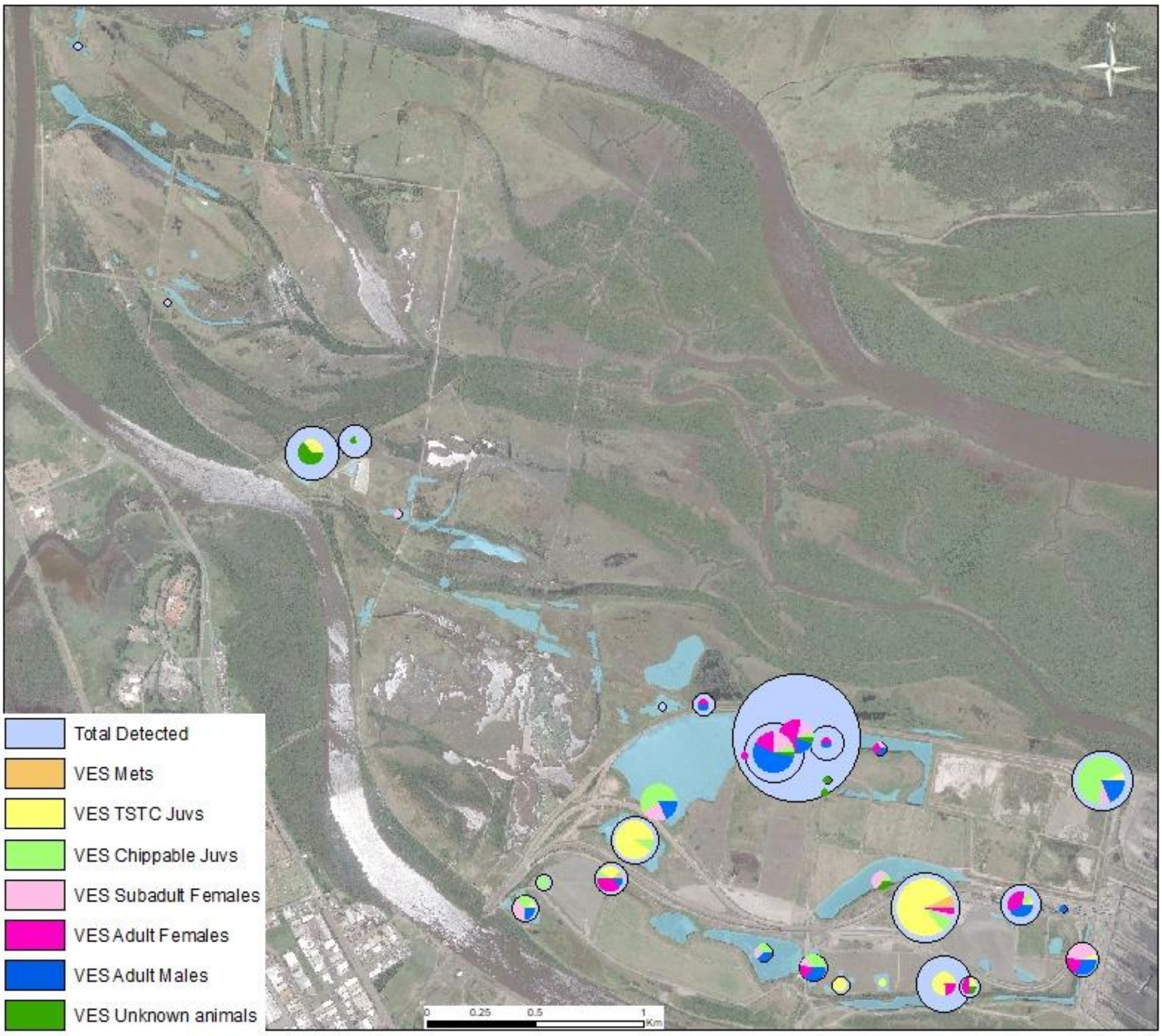


Figure 3.3.5: Demographic GIS plots for round 2. See Figure 3.2.4 for explanation of demographic categories.

Round 2 (late January – early February 2018): This full round was undertaken as many of the wetlands were starting to become dry. There were large numbers of small juveniles at K114 and K105B, that resulted from recruitment in late spring. Small juveniles were also present at K121 and K123. High numbers of large juveniles at K105AS (southern end of K105A) and K104 indicate a slightly earlier recruitment event (very early spring? – see Section 3.6).

Capture-mark-recapture surveys were conducted at K29, but the drying at K23 and K104 made CMR surveys logistically very difficult (soft mud at each wetland), and these wetlands were surveyed only with VES in Round 2.

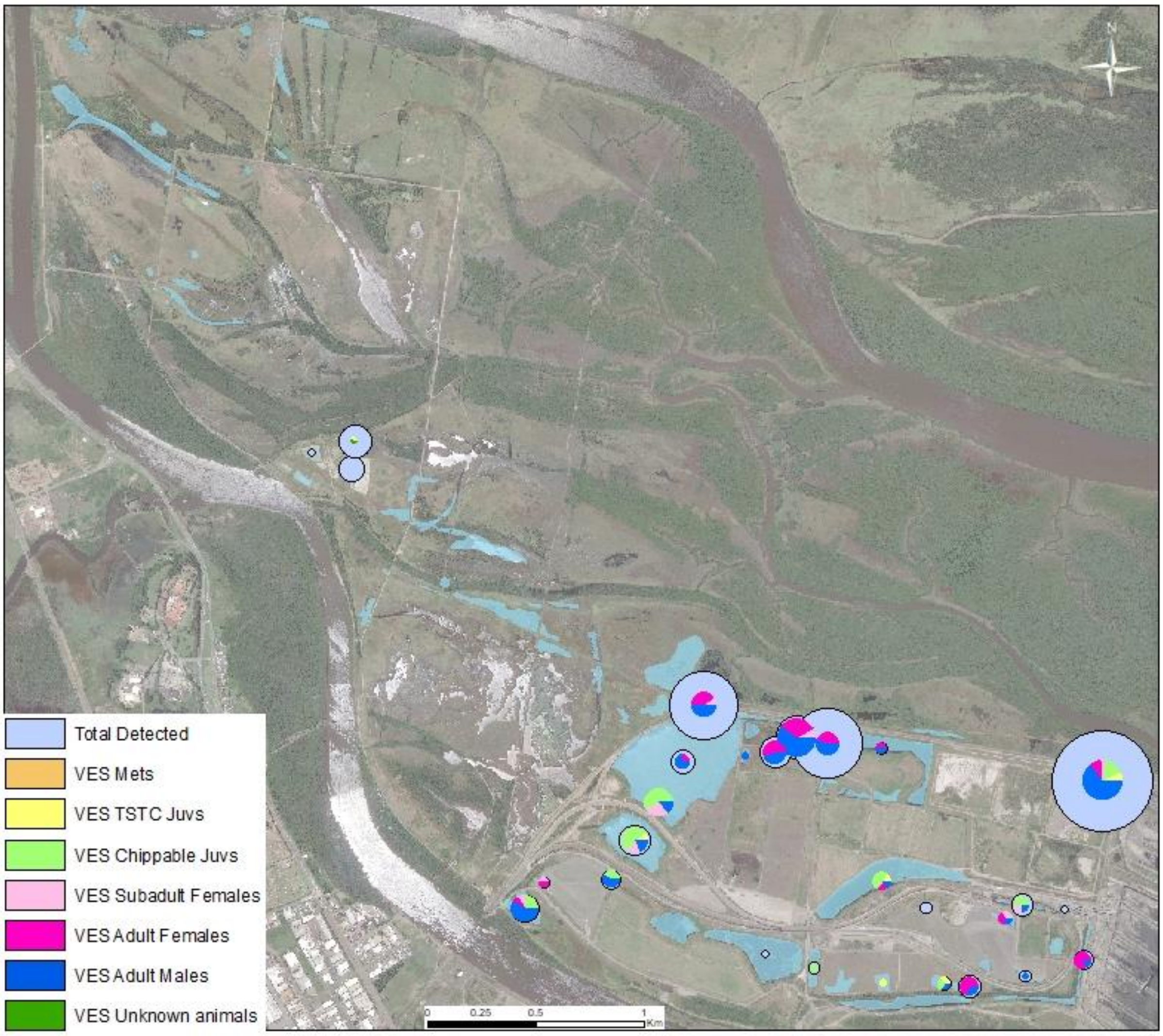


Figure 3.3.6: Demographic GIS plots for round 3. See Figure 3.2.4 for explanation of demographic categories.

Round 3 (late February – early March 2018): Significant rainfall immediately prior to the commencement of this round meant that nearly all wetlands contained water, and calling was heard in many locations (c.f. Section 3.6). Of the adults detected, a high proportion were males. The temporary wetlands such as K106B, which had not contained water all season thus far, now held water and calling males (and a gravid female) were detected there; one of these was marked with a PIT tag and had previously been found in K105A (see Section 3.5).

Capture-mark-recapture surveys were conducted at K22-23 and K104, but not at K29; this decision was made in order to allow for VES surveys across the whole island in the days immediately following the rain so as to gain as full a picture of breeding behaviour as possible.

By the start of March 2018 there were very few small juveniles detected at any wetlands. Large juveniles were present at K105AS and K105B, K118, K46, K36, K102, K115, and K123.

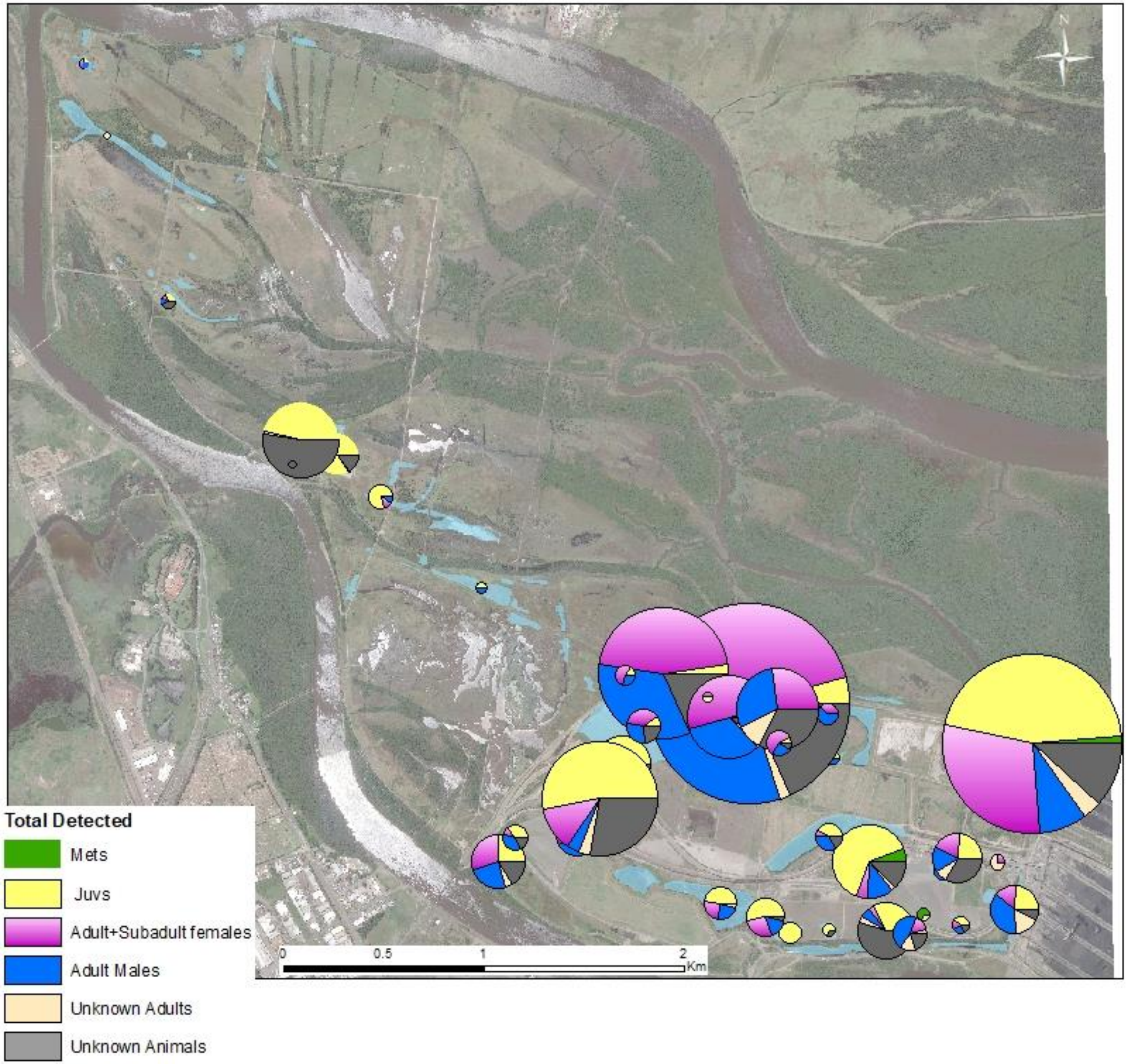


Figure 3.3.7: Demography of all detected frogs during the 2017-18 surveys, summed across all survey rounds. Note that where surveys are primarily visual (rather than capture), it is difficult to distinguish between juvenile and adult females and so these categories are grouped together; similarly, small and large juveniles are not separated (as they are for the principal VES rounds).

iii. Total Detected. VES surveys are standardised, timed surveys of each wetland. However, many *L. aurea* are detected outside of the primary VES, either as part of secondary VES (which are undertaken for a variety of reasons, such as surveying for breeding behaviour following rain), or during CMR surveys.

Figure 3.3.7 shows the numbers of *L. aurea* detected, pooled across all surveys. It shows that there were high numbers of adults around K29, C1, and K106C, whilst there large numbers of juveniles at K104, K105B, and in various wetlands across the southern region of the Industrial Zone.

Viewed by each round, the Total Detected plots further highlight the large number of juveniles at K104 and K105B in round 1 It is not certain whether these animals overwintered as tadpoles, or were spawned in early spring (Section 3.6).

Of the adults detected, a large proportion were females at K29 in the first round, and K104 in the third.

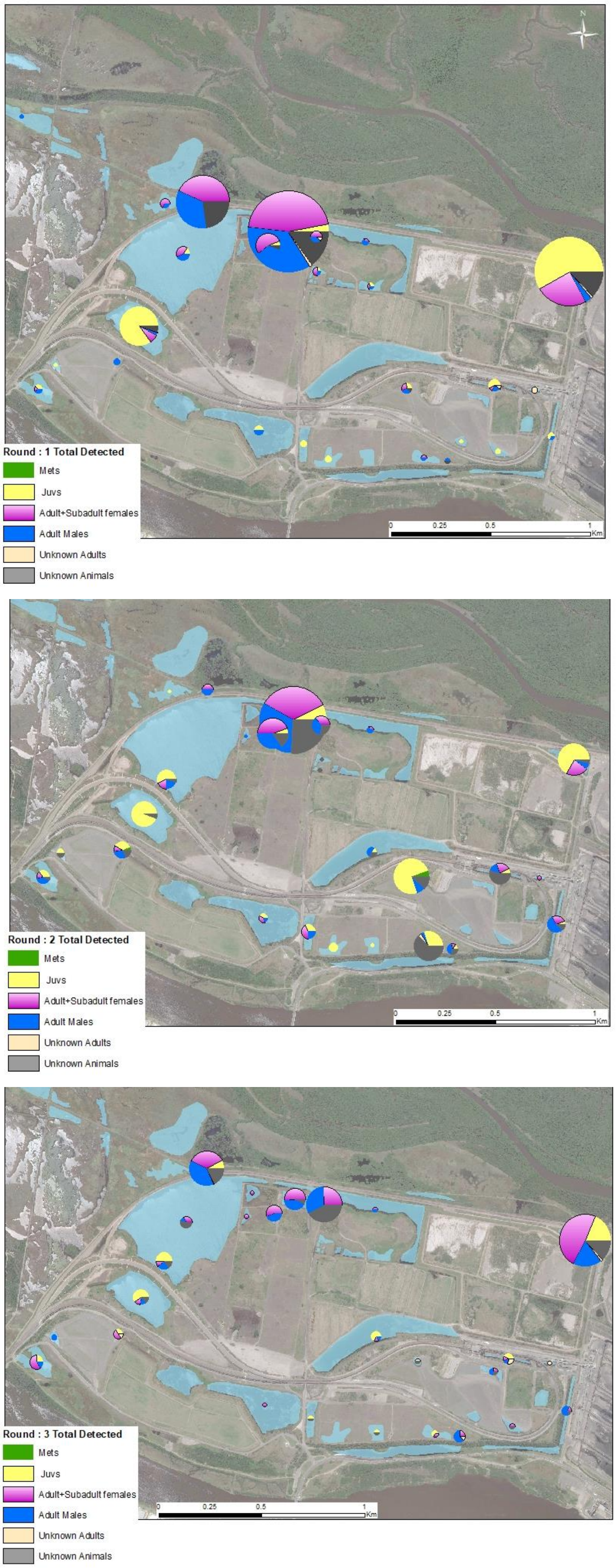


Figure 3.3.8: Demography of all detected frogs during the 2017-18 surveys, broken down to show data for the principal survey rounds. See Figure 3.3.4 for explanation of demographic categories.

For the additional incomplete survey rounds in mid to late autumn (3.1, and 4), there was a high proportion of adult females detected in Round 3.1. Note that this round immediately followed a large additional rain event in late March (Figure 3.2.1).

Following to the early to mid autumn rain and associated breeding, a minimal survey of suspected breeding locations detected numbers of juveniles and metamorphs in round 4, with the largest numbers at K104, but also metamorphs at K29, K114, and K112.

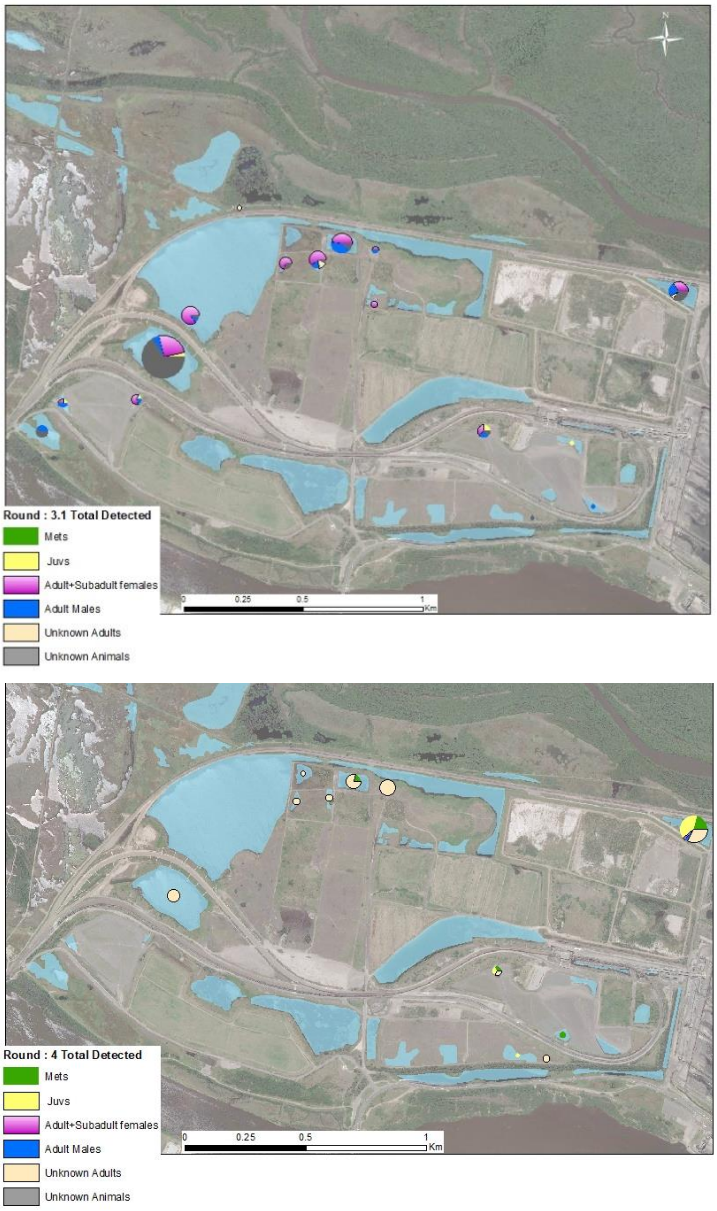


Figure 3.3.9: Demography of all detected frogs during the two additional survey rounds (#3.1 in late March 2017 and #4 in late April 2017. See Figure 3.3.4 for explanation of demographic categories.

3.4. Demographics

Proportions of juveniles, adult males, and adult females

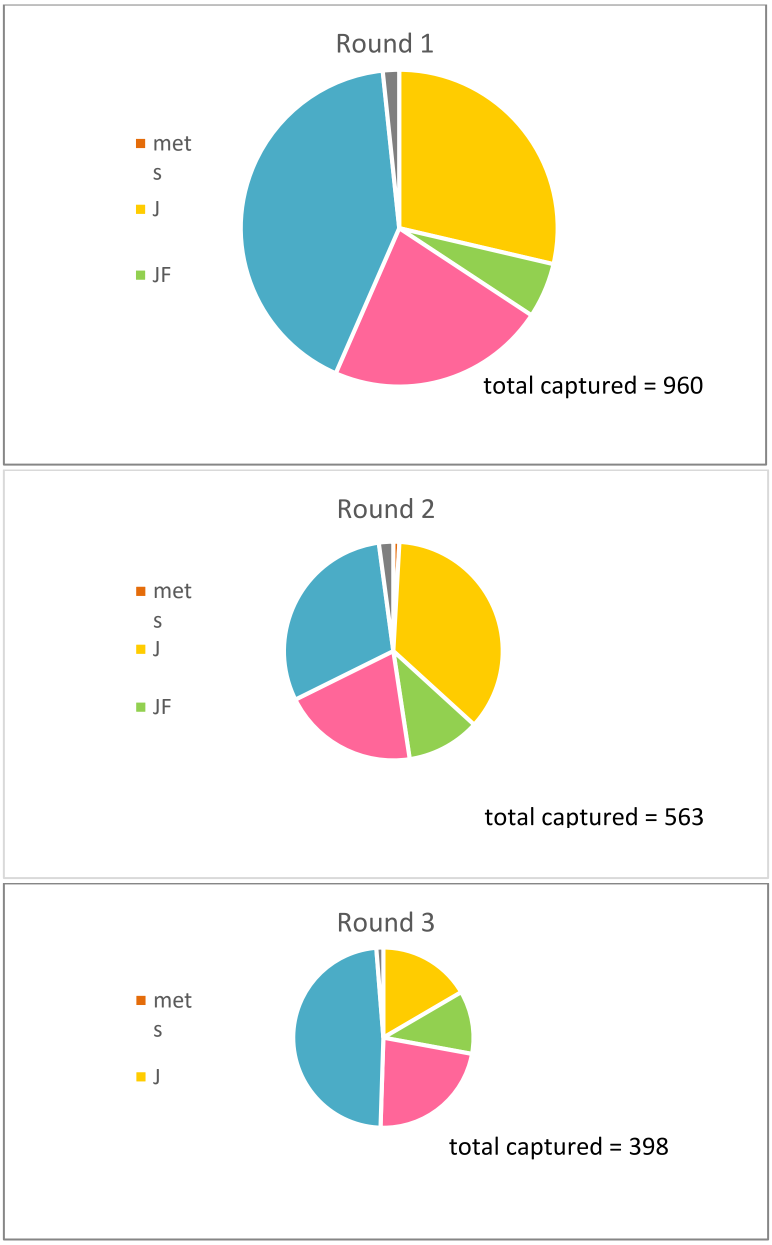
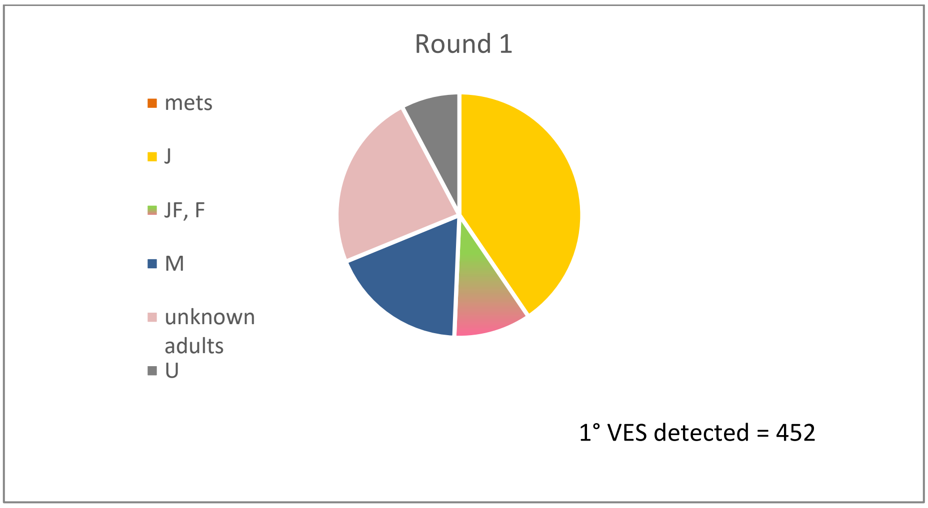
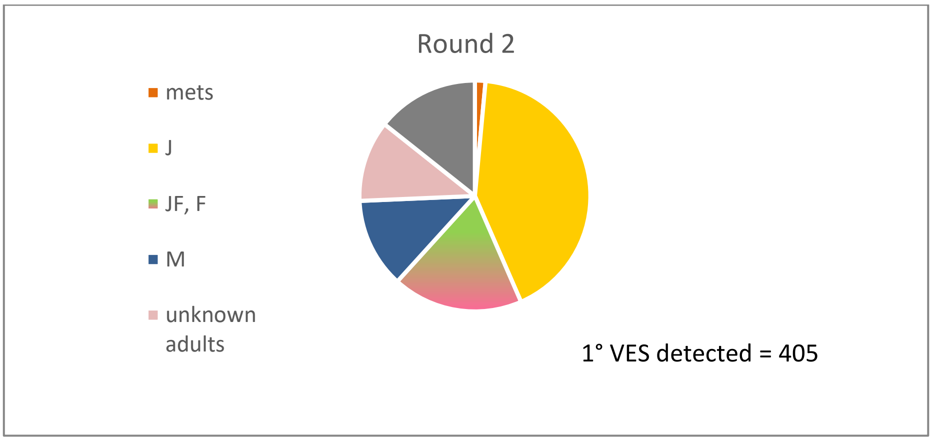


Figure 3.4.1: Summary demographics of all captured *L. aurea* (i.e. VES and CMR, including recaptures and non-tagged individuals), by round. Mets, metamorphs; M, adult males; J, juveniles; JF, subadult females; F, adult females; U, animals of unknown demography.

Figure 3.4.1 presents the demographic data in the preceding section, summarised for **captured** *L. aurea* across all wetlands. Overall, the highest numbers of *L. aurea* were captured in round 1. Approximately 2/3 of frogs captured in that round were adults (mostly males). By the second round, the proportion of adults captured was about 50%, and nearly half of these were females). Most frogs captured in the third round were adults, and most of those were males. Subadult females were always a small proportion of captured *L. aurea*.

VES Demographics





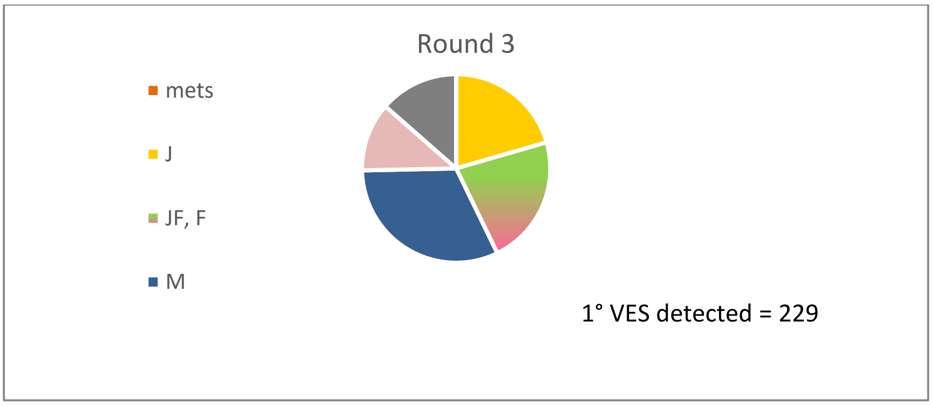


Figure 3.4.2: *L. aurea* detected during primary VES only, by round. M, adult males; F, adult females; JF, subadult females; J, juveniles; mets, metamorphs; unknown adults, *L. aurea* for whom demographic data was not collected.

Figure 3.4.2 shows a summary of the demographics breakdown across all wetlands, for VES detections only (note that for these counts, subadult females and females are counted together). The 'unknowns' are animals detected but not captured (i.e. 'missed'), and include juveniles **and** adults.

There were a large number of juveniles detected in rounds 1 and 2.

Unique individuals

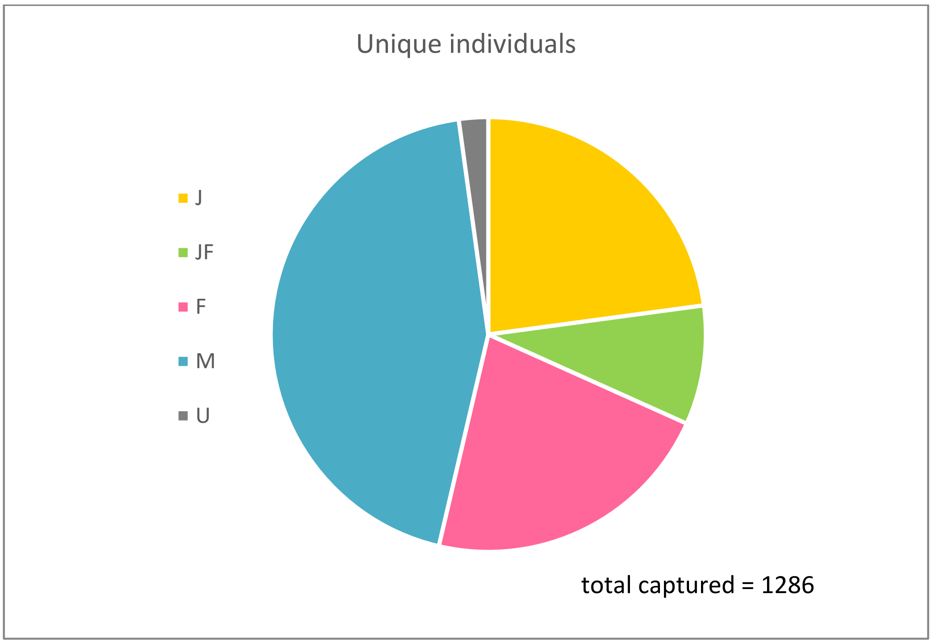


Figure 3.4.3A: Proportions and numbers of PIT-marked individuals captured during 2017-18 VES and CMR surveys. See Fig 3.4.1 for legend.

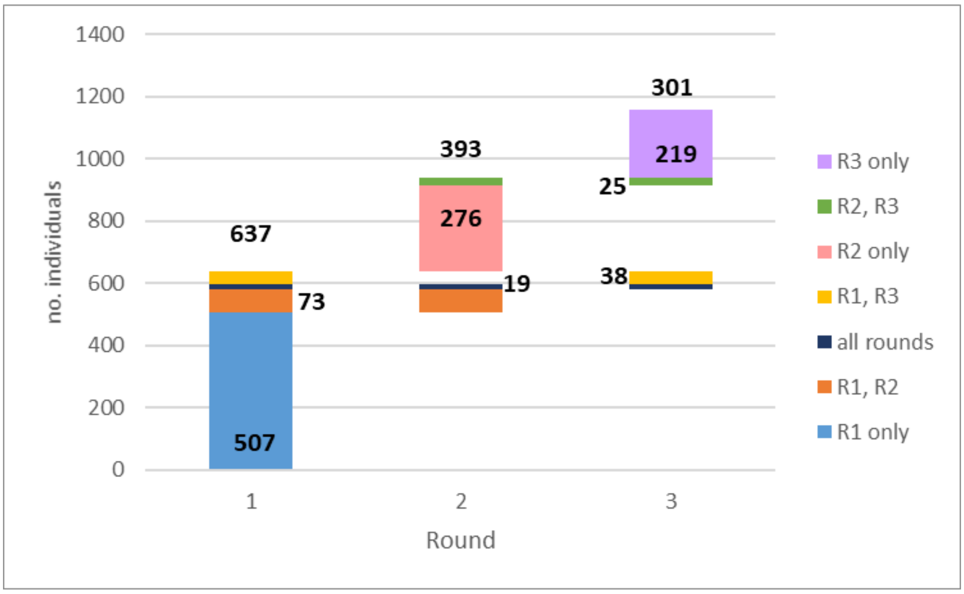
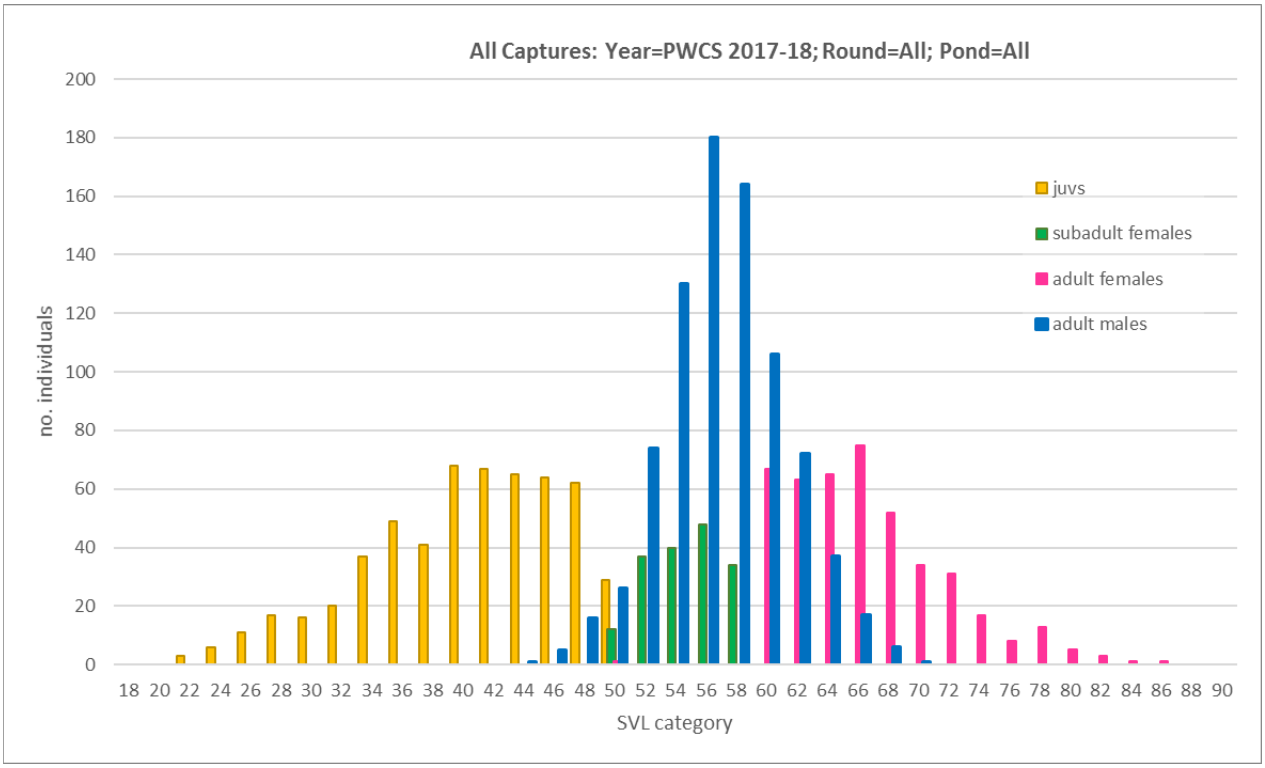


Figure 3.4.3B: Unique PIT-marked individuals captured in each of the three principal rounds, showing those animals caught in multiple rounds versus only one round.

Unique individuals are identified on the basis of PIT tags, and can only be ascertained from captured frogs. Figure 3.4.3A shows that a large proportion of these were adult males, but there were more adult females than subadult females.

Figure 3.4.3B shows the pattern of capture of these individuals across the three complete rounds. Only 19 animals were detected in all 3 rounds, but an additional 136 were captured in at least two of them. These 155 animals caught in more than one round were out of a total 1,156 unique animals detected across these three rounds.

Size classes and cohorts of captured frogs



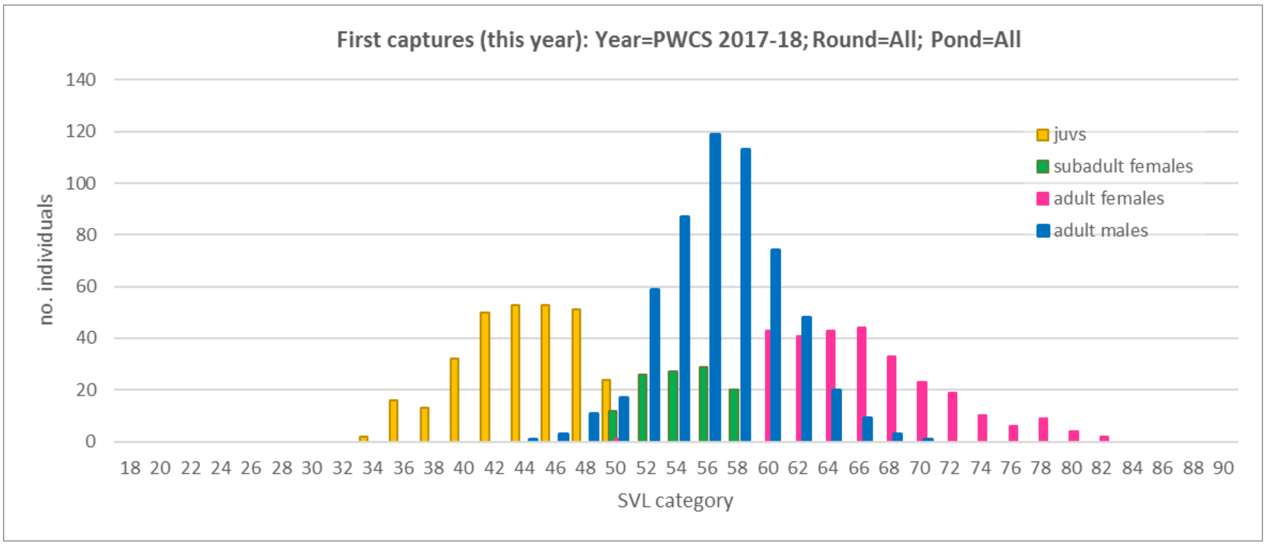


Figure 3.4.4: Frequency distribution of different sized animals captured, for VES and CMR surveys. Size is measured by snout-vent length (SVL), and size categories are measurements 'binned' into 2 mm groups, i.e. the frequency of animals 56 mm > SVL >= 58 mm is shown in the column labelled '58'. **Top**; all captures where demographic data was recorded. **Below**: 'Frist captures' shows only unique PIT tagged individuals (generally, SVL > 40 mm), i.e. with recapture data removed.

Figure 3.4.4 shows the frequency distribution of SVL class (in 2 mm 'bins'). The difference between 'all captures' and 'first captures' indicates (1) recaptured individuals (for SVL > 40 mm), and (2) the number of captured juveniles that were too small to mark with PIT tags.

The numbers of subadult females captured were low. Most adult males were between 52 and 62 mm SVL. Females above 68 mm SVL are nearly all gravid at some point during the season, but a large number of females appear to be reproductively active once they are 60 mm SVL.

All captures, by round

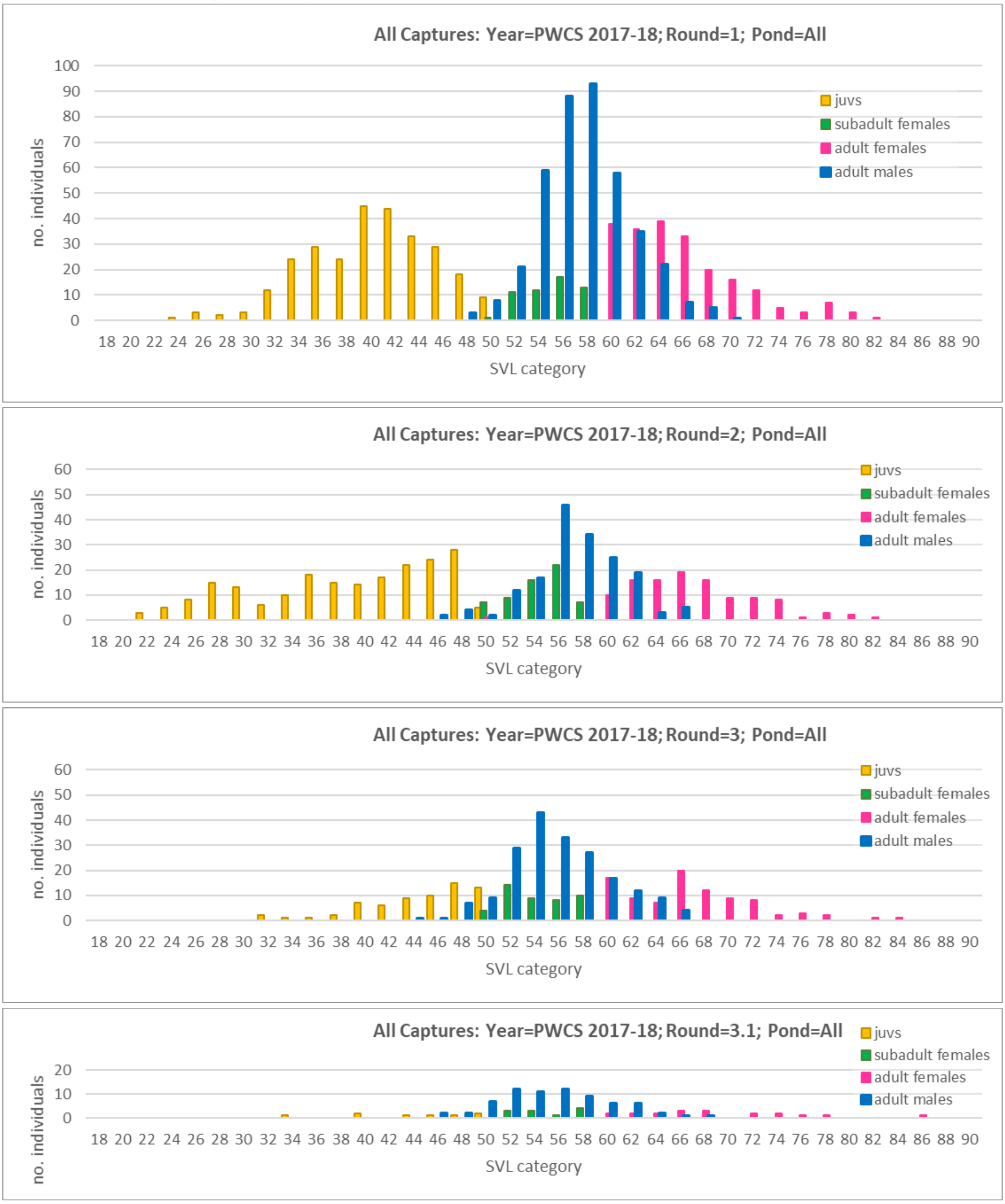


Figure 3.4.5: Frequency distribution of size classes, showing all captures for each survey round (VES and CMR). See Fig 3.4.1 for legend and Fig. 3.4.4. for explanation of size classes.

Plots of size/frequency distribution over the different rounds (Figure 3.4.5) show a pulse of mid to large juveniles in round 1, becoming large juveniles/small adults in round 2. These juveniles are most likely the result of spawning in the autumn of 2017, with the tadpoles growing through the winter season and metamorphosing in early spring. Some of these had become small to mid-sized males by round 3. Round 2 shows another pulse of very small juveniles; this cohort is likely to have spawned in early spring 2017-18. These have become large juveniles by round 3. There were small number of adults in round 3.1, but there were some very large females present.

Captures by wetland – K29

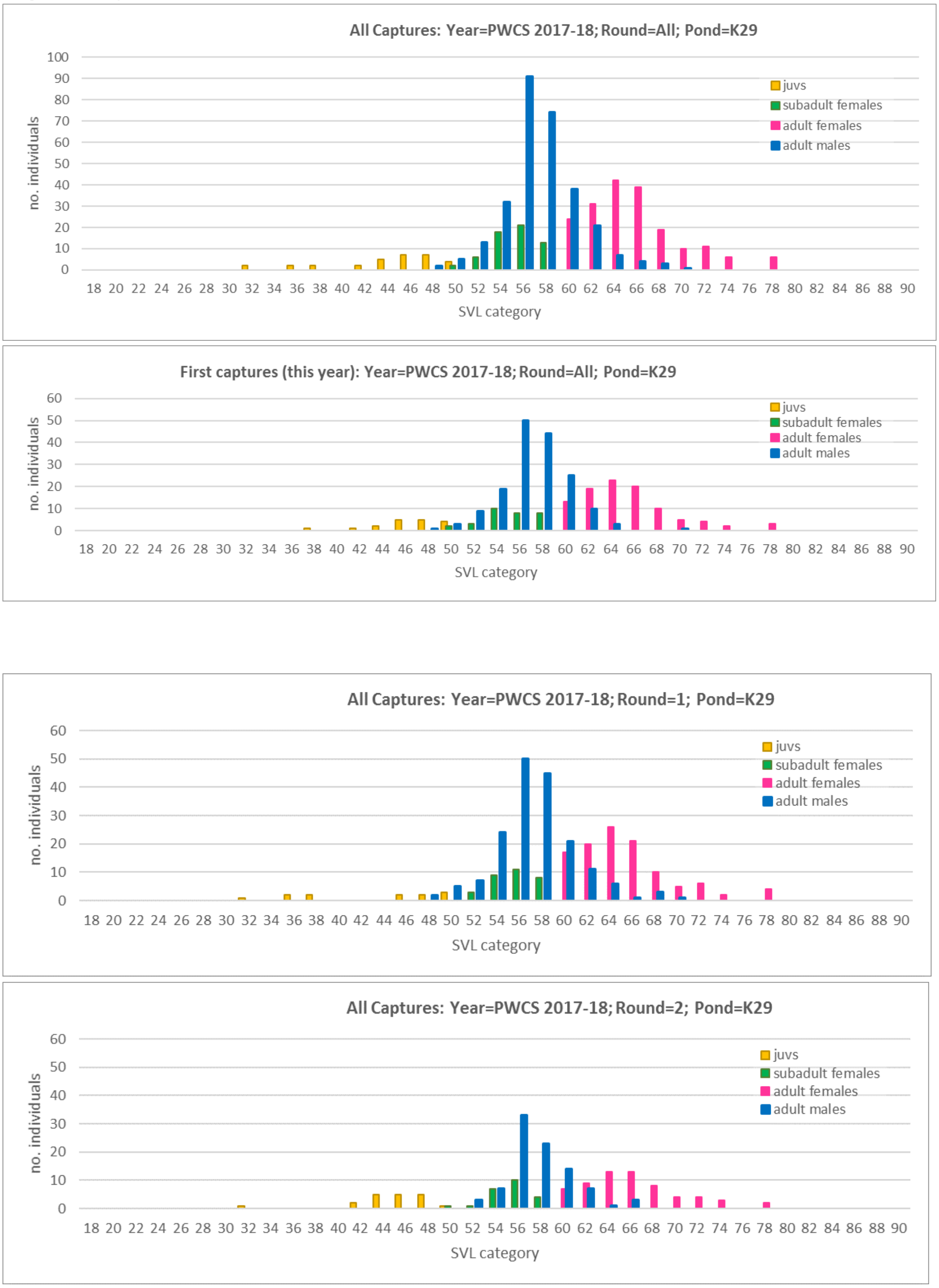


Figure 3.4.6: Frequency distribution of size classes at K29. Top: Data for all captured animals (above) and tagged individuals (below), summed across all three rounds. Bottom: Frequency distribution per round, for rounds 1 and 2. See Fig. 3.4.1 for legend and Fig. 3.4.4. for explanation of size classes.

Northern industrial zone: K29 had some small juveniles in round 1, becoming large juveniles in round 2 (Figure 3.4.6).

K104

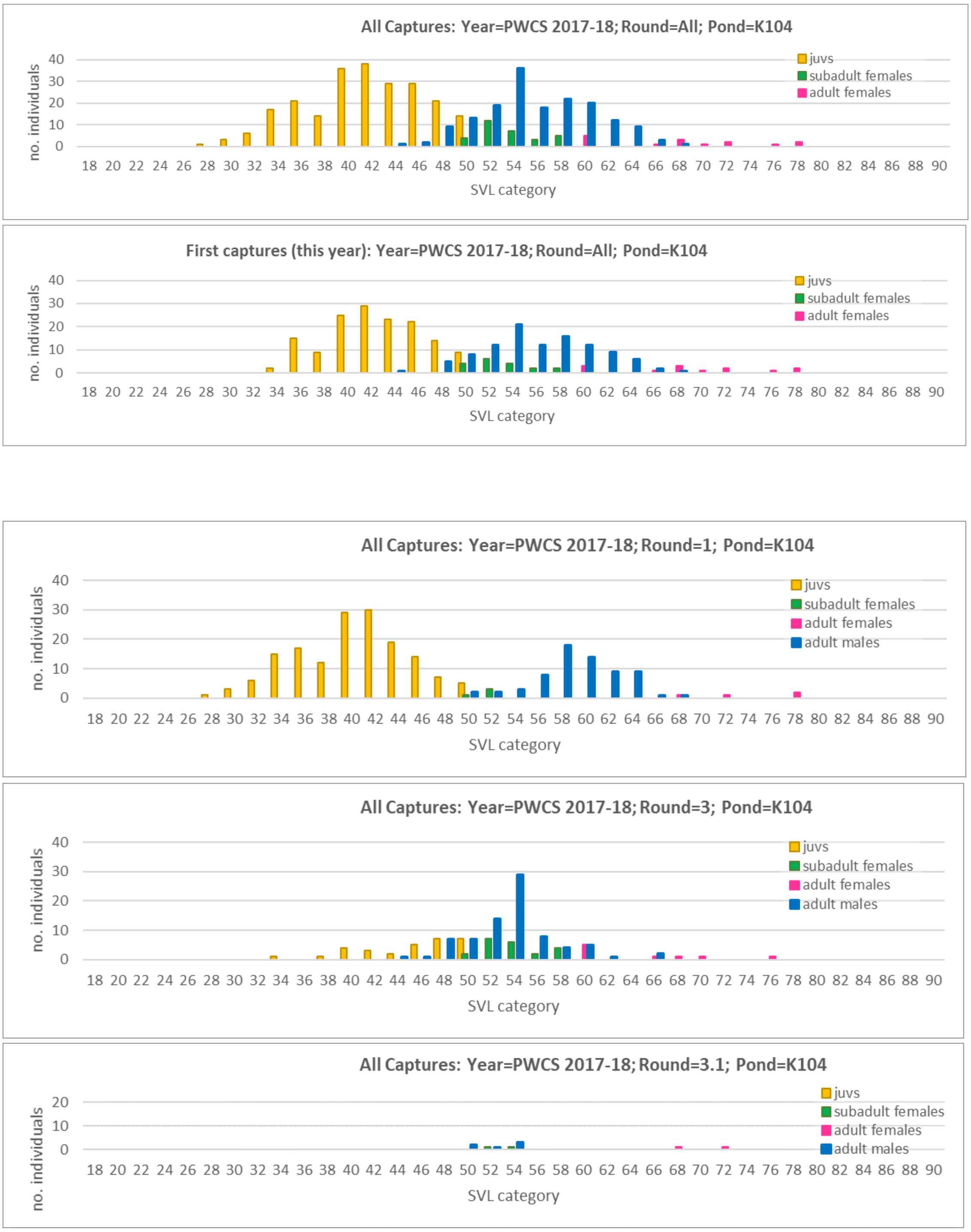


Figure 3.4.7: Frequency distributions for K104 wetland. Refer to Fig. 3.4.6 for explanation of charts.

In round 1, **K104** (Figure 3.4.7) had a large number of juveniles; most of these were mid-sized, and may indicate spawning the previous autumn. There were much lower numbers of these juveniles by round 3, and those still present had become large juveniles or small adults.

Only small numbers of adults, and no juveniles, were captured in round 3.1.

K23

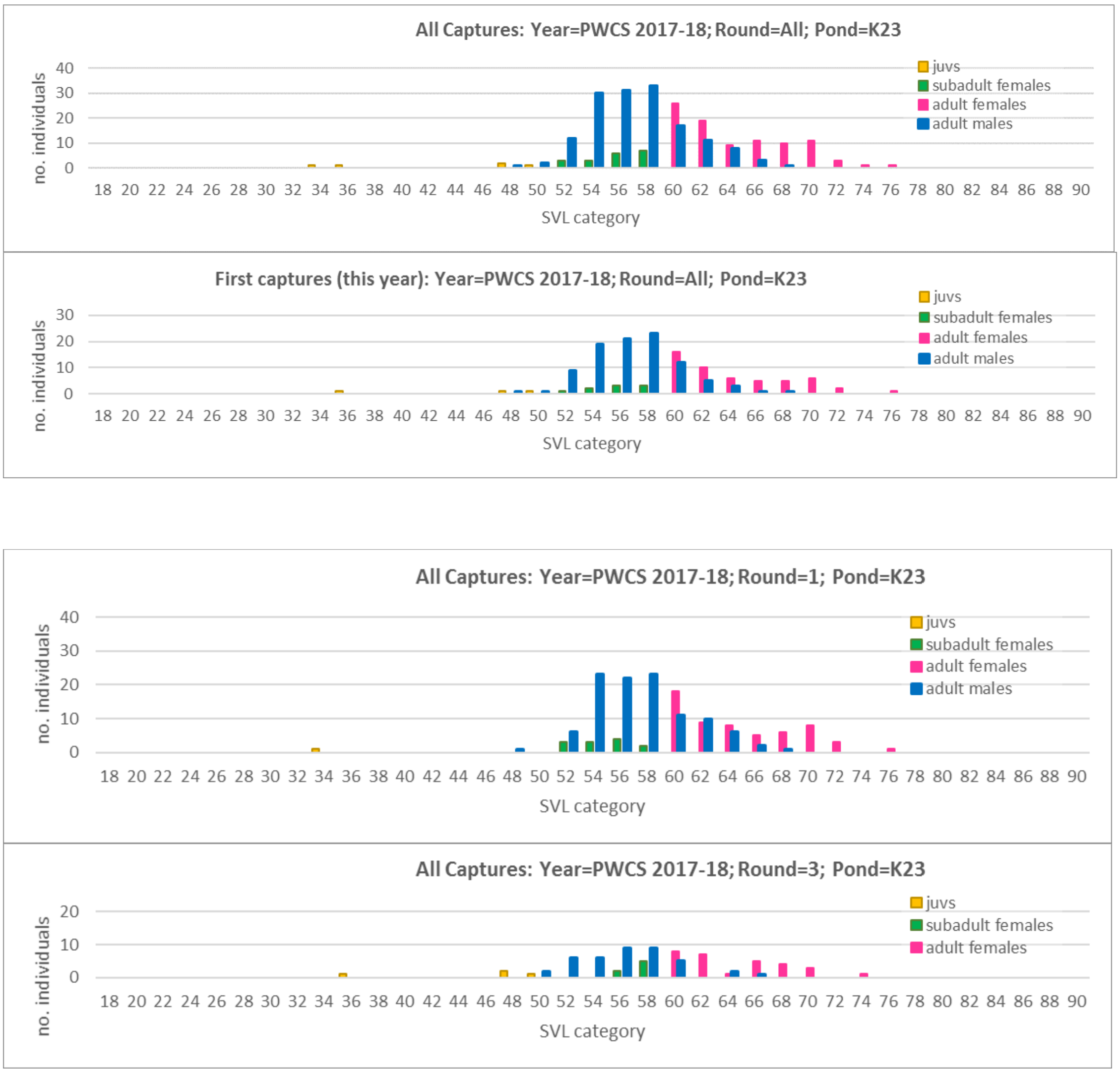
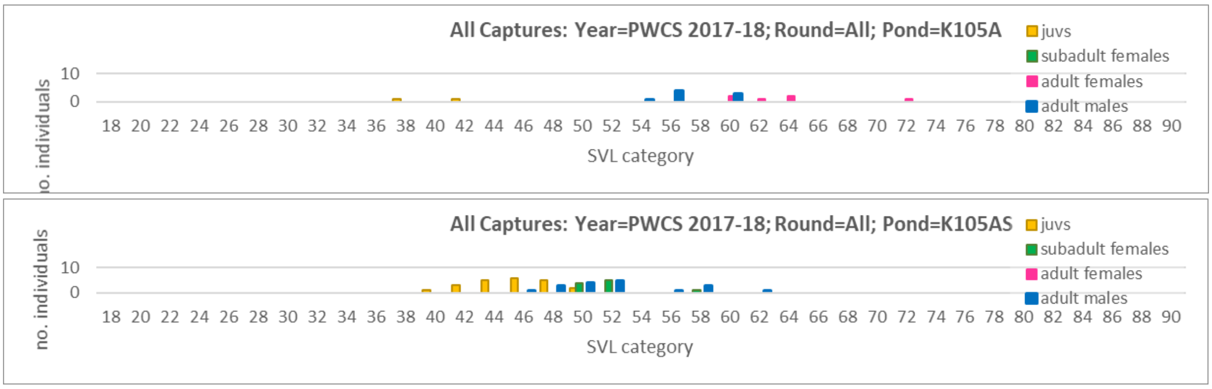


Figure 3.4.8: Frequency distributions for K23 wetland. Refer to Fig. 3.4.6 for explanation of charts.

Both K29 and K104 are understood to be ‘refuge’ wetlands that support large numbers of adult *L. aurea* from year to year (which is one of the reasons why they are the focus of CMR studies). Another such wetland is **K23** (Figure 3.4.8); although not technically in the Northern Industrial Zone, it is very close to this region. In 2017-18, K23 had a large number of adults in round 1 (but hardly any juveniles). A small number of juveniles were present in round 3.

In both rounds, a large number of *L. aurea* were found in the vegetation (mainly fennel and pampas) along the adjoining road. During round 3 in particular, most of the *L. aurea* captured at K23 were along the road, rather than in the wetland. A large proportion of these were not tagged, i.e. had not been detected at K23 previously. They were distributed towards K107, and may indicate movement towards or away from the wetland at that time.

K105A



K105B

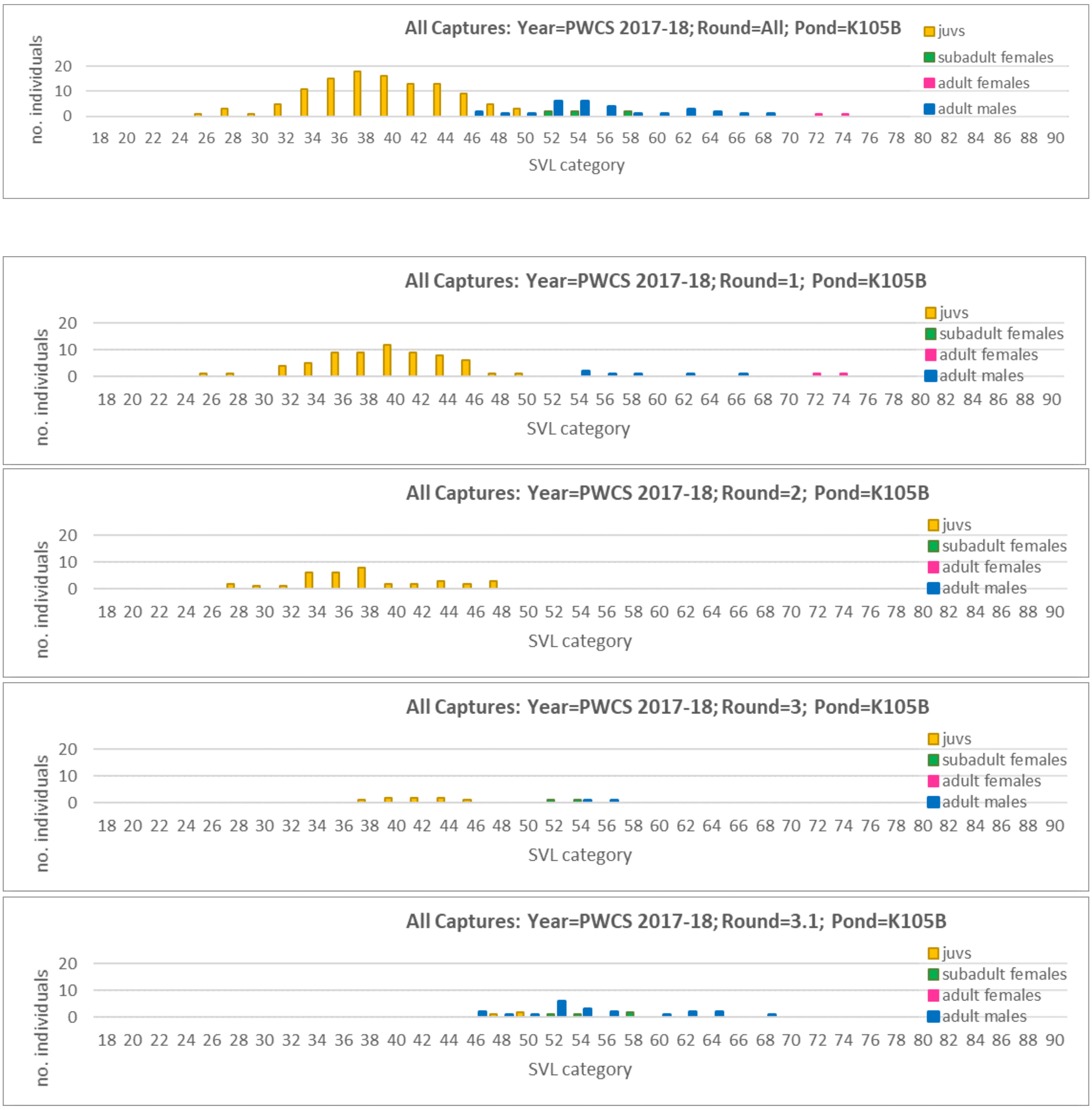


Figure 3.4.9: Frequency distributions for the large **K105** wetlands west of K29. Refer to Fig. 3.4.6 for explanation of charts.

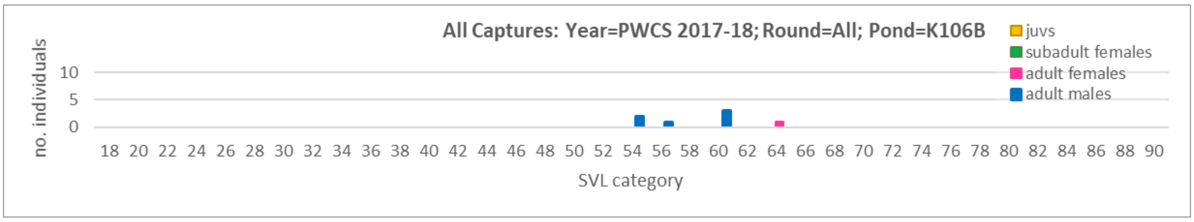
'Deep pond' was originally a single very large wetland in the NW part of the Industrial Zone; it sits on the original substrate of the island (rather than on artificial substrate, as is the case with some other wetlands), and appears to be a remnant of the natural wetlands in this part of Kooragang that were present prior to substantial alteration by human activity. Following the completion of the NCIG infrastructure, this wetland was split into a larger northern part (**K105A)**, and a smaller southern part **(K105B)**. These are surveyed separately; furthermore, the southern part of K105A has been surveyed separately to the northern edges and is labelled **K105AS** in our analyses.

This southern edge of K105A (i.e. **K105AS**) had number of large juveniles and small adults (Figure 3.4.9). These were detected in round 2 and 3 (there was no survey of K105AS in round 1). In particular, there were a large number of juveniles in a relatively small area, in *Typha* stand at SW corner of wetland.

In **K105A**, most adults were detected along the northern edge of the wetland (near K23) in round 3. The wetland has become very dry by this time, and the dense edge vegetation along the northern bank had been the closest to the remaining water for some time.

K105B had dried out completely the previous season, with the result that *Gambusia* were no longer present, and the shallow-sloped muddy edges had been overgrown with paspalum grass. This, combined with dense edge vegetation of emergent reeds (mainly *Typha* and *Phragmites*) has apparently created a highly suitable environment for *L. aurea*, both for adults and for breeding. There were large numbers of juveniles and small numbers of adults in round 1. The captured frogs were almost exclusively juveniles in round 2, mostly small (<40 mm). The size/frequency distribution of large juveniles in round 1 and small juveniles in round 2 indicates at least a couple of breeding events prior to December, most likely in autumn 2017 and spring 2017 respectively. There were only small numbers in round 3, but following the second and larger rainfall event of the autumn there were large numbers of adults in round 3.1; these were predominantly males calling from flooded grass.

K106B



K106C

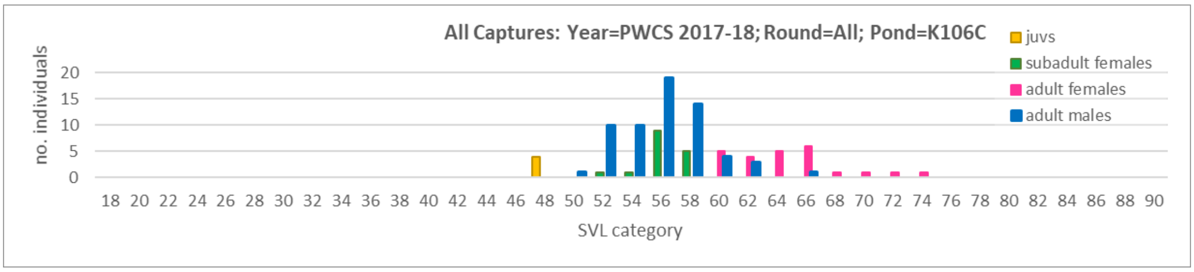


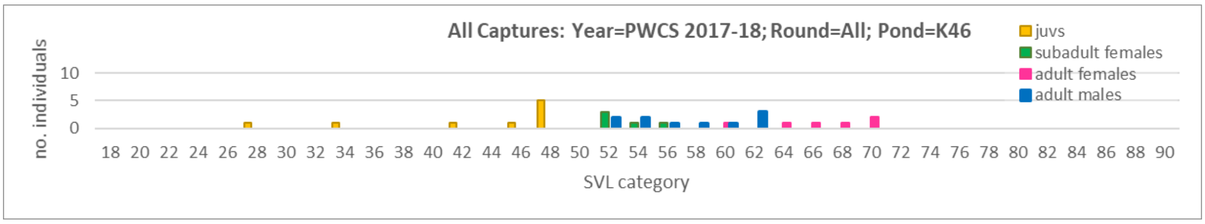
Figure 3.4.10: Frequency distributions for the K106B and C wetlands immediately west of K29. Refer to Fig. 3.4.6 for explanation of charts.

K106B is a temporary ephemeral wetland, and was dry throughout the season until the autumn rain in 2018. As a result, few frogs were detected until a number of adults, mostly calling males, in round 3 (Figure 3.4.10). One male had been tagged in K105A in the first round; providing a specific example of the general principal the *L. aurea* adults move towards ephemeral wetland during rain events.

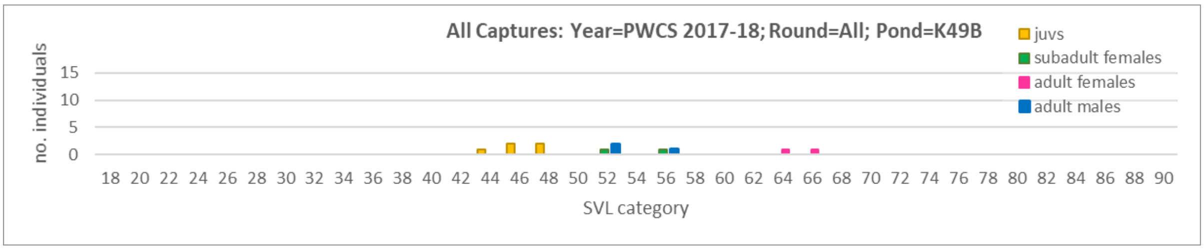
K106C is a small, deep wetland that is nearly permanent. It is well shaded and surrounded by emergent reeds, and has no Gambusia; in some ways, it might be considered to be a 'natural' version of the cluster ponds (C1 and C2). It usually contains a lot of adults, and this season had a large number of adult males and small adult females (Figure 3.4.10). As with previous seasons, there was very little or no breeding.

Many of the adults captured at K106C are recaptured individuals that have been PIT tagged previously; this data shows that the wetland is highly connected (in terms of *L. aurea* movements) to the nearby K29 wetland (Section 3.5).

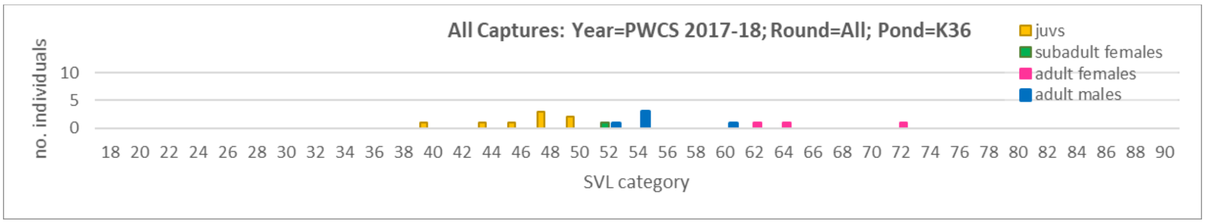
K46



K49B



K36



K102

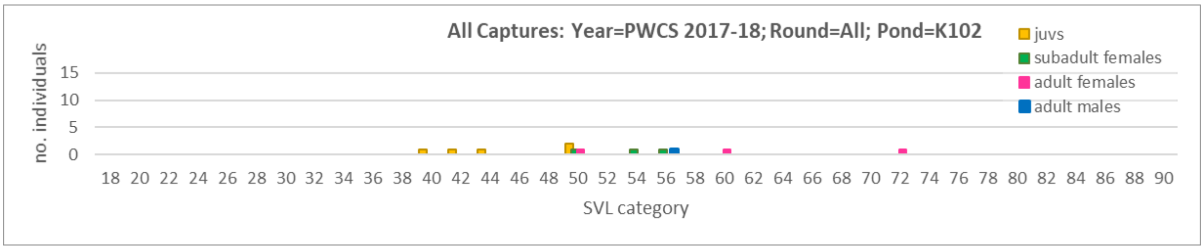


Figure 3.4.11: Frequency distributions for selected PWCS wetlands in the southern part of the industrial site. Refer to Fig. 3.4.6 for explanation of charts.

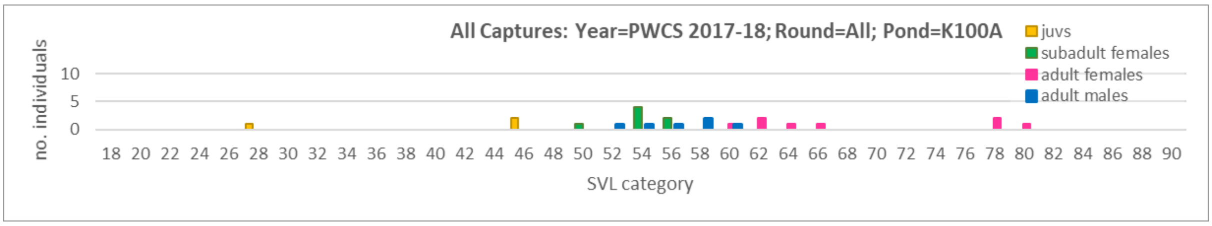
Southern PWCS wetlands: A number of wetlands across the southern region of the industrial zone support important numbers of *Litoria aurea* (although the numbers are not as large as in the northern part of the industrial zone). Some of these are 'older' wetlands have been established for many decades; they are shown in Figure 3.4.11.

A large number of adults were present in **K46**. In addition, there were many adults chorusing in round 0 (these were not captured and are thus not included in the size-frequency distribution shown here). Breeding may have been successful in this wetland, as small juveniles in subsequent rounds.

There were low numbers of *L. aurea* (but some large juveniles) in **K49B**. The adjacent **K36** is a deep permanent wetland – one of only four to contain deep water by the end of February 2018 – and always contains *Gambusia*. It has small but consistent numbers of adults, with some large juveniles; it may now act as a refuge for adults breeding in K121, following construction of that wetland in 2017.

K102 (‘Boomerang' pond) is a very large wetland but appears to have low density of *L. aurea*; there were small numbers of adults detected, but some large juveniles were present. Since this wetland contains *Gambusia*, these juveniles may have spawned in nearby wetlands such as K114.

K100A



K115

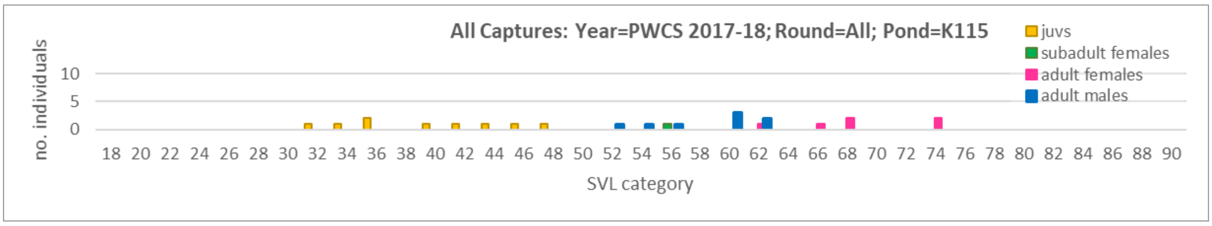
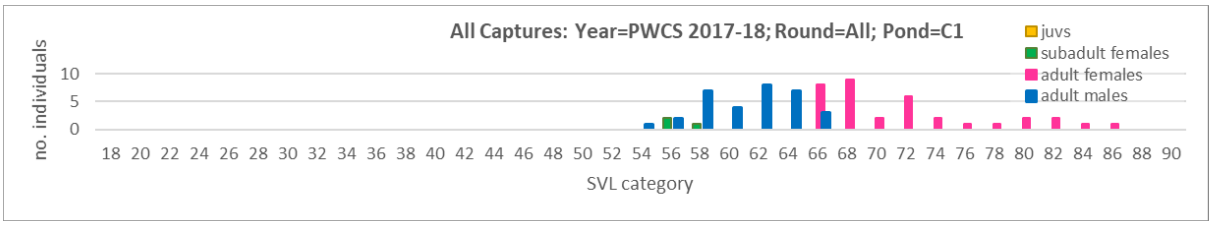


Figure 3.4.12: Frequency distributions for selected wetland immediately near the NCIG rail loop. Refer to Fig. 3.4.6 for explanation of charts.

K100A is a deep permanent wetland alongside Windmill Road, on the eastern edge of the Industrial Zone. It is surrounded by dense stands of *Casuarina* trees, and contains *Gambusia*. It often has relatively large numbers of *L. aurea*, but does not appear to support breeding. The pattern was 2017-18 was consistent with previous years; in particular, there were some very large adult females present. The very small juvenile may be been spawned in K100A but may also have immigrated from a nearby wetland.

K115 is an artificial sump pond for the NCIG dump station. It is a managed wetland (water is pumped in and drained out according to the operational requirements of the dump station), and is mostly clear of aquatic vegetation except for a dense patch of *Typha* at its western end. In 2017-18 it contained some adults and relatively large numbers of juvenile *L. aurea*. Breeding behaviours (such as calling, tadpoles, or metamorphs) have never been observed at K115, but it is close to K114 where breeding occurs consistently, and these juveniles may have been spawned in K114 or other HDC ponds.

C1



C2

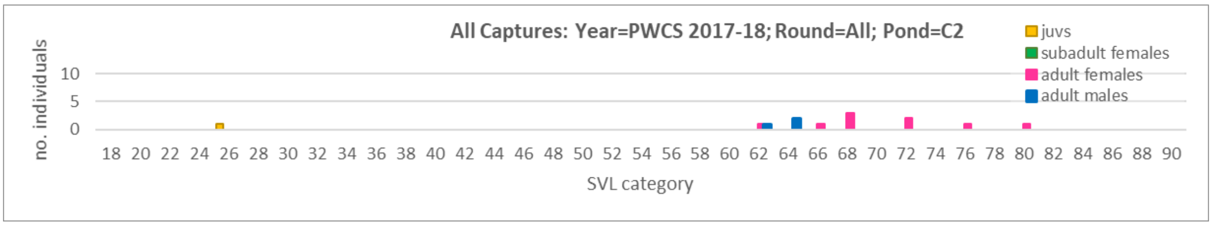


Figure 3.4.13: Frequency distributions for the PWCS 'Cluster Ponds'. Refer to Fig. 3.4.6 for explanation of charts.

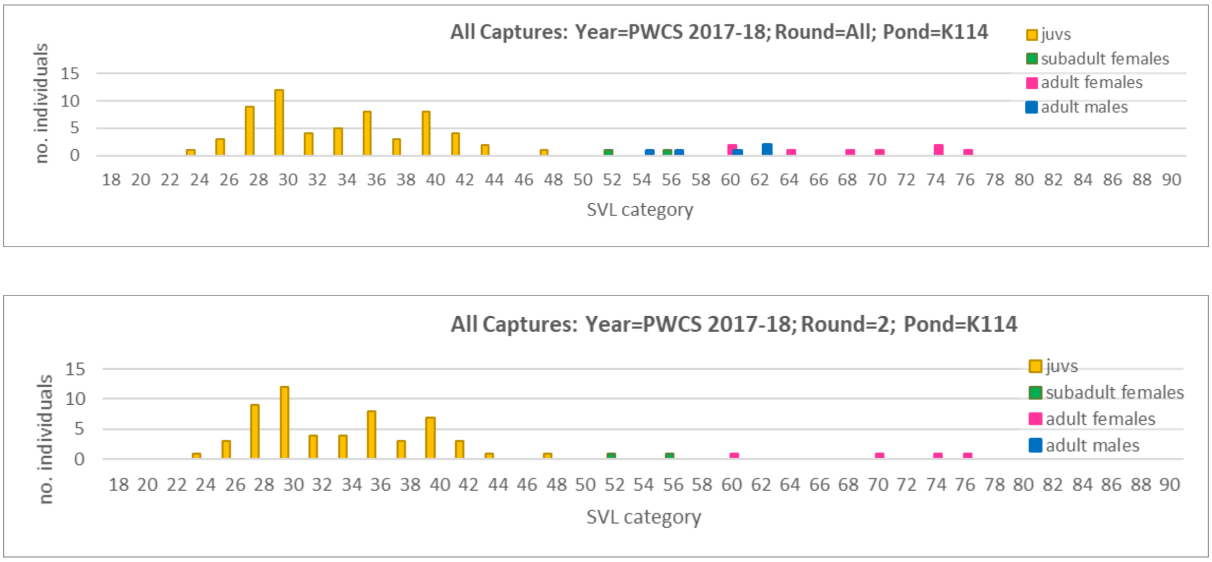
The 'cluster ponds': these (**C1** and **C2**) are artificial wetlands installed by PWCS in the northern and southern regions of the industrial zone respectively. Although they are small, they are deep permanent wetlands that can be managed to ensure they hold water during drought, and are free of *Gambusia*. C1 is part of the habitat mosaic close to K29, and has held relatively high densities of *L. aurea* for several seasons. When constructed, C2 was further away from other *L. aurea* habitat and until the construction of the HDC wetlands in 2015-17 contained no (or very few) *L. aurea*. With the construction of the HDC wetlands, C2 is now apparently part of a connected habitat mosaic, and supported *L. aurea* for the first time in the previous (2016-17) season.

In 2017-18, **C1** contained a large number of adults, but no juveniles - or indeed any evidence of breeding (a lot of *Litoria peronii* tadpoles were observed, however). There were some very large females, which appear to be resident. There were also numbers of previously untagged animals that don't remain at the wetland; these may be transient. As with K106C, C1 is closely connected with K29 in terms of *L. aurea* movement, with many frogs moving between the two (Section 3.5).

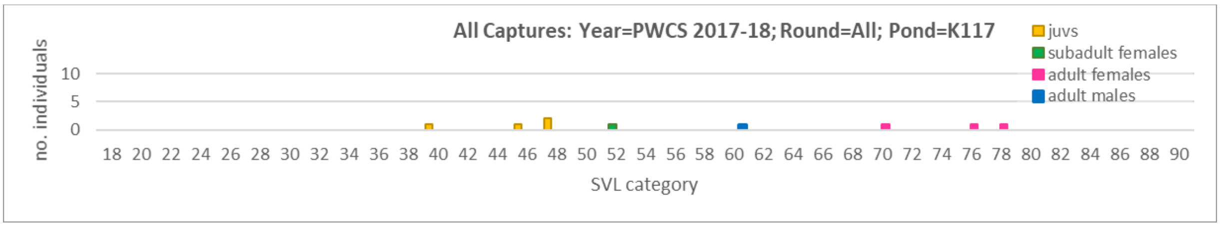
C2 had lower numbers of *L. aurea*, but some moderate to large females. The numbers present were greater than the previous season; the numbers of *L. aurea* making use of this wetland appears to be growing. The very small juvenile observed may have come from K123, where breeding was observed. There was no observed evidence of breeding in C2.

HDC constructed wetlands: the wetlands K111-K114 (in the rail loop) and K117-K118 (in the KIWEF *K2* subregion) were completed in 2015 and all supported adult *L. aurea* by the 2016-17 season. By then, breeding had been recorded in all of these with the exception of K112 and K118.

K114



K117



K118

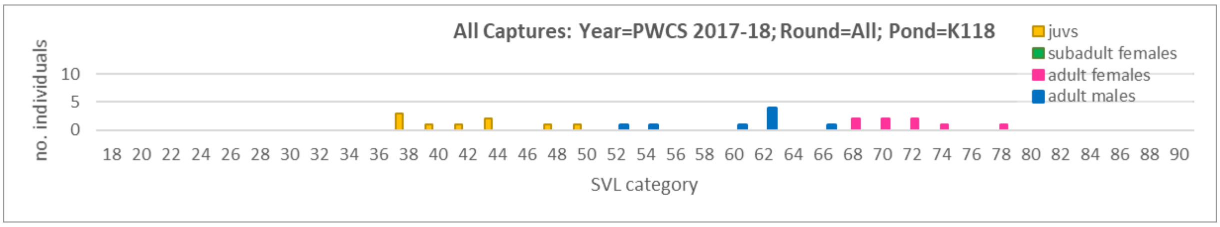


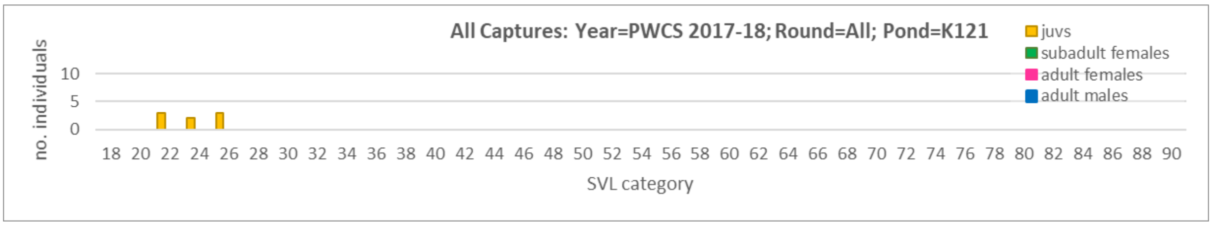
Figure 3.4.14: Frequency distributions for selected HDC constructed wetlands. Refer to Fig., 3.4.6 for explanation of charts.

In 2017-18, **K114** supported a significant breeding event, with large numbers of small juveniles detected in round 2. The size of these juveniles suggests a breeding event early in the 2017-18 season. As usual for this wetland, the number of adults was low but consistent.

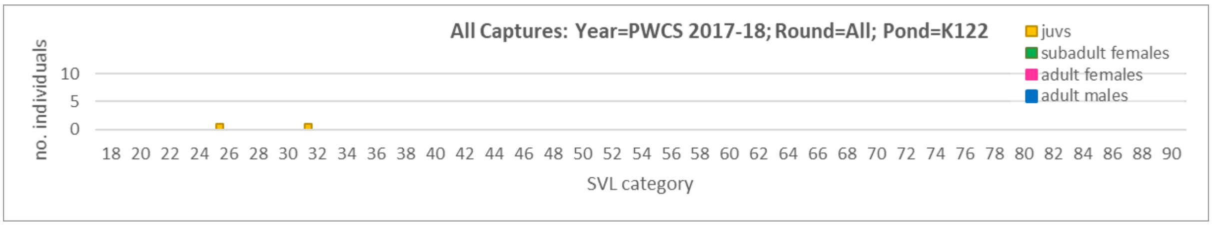
K117 and **K118** both supported adults and juveniles, with the larger numbers in K118. Breeding evidently took place in K118 this year (both tadpoles and metamorphs were detected; see Section 3.6). The occurrence of juveniles and adults in K118 may be linked to its proximity to K105B.

Note that K117 lies close to K46, and one adult female tagged in K46 in the previous season was found in K117 this year (see Section 3.5).

K121



K122



K123

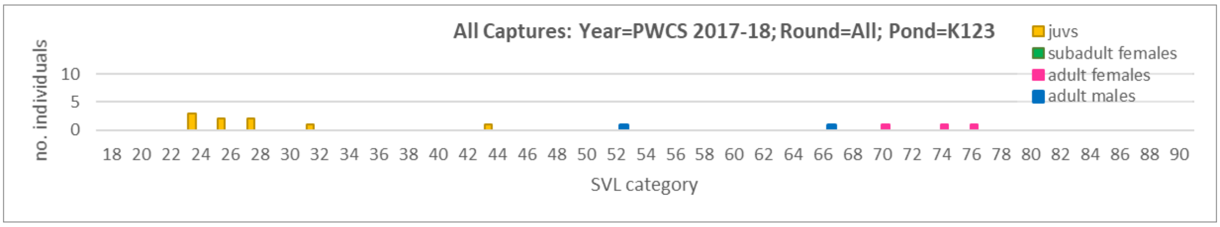


Figure 3.4.15: Frequency distributions for HDC constructed wetlands in Area 3 (constructed in 2017). Refer to Fig., 3.4.6 for explanation of charts.

K121, **K122**, and **K123** are new wetlands, constructed in 2016-17 and located in the KIWEF K10 South subregion, adjacent to the rail loop. They lie between C2 and K36, and greatly increase the amount of aquatic habitat in that area. 2017-18 is the first season that they have been surveyed.

All of these held good levels of water, but had very little vegetation. Small juveniles of *Litoria aurea* were observe*d* in **K121**. This wetland was unshaded and the water was warm and it is possible that the combination of water temperature and sparse vegetation led to these *L. aurea* tadpoles developing quickly and metamorphosing when small. There were also abundant *Limnodynastes tasmaniensis* calling throughout the season, especially at K121.

No adults were found in **K121** & **K122**, perhaps due to the lack of aquatic vegetation that *L. aurea* use for cover. **K123** is close to C2, which does have established aquatic vegetation, and some adults were detected in this wetland.

3.5. Longitudinal data: persistence and movement

The best measures of how animals grow, how they move around the study site, and how long they live comes from repeated surveys at the selected wetlands. This provides what is known as a longitudinal dataset, and is enabled by the use of PIT tags.

In order to maximise the power of analysis of persistence and movement, we combined several datasets from research programs focusing on *L. aurea* on Kooragang Island. Four of these were four years' of records from the island wide research program (i.e. 2014-15, 2015-16, 2016-17, and 2017-18). We also included datasets from other research and monitoring projects conducted at the UoN Amphibian Research Laboratory. Combined, these seven sources resulted in a single dataset with >10,000 individual records of *L. aurea* captures where the frog was marked with a PIT tag (Table 3.5.1).

Source data	Seasons spanned
Alex Callan (PhD study)	2013-17
IWS 2014-15 (James & Campbell)	2014-15
IWS 2015-16 (McHenry & Moses)	2015-16
SOS surveys (Beranek, King, McHenry)	2016-18
IWS 2016-17 (McHenry & King)	2016-17
IWS 2017-18 (McHenry & Maynard)	2017-18
SOS surveys (Beranek, Lenga, McHenry, Maynard	2017-18

Table 3.5.1: Individual study datasets used for the longitudinal analysis of persistence and movement in this section. Names shown for IWS (Island Wide Survey) studies are project officers for each season.

Persistence

As used here, persistence refers to the period between the first and most recent capture of frogs, of taggable size, that were caught on multiple occasions. It is related to concepts of age and longevity, but is not identical to them as the age when they were first tagged is unknown.

Table 3.5.2 summarises the persistence of *L. aurea* based on the extended dataset. It shows that 2,545 tagged frogs where recaptured at least once. Of these, a large majority had less than 6 months between their first and last capture. Only 554 frogs had more than 3 months between first and last capture; for most of these (335; 21.8%) the period was less than 12 months. Only 219 frogs were recaptured more than 12 months after first capture. The number of frogs that persisted more than 2 years was 38, and 6 of these lasted longer than 3 years. Three animals persisted for more than 4 years.

Calculation of survivorship rate should include data for animals that were tagged but never recaptured, which have not been analysed here. However, calculating the proportion of marked-and-recaptured animals in each time class gives a 'persistence rate' which might be expected to have a similar shape to a true survival rate (Table 3.5.2; see also Figure 3.5.3). Persistence of animals even one year beyond the time of first capture is low, and persistence beyond 2 years is very low.

Time between first and most recent capture	***N***	**persistence rate**
4 < x < 5 years	3	0.1%
3 < x < 4 years	3	0.2%
2 < x < 3 years	32	1.5%
1 < x < 2 years	181	8.6%
6 < x < 12 months	**335**	21.8%
x < 6 months	1,991	
Total	2,545	

Table 3.5.2: Persistence of *L. aurea* marked in multiple studies. See text for explanation.

It is important to note that persistence time categories are not age categories. For example, a *L. aurea* may be a year old when it is first marked; if it survives more than 12 months after that, then it has reached its third year. As frogs are only marked when they are large juveniles (i.e. SVL > 40 mm), they are generally at least 6 months old and more often are older.

Movement

Total animals tagged	6,713
Total animals recaptured	2,551
Total movements detected	243
Within BHP_CHEMP	117
Within NCIG_CHEMP stages	15
Between K22-K23	51
Other movements	60

Table 3.5.3: Movement detected from recaptures of *L. aurea* marked with PIT tags. Recaptures are taken to indicate a movement if they are located in a different wetland to the previous capture, i.e. they do not include movements within a wetland (which can be considerable). Most detected movements are within the BHP CHEMP wetlands, between K22 and K23, and with the stages of NCIG CHEMP wetlands. The 'Other movements' are detailed in **Tables 3.5.4** and **3.5.5** and **Figures 3.5.1** and **3.5.2**.

A small proportion of recaptures (243 out of 2,551) *L. aurea* that moved between wetlands from one capture to the next (Table 3.5.3). Of those, most were relatively small movements, such as within the BHP CHEMP wetlands, between K22 and K23, or within stages in the NCIG CHEMP wetlands.

Details of the other 63 detected movements are shown in Table 3.5.4 (for movements within a season) and Table 3.5.5 (for movements between seasons), and in Figures 3.5.1 and 3.5.2 respectively. A large number (31) of these involve movements between K29 and its nearby wetlands (especially C1 and K106C). Twelve records involve the CHEMP habitats. There are six recorded movements between wetlands along Bellfrog Way, four of which are short distances between K20C and K21. Eleven other records indicate movements between K9, K22, K23, K46, K100A, K103, K104, K105A, K106B, K106C, K108, K113, K114, K115, and K117.

Although most movements involve distances of less than a few hundred metres, several involve distances of more than a kilometre. Notable examples are;

i. K100A to K29 (1.5 km),
ii. K108 to K22 (2 km),
iii. K104 to K23 (1.7 km),
iv. K9 to K108 (3.6 km),
v. K21 to BHP_3A (1.5 km),
vi. BHP_2C to BHP_14B (1.2 km),
vii. K115 to K104 (0.6 km).

The first four of this list are movements recorded within a single season. The movement from K9 to K108 is a distance of over 3 kms, and occurred within a month from Dec 2015 to Jan 2016. The same animal was found the following season in K100A. The largest movements were recorded within-season.

Although the dataset is too small for quantitative analysis, there are some differences among within-season and between-season movements that are informative with respect to *L. aurea* biology.

1. Movements involving ephemeral wetlands such as K22, K106B, and K113 were all recorded within the same season, pointing to the use of these as breeding habitats by reproductive adults that normally reside in nearby permanent wetlands (K29, K05A, and K115 respectively).

2. Most movements (45) are less than 500 m distance, with 23 of these are less than 100 m. However, eight movements are greater than 1 km.

Animal ID (PIT #)	Sex	Initial date	Starting point	End date	Destination	Minimum distance (metres)
In/out of CHEMP (includes between NCIG stages)						
0007D3C6D7	M	7/03/2018	NCIG_6.2	29/03/2018	K58B	195
0007D3D3B7	J (JF)	17/01/2018	NCIG_7.3	29/03/2018	K58B	26
0007D3D51E	M	22/02/2018	NCIG_1.3	27/02/2018	NCIG_4.2	728
0007D63DEB	M	21/02/2018	NCIG_7.1	28/02/2018	NCIG_1.4	1,227
900108000628438	M	5/01/2014	K20B	27/03/2014	NCIG_Trial	-
900108000629912	J (F)	3/12/2014	K7	16/02/2015	NCIG_Trial	-
000791EFCB	J (J)	25/10/2017	BHP_2C	1/12/2017	K9	323
In/out of K29						
9001003188533	M	7/11/2011	K29	30/01/2012	K22	473
9001003342085	M	24/01/2012	K29	30/01/2012	K22	473
9001003342085	M	30/01/2012	K22	22/02/2012	K29	473
9001003345807	F	30/01/2012	K22	13/03/2012	K29	473
9001003347631	F	18/11/2011	K100A	24/01/2012	K29	1,529
000791EA95	M	22/11/2017	K29	10/01/2018	C1	65
0007A0A936	F	19/12/2016	K29	10/02/2017	C1	65
0007A0E85F	M	8/01/2017	K29	14/02/2017	K35	241
0007A0ED7D	F	12/01/2018	K29	2/03/2018	C1	65
0007D1DB69	M	22/11/2017	K29	28/02/2018	K105A	201
0007D1F6EF	M	15/01/2018	K106C	22/03/2018	K29	61
0007D29E7B	F	23/11/2017	K105A	12/01/2018	K29	201
0007D3B356	M	12/01/2018	K29	4/03/2018	K106C	61
0007DE3D35	F	28/02/2018	K106C	22/03/2018	K29	61
Other movements						
999005005001369	M	16/11/2012	K108	5/02/2013	K22	2,039
000763329F	M	3/03/2015	K104	12/03/2015	K23	1,759
00076338A8	J (JF)	11/12/2015	K9	8/01/2016	K108	3,600
0007D1B21F	M	23/11/2017	K105A	22/03/2018	K106B	26
0007D23BD2	M	23/11/2017	K105A	18/01/2018	K106C	170
0007D3BF60	J (JF)	6/12/2017	K115	7/03/2018	K113	56
Along Bellfrog Way						
0007634761	M	15/12/2014	K23	4/02/2015	K21	511
9001003170554	M	12/10/2014	K21	21/01/2015	K20C	102
9001003170554	M	21/01/2015	K20C	27/01/2015	K21	102
9001003180024	M	12/10/2014	K21	28/01/2015	K20C	102
900108000630571	M	19/01/2015	K21	4/02/2015	K20C	102
999005005000230	J (M)	9/12/2014	K23	10/03/2015	K50	465

Table 3.5.4: Detected movement within study seasons (i.e. between or within rounds). Data sourced from multiple studies (see text). Coloured fonts show individuals where multiple movements were detected (compare with Table 3.5.5 and Figure 3.5.1)

3. There are 18 recorded movements between K29 and two nearby small permanent wetlands, K106C and C1. Fourteen of these are from K29 to the smaller wetlands. This may be a product of sampling bias: survey effort at K29 is high, as it is a focus of CMR surveys, but both K106C and C1 are small enough that capture rates are expected to be high.

Animal ID (PIT #)	Sex	Year of first capture	Starting point	Year of recapture	Destination	Minimum distance (metres)
	In/out of CHEMP (includes between NCIG stages)					
900108000630037	M	4/02/2015	K21	4/01/2017	BHP_3A	1,487
900108000630541	M	12/10/2016	BHP_2C	3/10/2017	BHP_14B	1,184
956000003476551	M	26/10/2016	K22	17/01/2018	BHP_14B	691
900108000629912	J (F)	6/02/2014	NCIG_Trial	3/12/2014	K7	
900108001466466	J (M)	30/12/2015	NCIG_Trial	1/03/2018	NCIG_6.6	
	In/out of K29					
956000003446167	F	10/02/2016	K29	10/02/2017	C1	65
999005005000389	M	13/02/2013	K23	8/11/2013	K29	367
999005005000563	M	7/02/2013	K23	5/11/2013	K29	367
000763393E	M	22/12/2015	K106C	4/01/2017	K29	61
000791EA95	M	10/02/2017	C1	20/11/2017	K29	65
000792075A	JF (F)	14/12/2016	K29	23/11/2017	K106C	64
00079EAB05	F	21/12/2016	K42	22/11/2017	K29	378
0007A0CD9F	M	19/12/2016	K29	23/11/2017	K106C	61
0007A0D1E9	M	19/12/2016	K29	23/11/2017	K106C	61
0007A0E85F	M	14/02/2017	K35	20/11/2017	K29	241
0007A0E99B	J (F)	10/02/2017	K29	10/01/2018	C1	65
0007A0F899	JF (F)	8/01/2017	K29	1/03/2018	C1	65
0007A0FA8F	J (M)	19/12/2016	K29	23/11/2017	K106C	61
0007D1E585	JF (M)	9/02/2017	K29	28/02/2018	K106C	61
0007D1F6EF	M	16/12/2016	K29	15/01/2018	K106C	61
0007D23AF1	M	8/01/2017	K29	1/03/2018	C1	65
	Other movements					
956000003481695	F	2/12/2016	K46	24/03/2018	K117	75
956000003486327	JF (F)	4/02/2016	K115	18/12/2016	K104	629
00076338A8	J (F)	8/01/2016	K108	24/01/2018	K100A	97
0007633CA4	M	18/03/2015	K103	28/11/2016	K22/23	330
0007D295DA	J (M)	16/01/2017	K114	25/01/2018	K115	314
	Along Bellfrog Way					
900108000628396	M	30/12/2013	K20B	21/01/2015	K21	158

Table 3.5.5: Detected movement between study seasons. Data sourced from multiple studies (see text). Coloured fonts show individuals where multiple movements were detected (compare with Table 3.5.3 and Figure 3.5.2)

4. Most (40) of these 60 movements involve males, 5 which were first caught as juveniles (Table 3.5.6). Of the 19 females detected, 10 were first caught as juveniles.

Age/Sex class	n
J (J)	1
J (M)	5
J (F)	10
M	35
F	9

Table 3.5.6: Age/sex class summary of the 60 movements detailed in **Tables 3.5.4** and **3.5.5** ('Other movements' of **Table 3.5.3**). Brackets indicate sex at maturity for animals first captured as juveniles. See text for discussion.

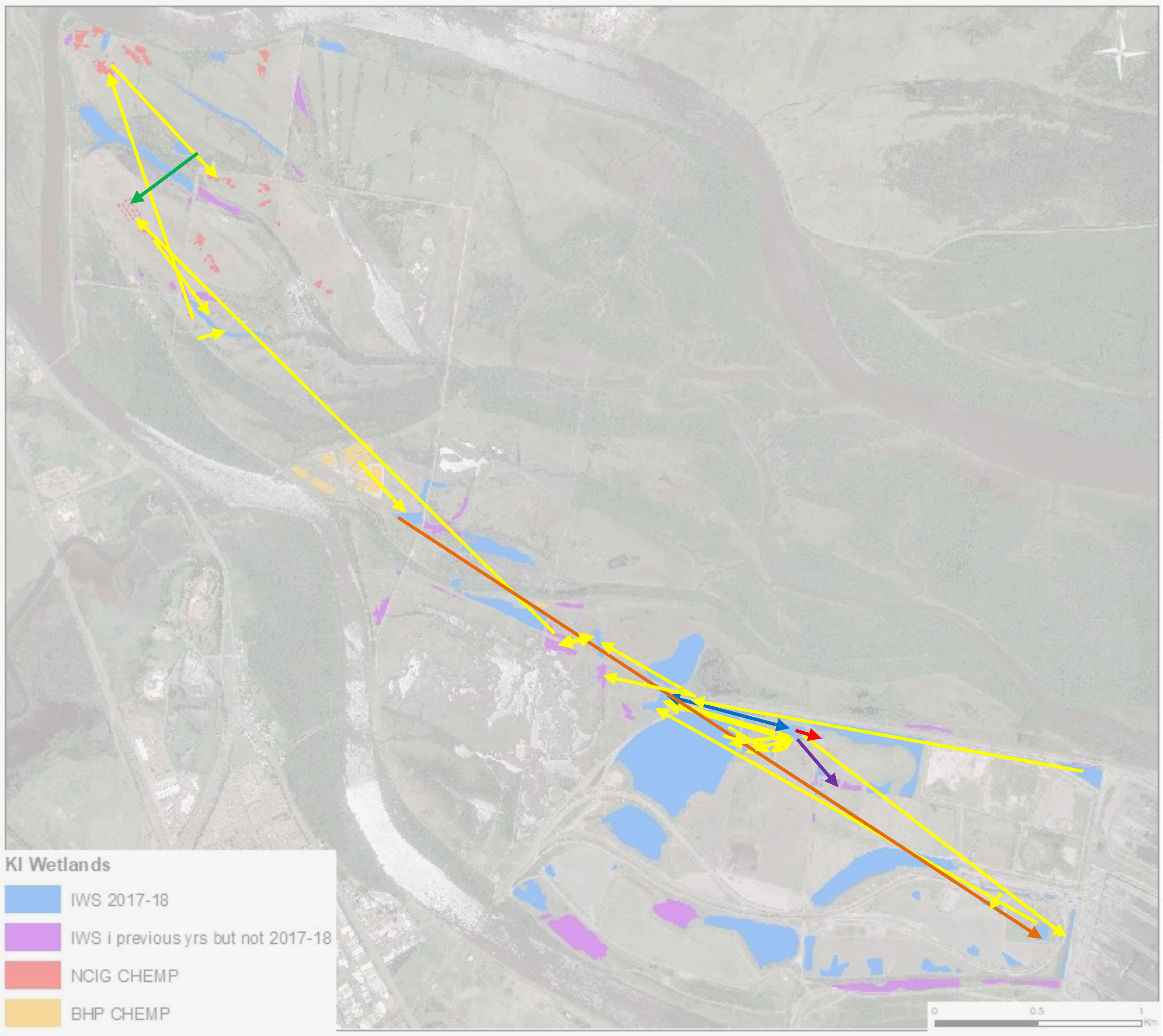


Figure 3.5.1: Visualisation of movement within seasons, from data detailed in Tables 3.5.3. Colours other than yellow relate to individuals with multiple detected movements (c.f. Tables 3.5.3 and 3.5.4). The largest within-season movements are the largest distances recorded.

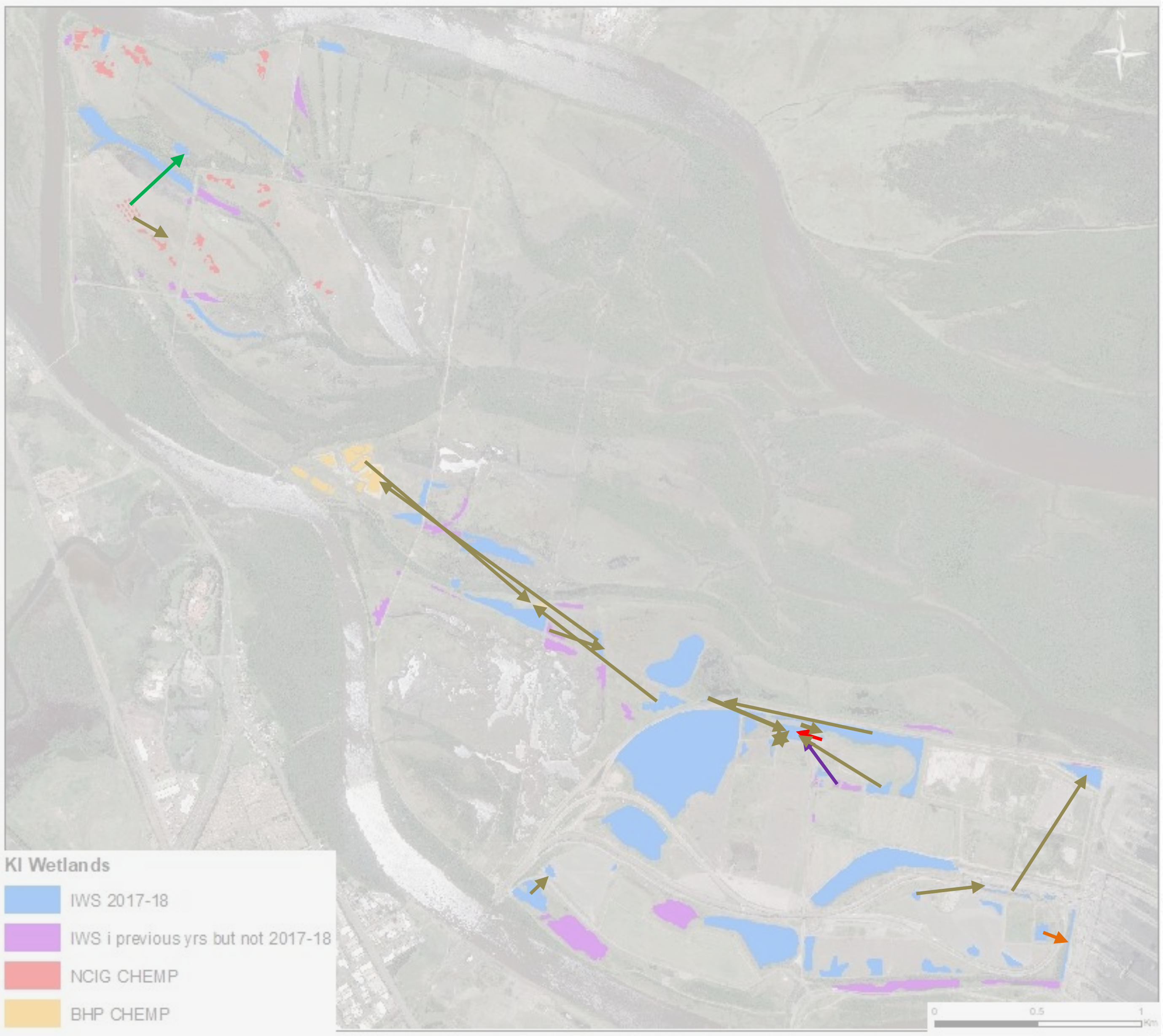


Figure 3.5.2: Visualisation of movement between seasons, from data detailed in Tables 3.5.4. Colours other than dark tan relate to individuals with multiple detected movements (c.f. Tables 3.5.3 and 3.5.4). The largest between-season movements involved smaller distances than some of the within-season movements (c.f. **Figure 3.5.1**)

***Litoria aurea*: Dispersive or philopatric?**

The vast majority (2,201 out of 2,551) of *L. aurea* that are tagged and recaptured are re-caught in the same wetland as their first capture. *Prima facie*, this presents a picture of an animal with a high level of philopatry; even if they do move to other wetlands, they return to the one in which they were first captured.

There is, however, an important source of potential bias in a naïve reading of these numbers. As is clear from the statistics on persistence (and, by inference, survival), most *L. aurea* are not recaptured more than 6 months after their first capture; this leaves little time in which to detect movement. Of 1,991 frogs where the time between first and last capture is less than six months, movement was detected in only 8% (Table 3.5.6: ‘non-cumulative’ columns). But for recaptures that were between 12 and 24 months after the first capture, that rate rises to 22%. For *L. aurea* caught between 2 & 3 years after first capture, the proportion of animals that have moved to new wetlands is 44%.

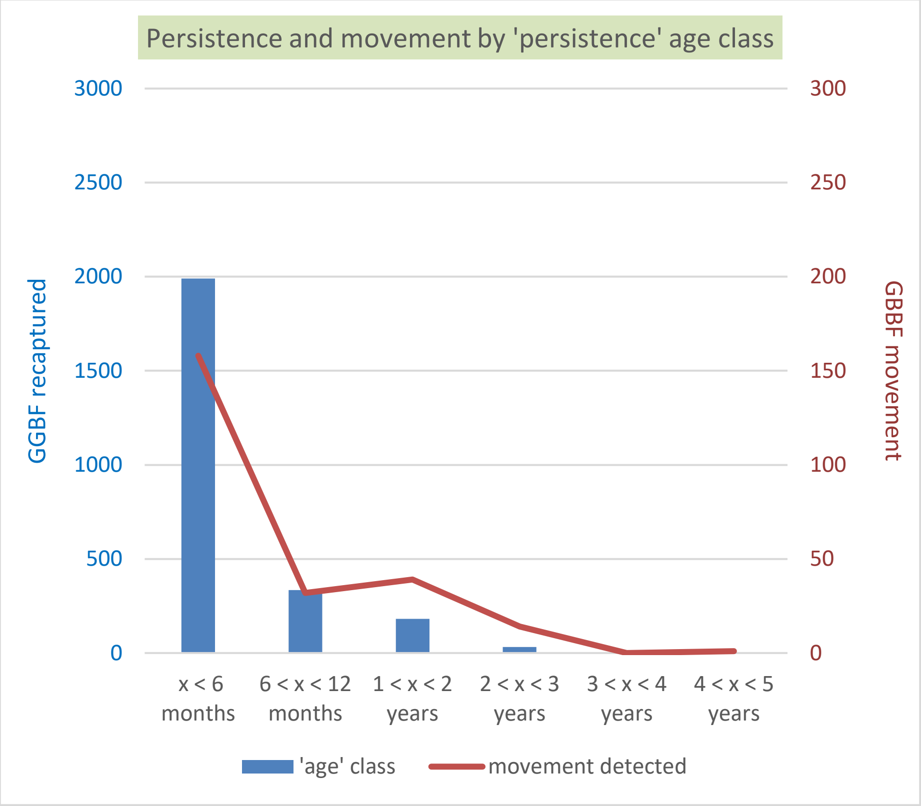
non-cumulative			
Persistence ‘age’ class	number of frogs		
	in persistence ‘age’ class	where movement detected	%
x < 6 mths	1,991	158	0.08
6 < x < 12 mths	335	32	0.10
1 < x < 2 years	181	39	0.22
2 < x < 3 years	32	14	0.44
3 < x < 4 years	3	0	0.00
4 < x < 5 years	3	1	0.33

cumulative			
Persistence ‘age’	Persistence ‘age’ at time of recapture		
	Total no. frogs	Where movement detected	%
x < 6 mths	2,545	174	0.07
x < 1 year	554	33	0.06
x < 2 years	219	31	0.14
x < 3 years	38	6	0.16
x < 4 years	6	0	0.00
x < 5 years	3	0	0.00

Table 3.5.6: Numbers of *L. aurea* in each persistence ‘age’ class (c.f. Table 3.5.2), numbers of movements detected, and proportions thereof. Columns to the left (‘non-cumulative’) organise data according to the time between first and last capture of each frog. Columns to the right (‘cumulative’) show data according to the time between first capture and the detection of movement. The data from these tables is plotted in Figure 3.5.3.

Movement between wetlands can potentially occur at any point in a frog’s lifespan following metamorphosis; for the 44% of frogs who survived between 1 and 2 years and moved to a new wetland, that movement could have happened at any time from 1 day to 2 years after that first capture. The right hand set of columns in Table 3.5.6 (headed ‘cumulative’) show the number of detected movements, calculated at the time since first capture for each detected movement. The overall pattern has a similar but not identical shape as the non-cumulative count (Figure 3.5.3).

Thus, it appears that movement between wetlands is relatively common in *L. aurea* but is rarely detected because of low rates of survival. *L. aurea* may not be quite as philopatric as a first reading of the data suggests. However, movement takes time, and survival rates of *L. aurea* are low; hence, most recaptures are within a short time-span and indicate no movement between wetlands.



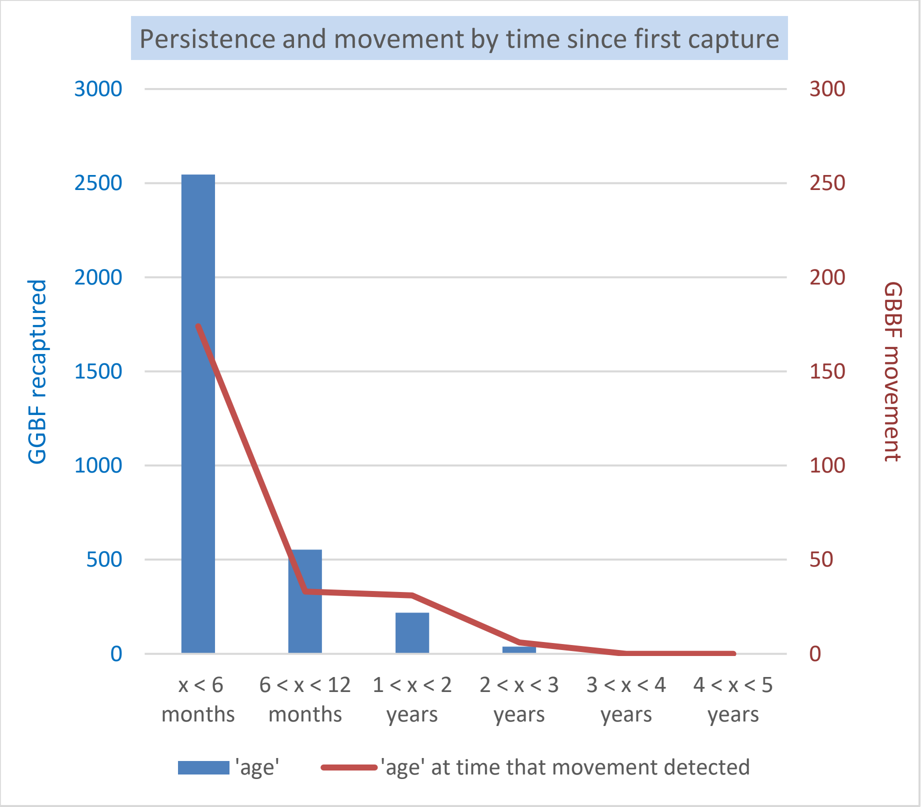


Figure 3.5.3: Visualisation of the combined data for persistence and movement as presented in Table 3.5.6. Upper chart relates to the 'non-cumulative' data columns in that table, lower chart to the 'cumulative' (see text for explanation). Note that the Y axes are displayed at different scales; the Y2 axis (movement) is 10 x the scale of the Y1 (persistence).

3.6. Breeding and recruitment

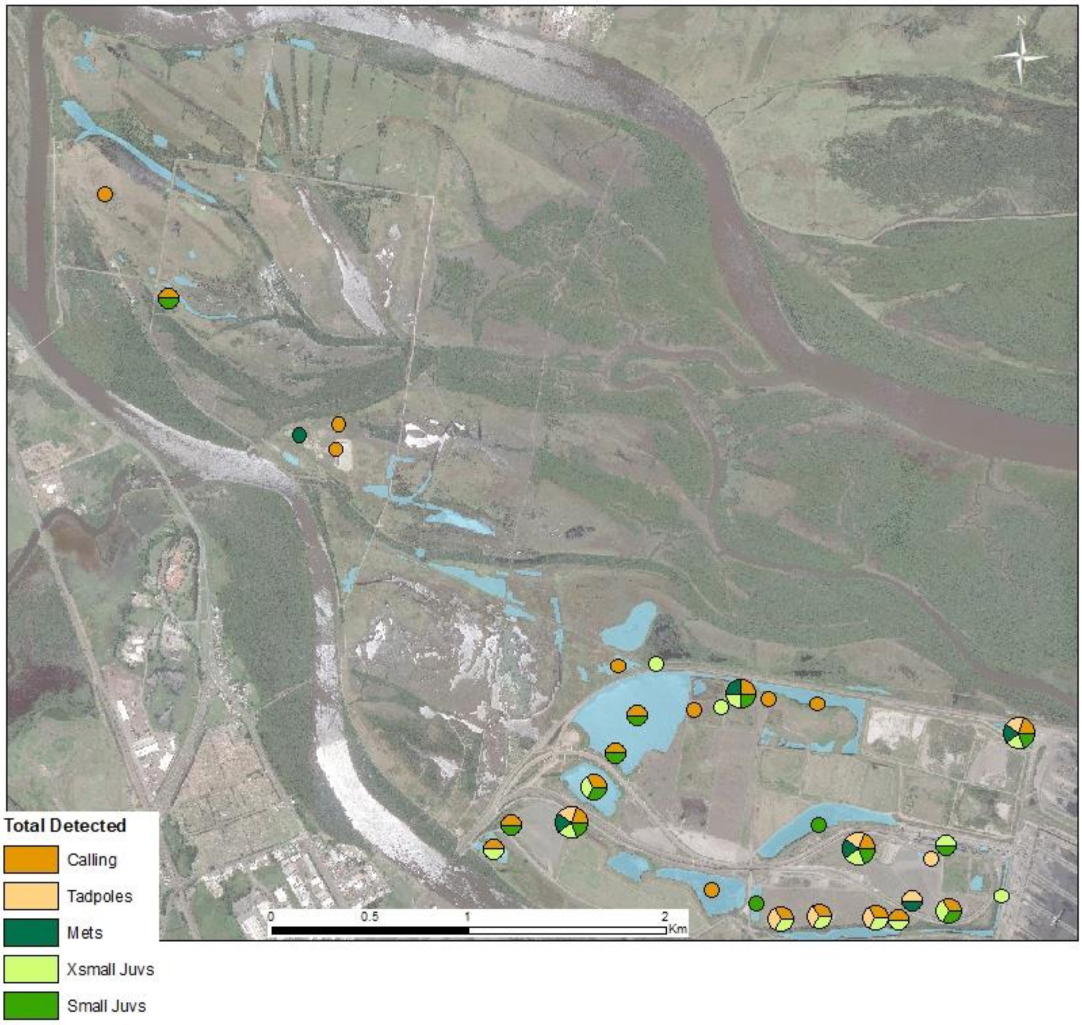


Figure 3.6.1: *L. aurea* breeding (i.e. calling, detection of tadpoles and/or metamorphs, small juveniles) during the 2017-18 survey season. 'Xsmall' juveniles have SVL < 35 mm; 'Small' juveniles have 35 < SVL < 40 mm. Note that the size of the segments within the pie charts denotes only presence of an age/six class or breeding behaviour; it does not indicate the quantity within each categories. See Figure 3.6.2 for close up of Industrial Zone wetlands.

There are several field observations that indicate breeding in *L. aurea*:

- The most direct evidence is tadpoles, but these need to be positively identified (which is not always possible in the field).
- *L. aurea* metamorphs can be reliably identified in the field and usually (but not always) indicate breeding has occurred in the wetland where they were observed.
- Juvenile frogs are of course mobile and do not provide a reliable indication that breeding as occurred in a specific wetland; however, large numbers of small juveniles (SVL < 30 mm) in a wetland are suggestive of a cohort of frogs that have spawned in that wetland.
- Males call during wet periods, that may occur at any time in the spring/summer seasons. Calling indicates the potential for breeding but does not indicate successful breeding at a specific location. However, because calling can be readily detected from some distance it provides a useful indication of potential breeding behaviour.

Figure 3.6.1 shows a map of wetlands where one or more of these ‘breeding indicators’ was detected during the 2017-18 season. Calling was heard at many wetlands, but for most of these there was also direct (tadpoles, metamorphs) or indirect (small juveniles) evidence of breeding.

Wetlands where breeding indicators were detected were overwhelmingly in the Industrial Zone (Figures 3.6.1, 3.6.2). In most instances, calling was detected along with other indicators; the only wetlands where only calling was detected were NCIG (CHEMP)-T14, K22, K49B, K103, K106B and C1.

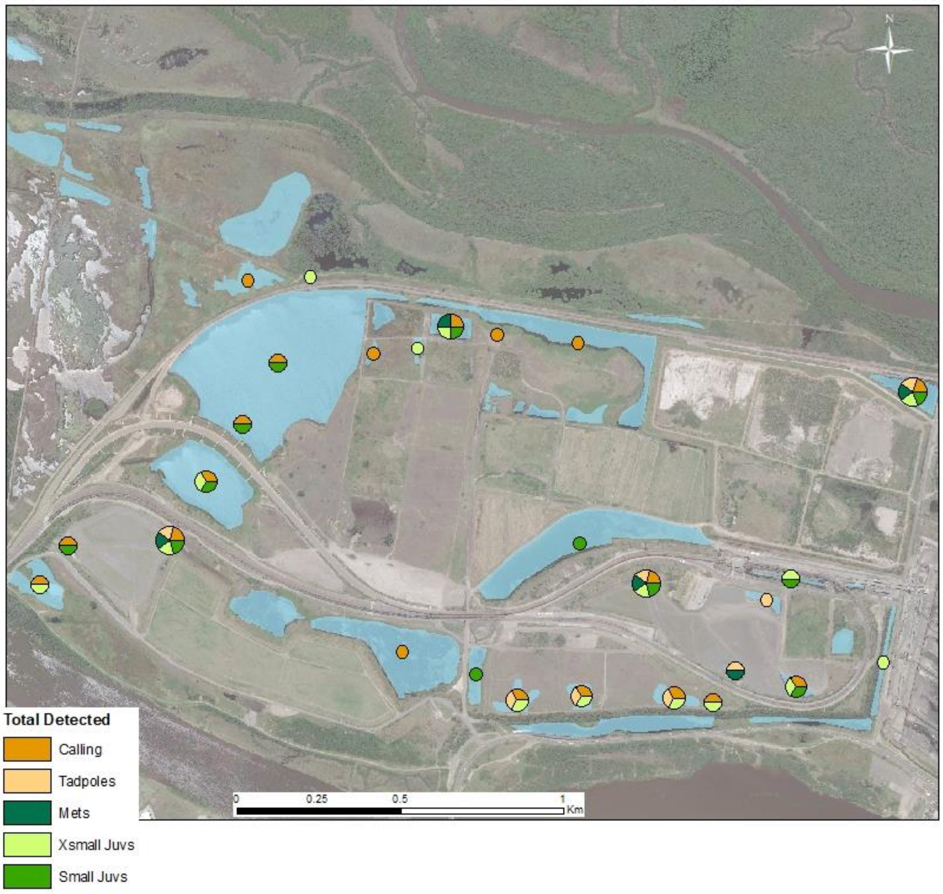


Figure 3.6.2: Evidence for *L. aurea* breeding in southern Kooragang Island. See Fig. 3.6.1 for explanation.

Within the Industrial Zone (Figure 3.6.2), seven out the nine wetlands where tadpoles and/or metamorphs were detected where HDC constructed wetlands; of these, the largest breeding event appears to have been at K114. The two other wetlands within the Industrial Zone were K104 and K29. Evidence of breeding at K29 was limited, but there appears to have been a significant breeding event at K104, which may be linked to the very low numbers of *Gambusia* present there in spring 2018 following the dry year in 2016-17.

Large numbers of small juveniles in K105B indicates at least one significant breeding event in that wetland; cohort analysis of the size/frequency distribution suggests two separate cohorts of young frogs where spawned, in autumn 2018 and spring 2018. Very small (SVL < 30 mm) were also abundant at K104. They were detected at K23, K46, K117, K106C, K122, C2, K115, and K111, but in very small numbers (less than 4). Moderate numbers were found at K121 and K123.

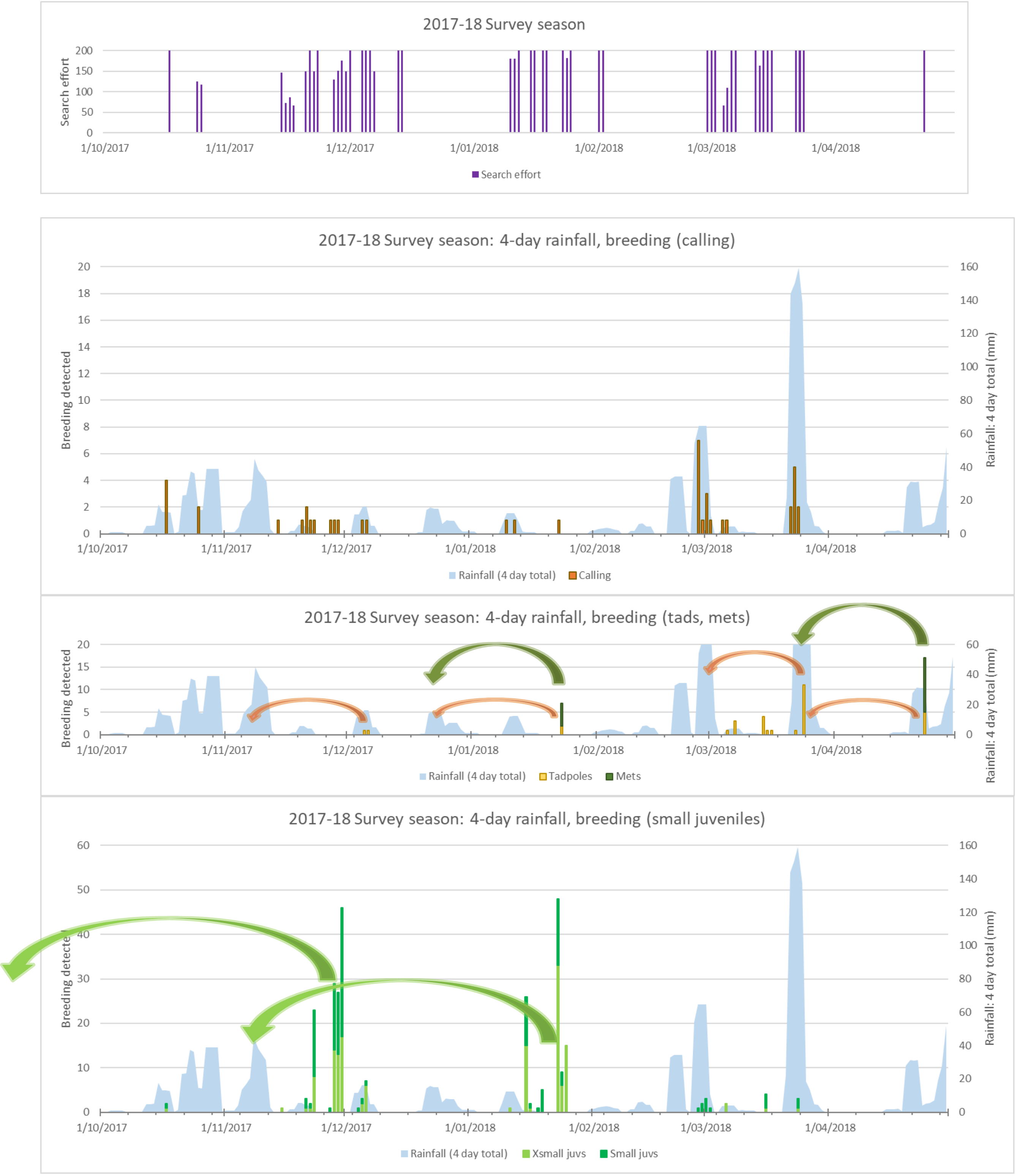


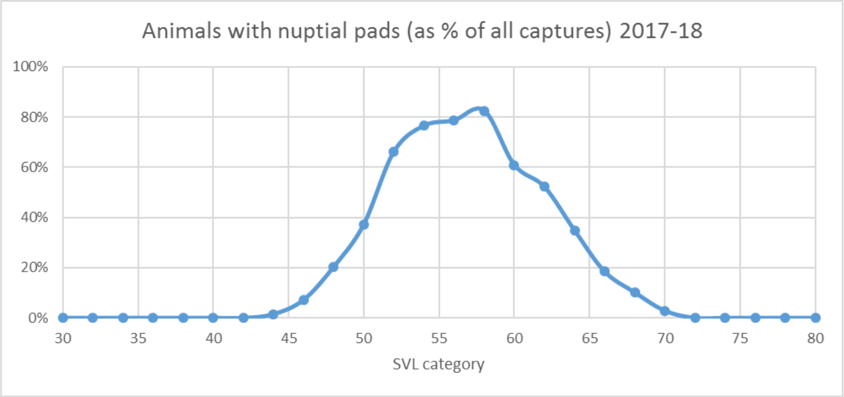
Figure 3.6.3: Survey nights (top), nights where calling was heard, detections of tadpoles and metamorphs, and detecttions of small juveniles (bottom), correlated with rainfall. Arrows indicate potential laying dates for animals detected as tadpoles (brown arrows), metamorphs (dark green), and extra-small ('Xsmall'; SVL < 35 mm) juveniles.

Calling was very closely associated with periods of recent rain between October and March (Figure 3.6.2) (note that for some periods of rain, such as early November and late December, did not occur during survey periods and thus data is lacking for these). Metamorphosis in *Litoria aurea* happens within a relatively short time frame and detection of metamorphs generally indicates spawning 4-5 weeks earlier (although this can extend to 6 weeks or more in spring or autumn, when temperatures are lower). The detection of tadpoles provides a less precise indication of spawning time but can still be correlated with rain events.

The large numbers of ‘Xsmall’ (SVL < 35 mm) juveniles indicate two cohorts, possibly resulting from:

1. Frogs that were spawned in April 2017, following significant rain caused by cyclone Debbie,
2. Frogs that were spawned in spring 2017 following moderate rain in October to early November.

Size at sexual maturity



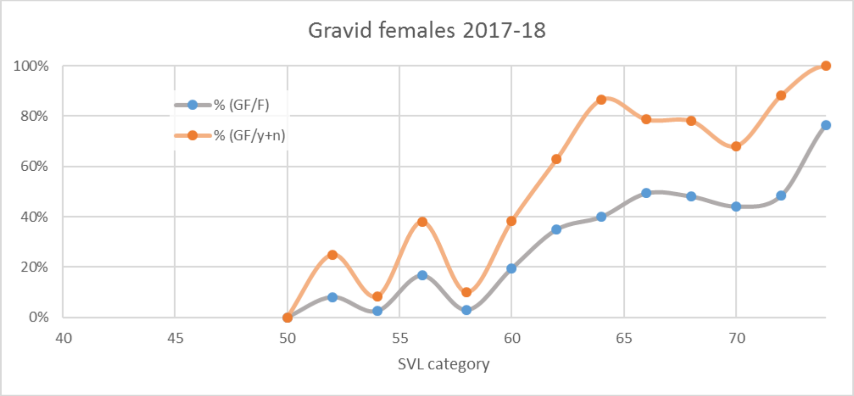


Figure 3.6.4: Proportions of animals with nuptial pads (top), and proportion of gravid animals (bottom). See text for discussion.

Data from the 2017-18 season (Figure 3.6.4) is broadly consistent with the observation from the previous season (Section 2.6, Figure 2.6.2) that male *Litoria aurea* reach sexual maturity at approximately 50 mm SVL. There were some slight differences; the proportion of *L. aurea* with nuptial pads plateaued at approximately 60% in 2016-17, but at closer to 80% for the 2017-18 dataset. That ~80% plateau was achieved at approximately 53 mm SVL, compared to the 60% plateau being achieved at 50 mm SVL in the 2016-17 dataset.

The exact point of this plateau does not affect the counts of males (which are positively identified by the presence of nuptial pads), but does affect the counts of juvenile females (which are identified by the absence of nuptial pads but an SVL greater that 49.5 mm). The data from the current 2017-18 season indicates that that size threshold for identifying an animal as a juvenile female (as opposed to simply a juvenile of unknown gender) may be slightly too small. We have not adjusted that threshold in analysing the demographics for the 2017-18 data (Sections 2.3 & 2.4), but highlight this issue here for future consideration.

If the onset of sexual maturity for female *Litoria aurea* is the production of eggs, and if egg masses can be reliably detected using candling (Section 2.6), then it appears that some females achieve sexual maturity at 52 mm SVL (Figure 3.6.4). The size threshold used to delineate between adult and juvenile females in 2016-17 was 58 mm SVL; we here adopt the cautious approach and retain that threshold. Confirmation of sexual maturity in *L. aurea* below a SVL of 58 mm awaits confirmation from hormone analysis.

Interactions between breeding and *Gambusia*

	Total wetlands with	Gambusia	no Gambusia
2015-16	tads/mets	3	4
	no tads/mets	56	15
2016-17	tads/mets	3	5
	no tads/mets	21	42
2017-18	tads/mets	1	9
	no tads/mets	15	35

Table 3.6.1: Interaction between presence of *Gambusia*, and breeding behaviour of *L. aurea* (as evidenced by the presence of tadpoles and/or metamorphs), for the last three survey seasons.

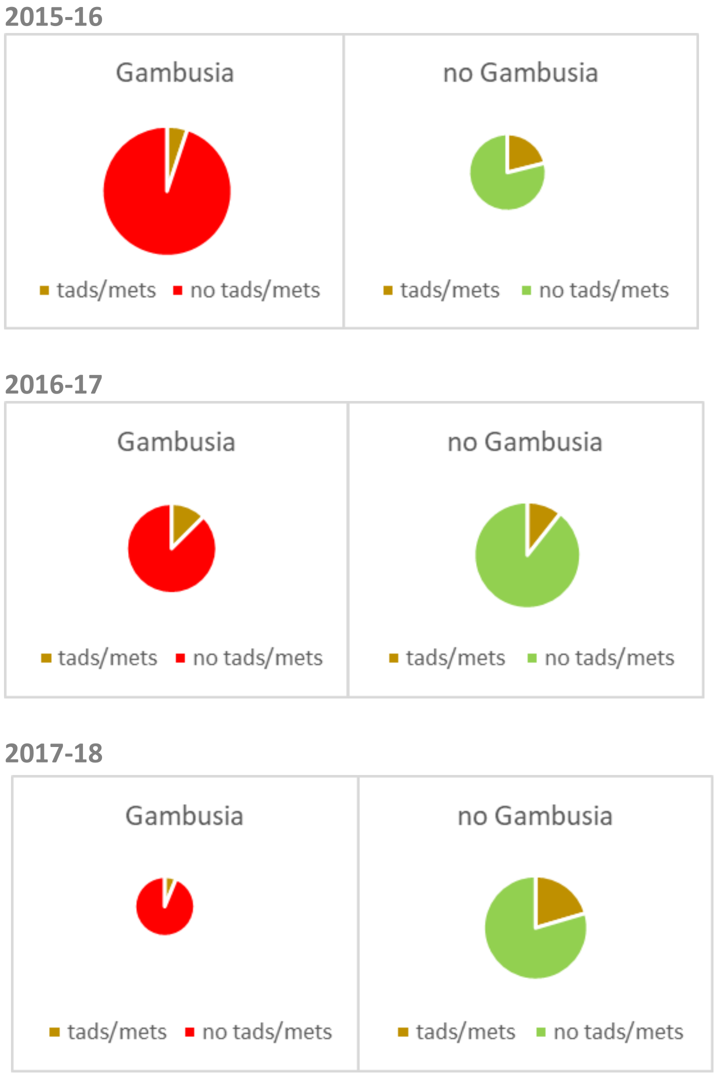


Figure 3.6.5: Graphical representation of the data presented in Table 3.6.1.

For the data presented in Table 3.6.1 and Figure 3.6.4, we deduce a **strong effect** when there are proportionally higher rates of breeding in *Gambusia*-free ponds than in wetlands where *Gambusia* is present.

There is a strong effect of *Gambusia* presence on *L. aurea* breeding in 2015-16 and 2017-18. However, there appears to be no detectable effect for the 2016-17 data.

We note that looking at simply presence/absence of *Gambusia* may underestimate this effect. Breeding of *L. aurea* is likely to be related to density of *Gambusia*, not just presence. For instance, in K104 there was a significant breeding event in 2017-18; *Gambusia* was present, but at much lower densities than in 2015-16. The differences in *Gambusia* density are directly related to the hydrology of the wetland prior to the breeding season.

3.7. Microhabitat and Habitat

Vegetation (microhabitat)

Structures	*n* (captures)
trees	46
emergent vegetation	1,311
water	110
ground	247
man-made structure	4
ground vegetation	142
shrubs	97

Table 3.7.1: Broad microhabitat categories of *L. aurea* captures, pooled across the 2017-18 season

Green and golden bell frogs were predominantly on emergent aquatic vegetation (Table 3.7.1); specifically, the reed plants *Typha, Phragmites, Bolboshoenus,* and *Schoenoplectus*, in addition to the weed species *Juncus acutus* (Table 3.7.2). They were also on frequently found on the ground. Males were often found at the surface of the in water when calling, including floating on the water surface in amongst flooded grass.

Where *L. aurea* were found in terrestrial shrubs close to wetlands, in was often in pampas. They are also regularly found in trees (Table 3.7.2).

Foeniculum	fennel
Hydrocotyle	penny-wort, dollar weed
Chrysanthemoides	bitou
Cortaderia	pampas
Ricinus	castor oil

Table 3.7.2: Detailed microhabitat of *L. aurea* captures, pooled across the whole season.

Species	*n* (captures
Acacia	11
Casuarina	3
tree	11
branch	4
dead branch	15
fallen tree	0
mangrove	2
Bolboshoenus	68
Juncus	194
Phragmites	239
Scheonoplectus	75
Typha	717
reed	18
water	106
algae	2
flooded grass	2
bank	11
ground	86
mud	63
rock	59
road	28
concrete	0
cable-tray	2
sump wall	1
tub	3
rope	0
Foeniculum	8
Hydrocotyle	18
Paspallum	41
grass	73
dead grass	1
Chrysanthemoides	15
Cortaderia	67
Lantana	4
nest	1
nightshade	1
Ricinus	2
shrub	9
vine	1

Wetland Physiognomy

Score	5	4	3	2	1
Size	Very large	Large	Med	Small	Very small
Openness (tall reeds)	Open	Nearly open	Partially open	Nearly closed	Closed
Edge vegetation extent (tall reeds)	Totally surrounded by reeds	Lots	Approx. half	Small amount	Very little/none

Table 3.7.3: Qualitative scores used for preliminary analysis of the effects of wetland physiognomy upon *L. aurea* abundance; c.f. Fig. 3.7.1, Fig.3.7.2.

An important question in understanding *L. aurea* ecology, particularly for management, concerns the habitat requirments of this frog. We here provide a visualisation of the current dataset, with the purpose of generating insights into any links between *L. aurea* abundance and wetland physionomy.

Wetland physiognomy involves a subset of habitat parameters that incorporate 'physical' factors such as size, openness, and density of edge vegetation. Quantitative measurement of these factors for large numbers of wetlands is a logistically complex process. Here, we use qualitative scores to provide a preliminary analysis of the effects of these parameters on bell frog abundance.

Each surveyed wetland was scored for these parameters (Table 3.7.3). The scores for hydroperiod (**Section 3.2**) were also used.

When plotted against the numbers of frogs detected there is a great deal of noise in the data (which is one of the challenges for quantitative analysis). However, **qualitatively**, high values of T**otal Detected** are very strongly related to high scores for Openness, and Edge vegetation (Figure 3.7.1).

There are also strong effects by Wetland Size and Edge Depth. Wetlands with high values of Total Detected are all semi-permanent, nearly permanent, or deep permanent. The highest scores are for nearly permanent wetlands.

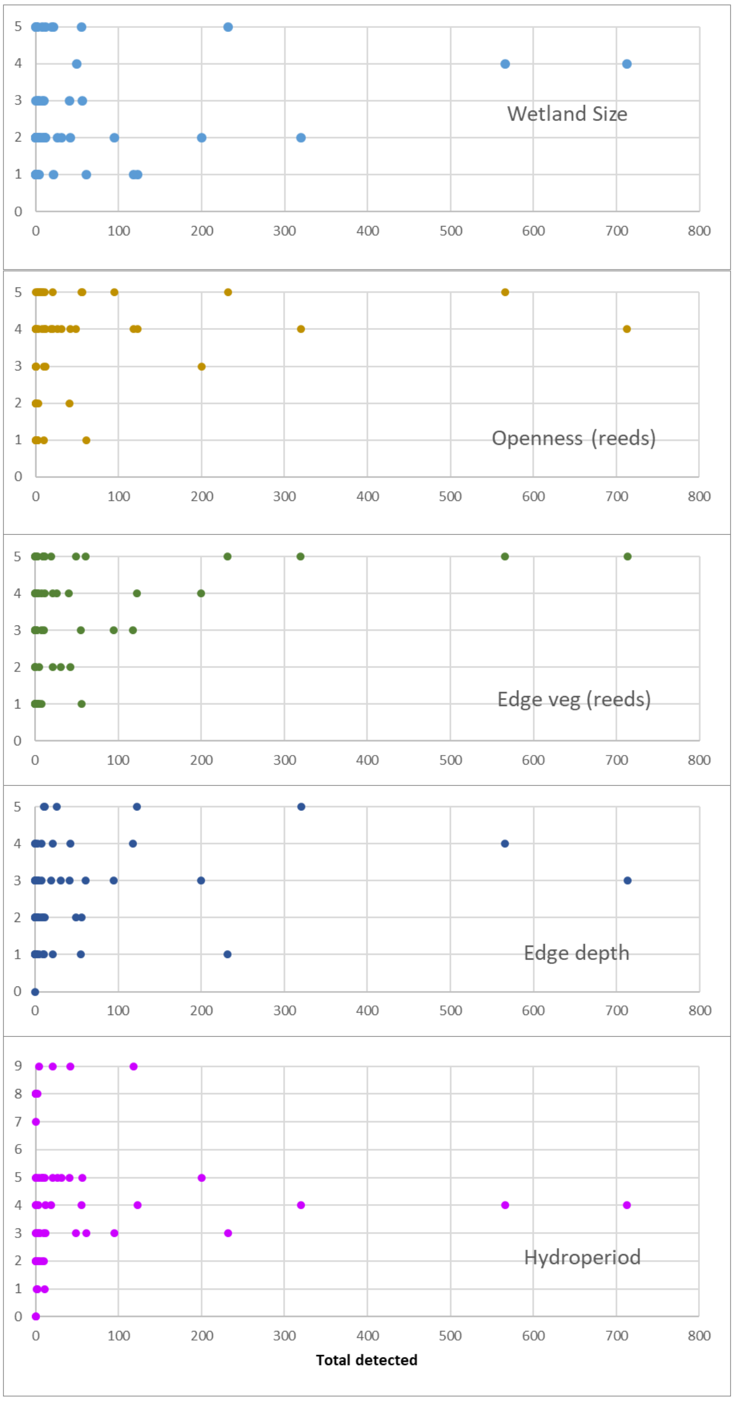


Figure 3.7.1: Scores for wetland size, openness, edge vegetation, edge depth, and hydroperiod, plotted against values of **Total Detected** bell frogs for each wetland surveyed in 2017-18.

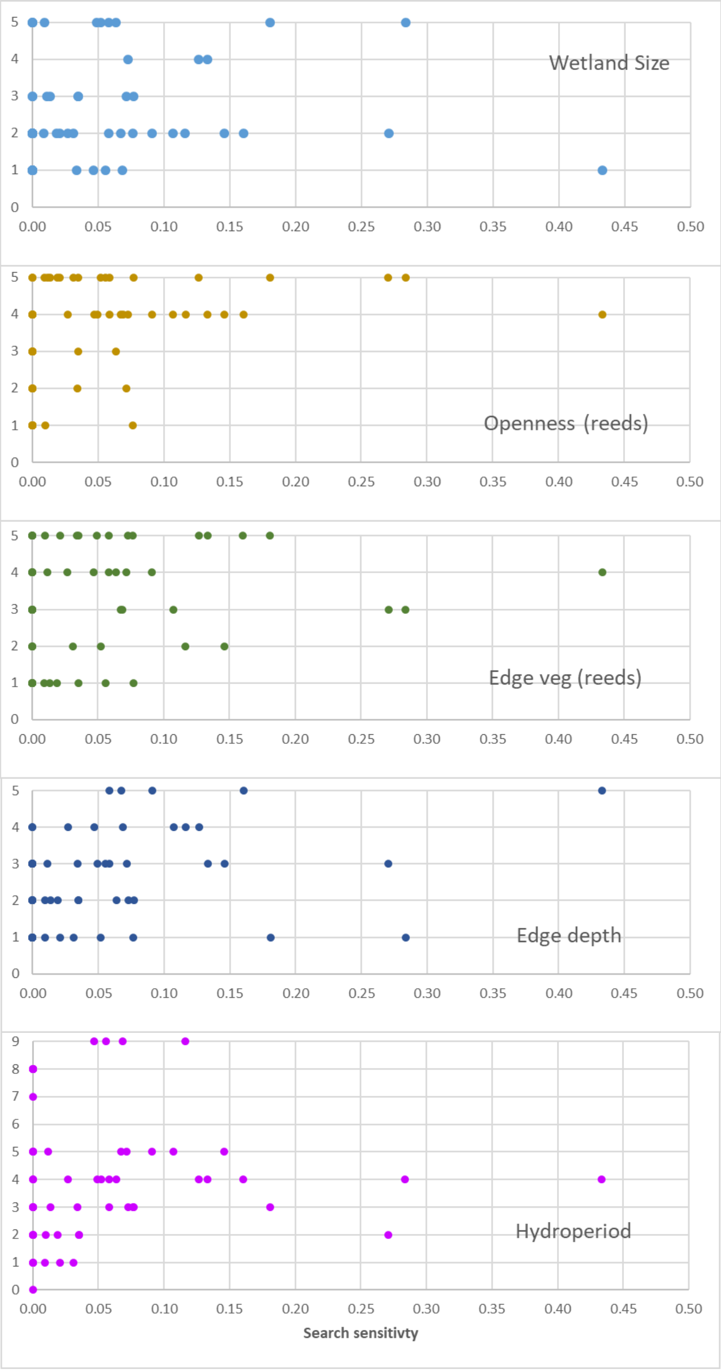


Figure 3.7.2: Scores for wetland size, openness, edge vegetation, edge depth, and hydroperiod, plotted against values of **Search Sensitivity** for each wetland surveyed in 2017-18.

The highest values **for Search sensitivity** (Figure 3.7.2) are likewise strongly affected by high scores for Openness and Edge vegetation, although not quite to the same degree as with Total Detected.
Wetland Size has a very weak interaction with Search Sensitivity**.** Relationship with Hydroperiod is similar to Total Detected.

This data indicates that high densities and high numbers of *L. aurea* are found in wetlands that are
(1) comparatively open, and
(2) and have densely vegetated (reeds) edges.

Deep edges also help. Population density does not increase with wetland size but overall numbers do. Only semi-permanent/permanent wetlands hold high numbers and densities of *L. aurea*.

Interestingly, this result, although preliminary, provides some data-driven support for the overall patterns that we have identified in advice on wetland design, i.e. *L. aurea* prefer well edge-vegetated (reeds), open wetlands, with deep water at the edge of the vegetated banks. Conciliant with this, adult *L. aurea* were not resident at K121-3, which lack edge vegetation; neither do they appear to be resident at K112, K113, which are temporary wetlands that often do not hold water. However, K121-3 and K111-2 do support breeding (Section 3.6), so it is important that there is suitable habitat for adult frogs nearby (i.e. C2 and K36 for K121-3; K114 and K111 for K112 and K113).

This initial analysis is constrained by low quality of the data for physiognomic parameters. Better quality data will inevitably allow more powerful analyses.

The question of how wetland physiognomy affects quality of breeding habitat is also important and should be explored further. However, we note that these patterns of occupancy connect strongly with the concept of the *L. aurea* ‘habitat mosaic’ outlined in Section 3.2 and discussed in Section 4.

3.8. Population size

Population estimate of wetlands surveyed using Capture-Mark-Recapture

Capture-Mark-Recapture (CMR) surveys were conducted at 3 wetlands; K22/23, K29, and K104. (Table 3.8.1). As detailed in section2, a single CMR survey at a given wetland should run for a minimum of three consecutive nights until the within-round recapture rate is above 20%. (i.e. when, on a given survey night, at least 20% of the animals captured had already been captured in that round: <marked animals recaptured on the night> / <total unique animals captured over the duration of the survey>). Note this not the same as 20% of animals being 'recaptures', i.e. animals that have previously been captured at some point in their lives. The information provided by a CMR survey round is maximised if there are at least 3 survey nights within the round.

As a matter of course we aim to complete a CMR survey at each of these three wetlands during each round. However, various logistical issues can impede these surveys; in previous years, CMR surveys have been abandoned because of insufficient frogs at the wetland in that round, sometimes combined with obvious high levels of immigration/emigration from the wetland during the survey. During the 2017-18 season, the CMR surveys at K22-23 and K104 in Round 2 were abandoned for a different reason; as the wetlands dried out during the drought, they were largely comprised of deep mud and were treacherous to work in. In contrast, the CMR survey at K29 in Round 3 was curtailed in order to survey for breeding activity across the island immediately after drought-breaking rain at the beginning of March 2018.

Wetland	Dates of primary survey periods	no. secondary surveys	*L. aurea* captures (total; unique)	Final recap. rate (%)	Naïve population estimate
	Round 1				
K22/23	14-17 Nov 2017	4	187; 122	26%	173
K29	20-22 Nov 2017	3	337; 227	26%	384
K104	28-30 Nov 2017	3	240; 165	21%	251
	Round 2				
K22/23	-	-	-	-	-
K29	10-12 Jan 2018	3	205; 152	24%	232
K104	-	-	-	-	-
	Round 3				
K22/23	12-15 Mar 2018	4	63; 43	14%	78
K29	-	-	-	-	-
K104	14-16 Mar 2018	3	111; 78	19%	136

Table 3.8.1: Surveys, captures, final recapture rates, and naïve population estimates at the three sites where CMR surveys were conducted. Final recapture is shown for last night of each survey (see text for explanation of calculation). Naïve population estimate is calculated as <total animals marked to date> x (<animals captured on final night>/<recaptured animals on final night>). Note that CMR surveys were not completed at all sites in rounds 2 and 3 (see text).

The results of the CMR surveys were analysed by Robust modelling using RMark code in the R programming language to interface with the program MARK (Table 3.3.3).

Rank	**Model**	**No. of parameters**	**AIC$_c$**	**ΔAIC$_c$**	**weight (*w*)**
	K22-23				
1	ϕ(.) $G'=G''(.)$ $p=c$(sess) f0(sess)	16	-215.403	0.000	0.134
2	ϕ(.) $G'=G''(.)$ $p=c$(het) f0(sess)	8	-214.969	0.434	0.108
3	ϕ(.) $G'(.)$ $G''(.)$ $p=c(.)$ f0(sess)	7	-214.265	1.138	0.076
5	ϕ(.) $G'=G''(.)$ $p=c(.)$ f0(sess)	6	-214.025	1.378	0.067
6	ϕ(t) $G'(.)$ $G''=0$ $p=c$(t) f0(sess)	8	-213.949	1.453	0.065
7	ϕ(.) $G'(.)$ $G''=0$ $p=c$(sess) f0(sess)	15	-213.838	1.565	0.061
	K29				
1	ϕ(.) $G'(.)$ $G''=0$ $p=c$(sess) f0(sess)	13	-1561.695	0.000	0.489
2	ϕ(.) $G'=G''(.)$ $p=c$(sess) f0(sess)	14	-1559.766	1.928	0.187
5	ϕ(.) $G'(.)$ $G''(.)$ $p=c$(sess) f0(sess)	15	-1557.658	4.037	0.065
	K104				
1	ϕ(.) $G'(.)$ $G''=0$ $p=c$(sess) f0(sess)	13	-1114.578	0.000	0.493
2	ϕ(t) $G'(.)$ $G''=0$ $p=c$(het) f0(sess)	14	-1112.435	2.143	0.169
3	ϕ(.) $G'=G''(.)$ $p=c$(sess) f0(sess)	14	-1112.433	2.143	0.169
5	ϕ(.) $G'(.)$ $G''(.)$ $p=c$(sess) f0(sess)	15	-1110.277	4.301	0.006

Table 3.8.2: Candidate set of models, ranked by ascending ΔAICc, used to estimate apparent survival probability (ϕ), capture (p) /recapture (c) probability, and number of uncaptured individuals in each wetland population (f0) of *L. aurea* at the CMR sites on Kooragang Island, 2017-18. In most models, net immigration/emigration (G', G") was set to zero. (.) indicates that the value of a parameter was constant, (t) that it varied with time, and (sess) that it varied between between primary sessions but was fixed for secondary sessions within each primary session.

Models are ranked according to their corrected Akaike Information Criteria (AICc) values. Delta AICc values <2 indicate reliable models. Instances where the top ranked model is the only one with a delta AICc <2 are taken as very strong support for that model (e.g. K104). In the case of K22-23, the top seven ranked models had delta AICc values <2, indicating poor support for a specific model. This was potentially a result of the low recapture rate in the third round. During that round, capture total within the wetland itself were low, and a large number of captures were made on the adjoining road, up to 100 metres from the wetland, suggesting that emigration from the wetland was high during the period of the CMR survey.

The top ranked models produced highly convergent estimates of population size (N-hat values), especially for K29 and K104 (Table 3.8.3). Selecting the best ranked model for each CMR site allowed estimates of total population size for each site, in each round.

	1st Primary Session (round 1)				2nd Primary Session (round 2)				3rd Primary Session (round 3)		
Wetland	N-hat (pop. size)	95% confidence levels			N-hat (pop. size)	95% confidence levels			N-hat (pop. size)	95% confidence levels	
model #		Lower	Upper			Lower	Upper			Lower	Upper
K22/23											
#1	171	152	204		-	-	-		68	54	98
#3	178	158	210		-	-	-		63	54	80
#7	171	152	204		-	-	-		69	55	102
K29											
#1	310	283	350		250	214	304		-	-	-
#2	310	283	350		247	211	304		-	-	-
#5	310	283	350		274	211	304		-	-	-
K104											
#1	277	236	340		-	-	-		140	115	188
#3	277	236	340		-	-	-		140	115	188
#5	277	236	340		-	-	-		140	115	188

Table 3.8.3: Population estimates for the wetlands surveyed using Capture-Mark-Recapture, analysed by Robust Modelling. Results from a selection of the best models as ranked by AICc scores (c.f. Table 3.8.2) are presented. N-hat values are population estimates for each wetland, listed by each model for each round. The top ranking models provide consistent estimates, and the range of the 95% confidence levels is reasonably narrow for all population estimates.

The population estimates for the 3 CMR sites (which between them incorporate 4 wetlands) are summed (Table 3.8.4).

	Robust model estimate			**Naïve population estimate**
	lower	**N-hat**	**upper**	
Round 1	671	758	894	808
Round 2*	214	250	304	232
Round 3**	169	208	286	214

Table 3.8.4: Total population estimates for CMR surveyed wetlands, for each round. Notes: *, round 2 did not include CMR surveys at K22-23 or K104; **, round 3 did not include CMR surveys at K29. The estimates from the robust models are based upon the top ranking model for each wetland, as shown in Table 3.8.3. The totals for the naïve population estimate are taken from Table 3.8.1. Note the consilience between the estimates derived from the two approaches.

Using VES data to convert CMR results into an island wide estimate of *L. aurea* population on Kooragang Island

The first step in producing a whole-island estimate of *L. aurea* numbers is to determine the proportion of frogs inhabiting a wetland that are detected during a Visual Encounter Survey. This is achieved by using the CMR survey results to calculate a conversion factor (1/<proportion detected in VES>) that can be used to estimate the total number of *L. aurea* at each surveyed wetland, based on the number of frogs detected in each VES (Table 3.8.5).

	Conversion factor (VES_detected -> CMR population_estimate)				
Wetland	min-lower	mean-lower	mean-N-hat	mean-upper	max-upper
pooled	2.80	6.42	**7.51**	9.38	21.52
K22-23	3.11	6.32	**7.40**	9.38	29.26
K29	4.98	6.85	**7.79**	9.16	11.97
K104	3.17	6.16	**7.40**	9.61	18.67

Table 3.8.5: Conversion factors (calculated as <population estimate> / <number detected in VES>) for the three CMR wetlands. 'min', 'mean', and 'max' relate to the minimum, mean, and maximum values for that ratio respectively, as a result of different VES counts at each wetland during each round. 'lower', 'N-hat', and 'upper' relate to the range of population estimates calculated for each wetland using robust modelling (see Table 3.3.4). Combining these two dimensions of variation produces a range of estimates for the conversion factor (see text for discussion). The 'pooled' row shows values combined from all CMR surveys; the other rows show the values for each specific CMR wetland.

There is a level of uncertainty around the precise value of the conversion factor; this uncertainty has two dimensions. The first stems from the fact that several VES surveys are conducted at each CMR wetland during each round (typically, one primary VES and two secondary VES); thus, we have several different values for frogs detected during VES for each estimate of population at that wetland. This leads to a range of ratios at each wetland, for each round; from these we calculate the minimum, the mean, and the maximum value for that ratio.

The second dimension of this uncertainty results from the range of estimates for the population estimate at each of the CMR surveyed wetlands. The robust modelling approach provides a preferred value ('N-hat', and also lower and upper 95% confidence intervals). Combining the min, mean, and max values for the detected/population ratio with these different estimates of CMR population size provides a range of values for the conversion factor. We use 5 of these potential values:

1. **Min-lower**: the minimum value of the <detected/population> ratio, using the lower estimate of population size.
2. **Mean-lower**: the mean value of the <detected/population> ratio, using the lower estimate of population size.
3. **Mean-N-hat**: the mean value of the <detected/population> ration, using the preferred ('N-hat') estimate of population size.
4. **Mean-upper**: the mean value of the <detected/population> ratio, using the upper estimate of population size.

5. **Max-upper**: the maximum value of the <detected/population> ratio, using the upper estimate of population size.

It is important to note that, although using this range of estimates decreases precision of the final population estimate, it increases accuracy of that estimate. Precision could be increased by only using a single ratio of detection/population size (for example, by only running one VES survey during the survey period at a CMR wetland), but that single value may very easily not represent the typical situation at that wetland (for example, a VES on a warm windless night just after rain will probably detect a very high proportion of the frogs present at that wetland, giving an unusually high value for the ratio of animals detected/actual population). The resulting population estimate would have a smaller range of values (giving the illusion of precision), but is less likely to be accurate.

The range of values for conversion factors are then used to generate estimates of population size at the 69 wetlands that were surveyed only by VES. The range of conversion values calculated from the three CMR wetlands was consistent, from 7.4 to 7.8 (mean-N-hat), i.e., based upon the mean-N-hat numbers, a VES survey will detect one *L. aurea* for every 7 or 8 bell frogs that are actually present. The pooled value (from Table 3.8.4) of 7.51 was used to calculate these estimates. Note that the population estimate was also restricted to animals >40 mm SVL, i.e. not including tadpoles, and small juveniles.

The final step in making the island-wide population estimate is to adjust for those wetlands that are too large to fully survey in a 30 minute VES. For these, the proportion of the wetland surveyed during VES was measuring using GIS to calculate an area weighting.

The estimates for total population for the VES surveyed wetlands are shown in Table 3.8.6.

	min-lower	**mean-lower**	**mean-N-hat**	**mean-upper**	**max-upper**
Non CHEMP wetlands					
Round 1	576	1,323	**1,548**	1,932	4,434
Round 2	898	1,959	**2,309**	2,916	6,406
Round 3	754	1,550	**1,813**	2,258	4,786
CHEMP wetlands					
Round 1	537	1,233	**1,442**	1,801	4,133
Round 2	173	398	**466**	581	1,335
Round 3	104	238	**278**	347	796
Total VES wetlands					
Round 1	1,113	2,556	**2,990**	3,733	8,567
Round 2	1,071	2,357	**2,775**	3,497	7,740
Round 3	858	1,788	**2,091**	2,605	5,582

Table 3.8.6: Population estimates for 47 non-CHEMP and 13 CHEMP wetlands. Estimates are based on the ratio of CMR(population):VES(detected) at the CMR survey sites (Table 3.8.4) Note that VES counts include K22-23 and K104 for round 2, and K29 for round 3, as CMR surveys were not completed at those wetlands in those rounds. See text for explanation.

Combining the population estimates for the CMR (Table 3.8.3) and VES (Table 3.8.6) surveyed wetlands provides a range of estimates for the actual population size across all 60 wetlands surveyed on Kooragang Island over the 2017-2018 season (Table 3.8.7).

Total population size	min-lower	mean-lower	mean-N-hat	mean-upper	max-upper
Round 1	1,524	2,629	**3,049**	3,754	7,459
Round 2	1,268	2,583	**3,030**	3,791	8,175
Round 3	1,014	1,966	**2,303**	2,883	5,965
Total population size (not including CHEMP wetlands)					
Round 1	1,247	1,994	**2,306**	2,826	5,328
Round 2	1,094	2,185	**2,564**	3,209	6,841
Round 3	910	1,728	**2,025**	2,536	5,169

Table 3.8.7: Estimates of total population size across all surveyed wetlands. See text for discussion.

These estimates should be interpreted as follows:

- It is **highly likely** that the population of *L. aurea* at the 60 surveyed wetlands was between the 'min-lower' and 'max-upper' limits (i.e. between 1,524 and 7,459 in November 2017).
- It is **probable** that the population was between the 'mean-lower' and the 'mean-upper' figures (i.e. between 2,629 and 3,754 in November 2017)
- The model estimation for the **approximate** population is the 'mean-N-hat' figure, i.e. 3,049 in December 2017.

It is not correct to say that that the population was 3,049 in round 1; rather, the population was **approximately** 3,049.

Note that these estimates include, for the first time in the island wide surveys, the CHEMP wetlands created in the Central and Northern Zones of Kooragang Island. Estimates from previous island wide surveys have not included those wetlands. Comparing the estimate for the non-CHEMP wetlands with data from the previous two seasons provides some indicate of the population dynamics for *L. aurea* on Kooragang Island since the island-wide surveys began in 2010 (Figure 3.8.1)

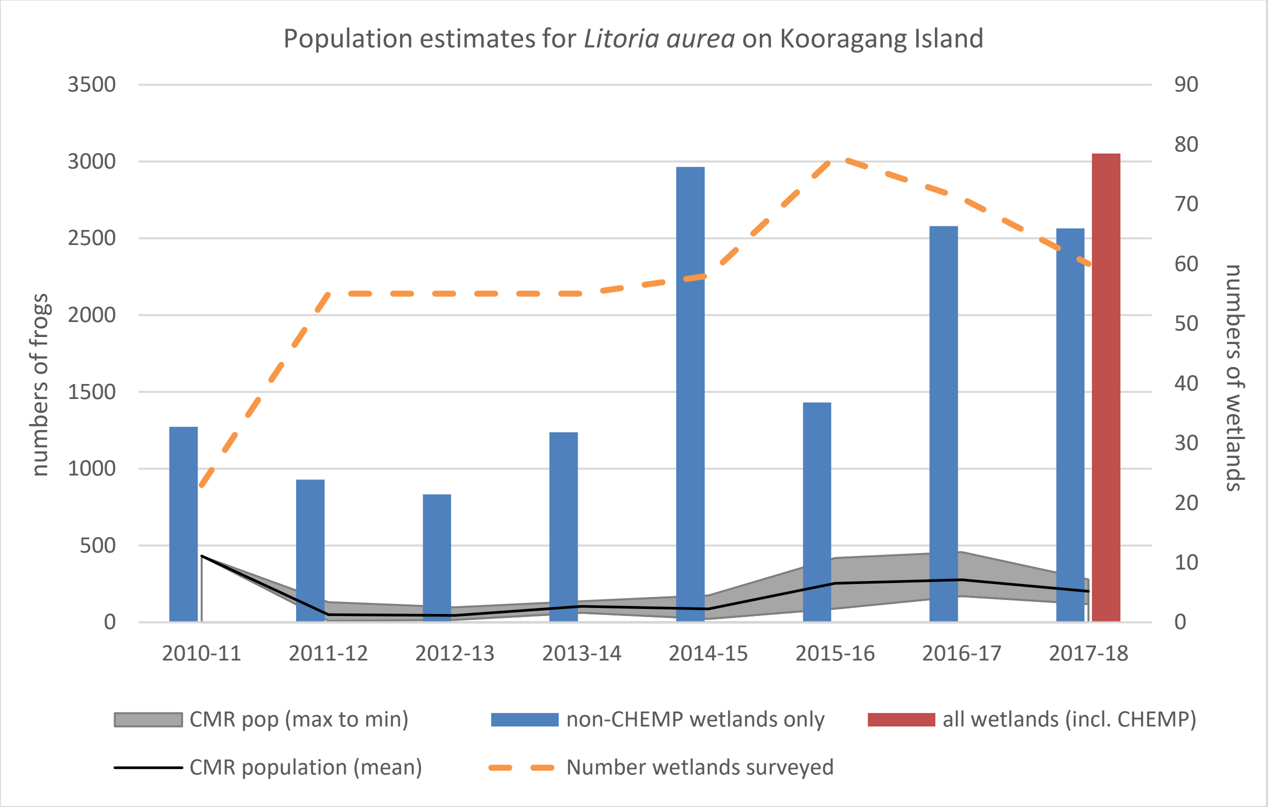


Figure 3.8.2: Population estimates for *Litoria aurea* on Kooragang Island. Data for 2010-2017 is from previous annual reports for the current project, while the 2017-18 data is from the current report. Blue columns show maximum population estimates derived from CMR-VES counts for the non-CHEMP wetlands only, while the red column shows the maximum 2017-18 estimate for all wetlands including the CHEMP (see data shown in Table 3.8.7). Maximum estimates are the largest of the instantaneous estimates ('mean-N-hat' of Table 3.8.7) made for each survey round (and are generally for rounds early in the season). The black line shows the average (across all rounds in a given season) total N-hat for wetlands where CMR surveys were conducted, whilst the greyed area shows maximum and minimum N-hat values across the different round; typically, the maximal value is in Round 1 and the minimal in Round 3 (see Table 3.8.4 for an example of that data for the 2017-18 season). The dashed orange line shows the number of wetlands surveyed each season (Y2 axis).

This analysis indicates a standing population of 500-1000 individuals from 2010-2014, increasing to a larger population of 1,500-2,500 from 2014-2018. Note that the surveys prior to 2013-14 targeted a smaller number of wetlands than did the those in 2015-16 and 2016-17, but the changes in population estimate do not appear to be a simple product of sampling effort and unintended bias. The population estimate for CMR-surveyed wetlands alone (for which model estimates should be most reliable) shows some overall increase from 2011-15 to 2015-18. Overall, the population seems to be at least stable, especially in the last four seasons, and there is no evidence for a sustained decline across the last seven seasons.

3.9. Multi-year occupancy

To provide a spatio-temporal context for occupancy of Kooragang Island by *L. aurea*, data from 2014-19 (i.e. four complete seasons) was analysed with respect to the subdivisions outlined in **Section 2.2**:

1. **Jurisdiction**: i.e. the organisations responsible for / active on various parts of the island.
2. **Zone**: splitting the Island into three large scale regions.
3. **Region**: subdivisions of zones, bounded broad geographic distance, at a scale of ~2 km.
4. **Subregion**: bounded by rail-lines, roads, and creeks, at a scale of up to ~1 km.

The following charts show data from survey counts, broken down by these four criteria. Survey count data is summarised according to:

viii. **VES detected** (number of *L. aurea* detected during primary VES surveys)
ix. **Total detected** (number of *L. aurea* detected during all surveys, including CMR)
x. **Search sensitivity** (a proxy for density; the number of animals detected in VES divided by the search effort)

Raw survey counts are not subject to the various assumptions inherent in estimating populations from robust modelling, and can therefore provide an additional and useful perspective on spatio-temporal trends in occupancy. However, they are a product of both occupancy and search effort; thus, in interpreting the counts to understand occupancy, it is important to take into account search effort. The landscape of Kooragang Island is not constant, and search effort and detectability has changed from year to year as new wetland habitats are created, and some old ones go through vegetative and hydrological changes.

For the data presented here, no single table provides a complete picture of *L. aurea* occupancy. Rather, the data for **VES Detected**, **Total Detected**, and **Search Sensitivity** should be viewed together. Large wetlands may contain large numbers of frogs (high values of **VES Detected** and **Total Detected**) at low or medium densities (lower values of **Search Sensitivity**). Conversely, small wetlands may contain high densities of frogs but with low overall numbers. Note that Total Detected is strongly affected by the location of the CMR wetlands (i.e. K22-23 is in the Central Zone, and K29 and K104 are in the Southern Zone); the large differences between values for VES Detected and Total Detected are mainly due to these.

The search effort (measured in person.minutes) of VES surveys across the last 4 seasons is shown in Table 3.9.1. Total search effort has increased slightly across this time (c.f. Table 2.5.1). Note that a large number of NPWS wetlands were surveyed in 2015-16 (most of these located in the North and Central zones). In the last two seasons, survey locations have been adjusted to incorporate new HDC wetlands and the CHEMP wetlands; consequently, surveys in the HDC (BHP) ('old BHP' wetlands), RMS, and some NPWS wetlands have decreased.

Data for **VES Detected** (Table 3.9.2) shows that the highest numbers of *L. aurea* detected during VES were in 2016-17, with a slight reduction in 2017-18 (but still much higher levels than 2014-15 or 2015-16). The high densities and numbers detected in 2016-17 were likely a result of a very wet year (2015-16), followed by a very dry year (2016-17). The wet year allowed high levels of recruitment, whilst at the same time making detection difficult as frogs dispersed widely across the landscape. In the following dry year, bell frogs were restricted to semi-permanent and permanent wetlands, where they could be detected; the populations were large, presumably due to high levels of recruitment the previous season. Note also that 2015-16 had only two survey rounds, whilst the others had three; the lower values of animals detected in that year is at least partly attributable to reduced survey periods.

	2014-15	2015-16	2016-17	2017-18
Jurisdiction				
NPWS	2028	3693	2758	1460
NCIG_CHEMP	0	0	0	296
BHP_CHEMP	30	279	0	1523
PoN	1475	697	1033	423
PWCS	2347	2224	3305	4563
NCIG	104	348	319	574
HDC	393	720	848	1681
HDC (BHP)	1304	615	442	582
RMS	298	278	156	0
Zone				
Nth	1027	1617	1056	1040
Central	2423	3052	2735	2662
Southern	4446	4185	5070	7400
Region				
Hunter North River	611	657	395	414
School House	469	960	661	626
Cobbans Creek	458	1132	651	1728
Bellfrog Way	1995	1920	2084	934
Industrial Zone North	2093	1783	2887	3924
Industrial Zone South	2353	2402	2183	3476
Subregion				
Scott's Point	174	264	201	259
Riverside park	437	393	194	155
Wet meadow	395	678	448	410
Millam’s Pond	74	282	213	216
Ramsar Road West	110	564	258	1601
Ramsar Road East	348	568	393	127
Bellfrog Way West	152	403	350	205
Bellfrog Way NE	270	588	465	306
Bellfrog Way SE	1573	929	1269	423
Delta Ponds (K104)	435	195	570	881
KIWEF *K7*	1436	1441	1823	2037
NCIG rail central & east	240	507	496	775
Rail loop *K10 Nth*	393	606	596	902
Cormorant Road	298	278	156	0
Rail loop SW *K10 Sth*	27	110	112	725
NCIG rail south	1345	555	474	405
KIWEF *K2*	50	346	349	669
Deep pond	222	147	494	1006

Table 3.9.1: Search effort (in person.minutes) across the last 4 seasons, tabulated by Jurisdiction, Zone, Region, and Subregion. Note that search effort is measured for visual encounter surveys (VES) only.

Below average levels of rainfall in 2017-18 probably resulted in reduced recruitment (perhaps even below 'average' levels; but difficult to tell as 2015-16 was so unusual), leading to lower overall numbers in 2017-18. Given the below average rainfall in 2017-18, it is possible that numbers in the coming 2018-19 season will be lower than in 2015-16. However, even though the summer of 2017-18 was very dry, there was more rain in early autumn of 2018 than in the previous year and that does appear to have led to extensive breeding.

	All *L. aurea* (not including mets)				**Adult *L. aurea* only**			
	2014-15	**2015-16**	**2016-17**	**2017-18**	**2014-15**	**2015-16**	**2016-17**	**2017-18**
Jurisdiction								
NPWS	34	25	11	13	27	17	7	4
NCIG_CHEMP	-	-	-	5	-	-	-	2
BHP_CHEMP	-	19	-	394	-	13	-	178
PoN	59	42	109	50	27	13	65	44
PWCS	323	87	588	703	128	52	303	377
NCIG	0	10	83	83	0	3	60	47
HDC	15	16	393	151	10	9	34	41
HDC (BHP)	10	2	48	58	6	0	18	35
RMS	0	0	6	-	0	0	3	-
Zone								
Nth	8	3	0	6	4	2	0	3
Central	85	83	120	456	50	41	72	225
Southern	348	115	1118	995	144	64	418	500
Region								
Hunter North River	0	0	0	1	0	0	0	1
School House	8	3	0	5	4	2	0	2
Cobbans Creek	13	31	3	404	13	20	2	180
Bellfrog Way	72	52	117	52	37	21	70	45
Industrial Zone North	322	86	546	649	127	52	278	347
Industrial Zone South	26	29	572	346	17	12	140	153
Subregion								
Scott's Point	0	0	0	1	0	0	0	1
Riverside park	0	0	0	0	0	0	0	0
Wet meadow	8	2	0	1	4	2	0	1
Millam's Pond	0	1	0	4	0	0	0	1
Ramsar Road West	1	25	2	404	1	14	2	180
Ramsar Road East	12	6	1	0	12	6	0	0
Bellfrog Way West	3	2	0	2	2	2	0	1
Bellfrog Way NE	8	4	3	0	6	3	1	0
Bellfrog Way SE	61	46	114	50	29	16	69	44
Delta Ponds (K104)	204	62	101	153	33	36	57	65
KIWEF *K7*	116	19	358	276	92	13	182	215
NCIG rail central & east	0	11	98	95	0	3	72	54
Rail loop *K10 Nth*	15	16	383	82	10	9	28	16
Cormorant Road	0	0	6	-	0	0	3	-
Rail loop SW *K10 Sth*	0	0	16	51	0	0	10	19
NCIG rail south	9	2	58	42	5	0	20	19
KIWEF *K2*	2	0	11	76	2	0	7	45
Deep pond	2	5	87	220	2	3	39	67

Table 3.9.2: VES Detected numbers for the last 4 seasons, summed for Jurisdiction, Zone, Region, and Subregion. Comparing the values for 'All *L. aurea*' (left columns) and 'Adult *L. aurea*' (right columns) provides an indication of the number of juveniles.

Overall, there is not any clear evidence that the population in 2017-18 is lower than in 2014-15. Rather, data for **VES Detected** (Table 3.9.2), **Search Sensitivity** (Table 3.9.3), and **Total Detected** (Table 3.9.4) all point to overall numbers and densities increasing across the four year period. This is a slightly different picture from that provided by the population estimates, which indicate that the total population was high in 2014-15 and has at best plateaued since (although the population does appear to have increased compared to levels prior to 2014).

	All *L. aurea* (not including mets)				Adult *L. aurea* only			
	2014-15	2015-16	2016-17	2017-18	2014-15	2015-16	2016-17	2017-18
Jurisdiction								
NPWS	0.02	0.01	0.00	0.01	0.01	0.00	0.00	0.00
NCIG_CHEMP	-	-	-	0.02	-	-	-	0.01
BHP_CHEMP	0.00	0.07	-	0.26	0.00	0.05	-	0.12
PoN	0.04	0.06	0.11	0.12	0.02	0.02	0.06	0.10
PWCS	0.14	0.04	0.18	0.15	0.05	0.02	0.09	0.08
NCIG	0.00	0.03	0.26	0.14	0.00	0.01	0.19	0.08
HDC	0.04	0.02	0.46	0.09	0.03	0.01	0.04	0.02
HDC (BHP)	0.01	0.00	0.11	0.10	0.00	0.00	0.04	0.06
RMS	0.00	0.00	0.04	-	0.00	0.00	0.02	-
Zone								
Nth	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Central	0.04	0.03	0.04	0.17	0.02	0.01	0.03	0.08
Southern	0.08	0.03	0.22	0.13	0.03	0.02	0.08	0.07
Region								
Hunter North River	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
School House	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Cobbans Creek	0.03	0.03	0.00	0.23	0.03	0.02	0.00	0.10
Bellfrog Way	0.04	0.03	0.06	0.06	0.02	0.01	0.03	0.05
Industrial Zone North	0.15	0.05	0.19	0.17	0.06	0.03	0.10	0.09
Industrial Zone South	0.01	0.01	0.26	0.10	0.01	0.00	0.06	0.04
Subregion								
Scott's Point	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Riverside park	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet meadow	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Millam’s Pond	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Ramsar Road West	0.01	0.04	0.01	0.25	0.01	0.02	0.01	0.11
Ramsar Road East	0.03	0.01	0.00	0.00	0.03	0.01	0.00	0.00
Bellfrog Way West	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Bellfrog Way NE	0.03	0.01	0.01	0.00	0.02	0.01	0.00	0.00
Bellfrog Way SE	0.04	0.05	0.09	0.12	0.02	0.02	0.05	0.10
Delta Ponds (K104)	0.47	0.32	0.18	0.17	0.08	0.18	0.10	0.07
KIWEF *K7*	0.08	0.01	0.20	0.14	0.06	0.01	0.10	0.11
NCIG rail central & east	0.00	0.02	0.20	0.12	0.00	0.01	0.15	0.07
Rail loop *K10 Nth*	0.04	0.03	0.64	0.09	0.03	0.01	0.05	0.02
Cormorant Road	0.00	0.00	0.04	-	0.00	0.00	0.02	-
Rail loop SW *K10 Sth*	0.00	0.00	0.14	0.07	0.00	0.00	0.09	0.03
NCIG rail south	0.01	0.00	0.12	0.10	0.00	0.00	0.04	0.05
KIWEF *K2*	0.04	0.00	0.03	0.11	0.04	0.00	0.02	0.07
Deep pond	0.01	0.03	0.18	0.22	0.01	0.02	0.08	0.07

Table 3.9.3: Search sensitivity for the last 4 seasons, summed for Jurisdiction, Zone, Region, and Subregion. The numbers indicate the number of frogs detected per person.minute of search effort, i.e. for a value of 0.25, one frog is detected every four person.minutes of search effort.

Even though search effort has increased over the four year period, the higher numbers of VES Detected and Total Detected cannot simply be an artefact of increased search effort, as Search Sensitivity has also increased.

Numbers and densities have generally been highest in the southern part of the island (Industrial Zone), and lowest in the Northern Zone. However, in 2017-18 the highest densities were in the Cobban's Creek region of the Central Zone (specifically, in the RAMSAR Road West subregion), where the BHP CHEMP wetlands are located, indicating the success of these new constructed habitats. In contrast, numbers and densities in the Ramsar Road west region are low.

Numbers along Bellfrog Way tend to be less than in the Industrial Zone North, but trends within this region are difficult to interpret. The number of adults detected has oscillated, but Search Sensitivity indicates higher densities in 2017-18 than in previous years. However, over this period the number of wetlands being surveyed has been reduced (i.e. search effort has decreased, Table 3.9.1), so that the two wetlands with the highest abundances (K22 and K23) now comprise a higher proportion of the wetlands surveyed in this region (resulting in increased values for Search Sensitivity as a result of this bias).

Overall, Bellfrog Way seems to be occupied by significantly less *L. aurea* than in the previous decade, when it merited its name (Pers. Obs., M. Mahony). At a subregional level, the western (K11-13, BHP-14A) and NE (K20A, K20B, K21, K63) Bellfrog Way wetlands have low densities of *L. aurea* and current levels are lower than in 2014-15. Only the SE part of Bellfrog Way (K20C, K50, K24, K107, and – crucially – K22 and K23) retains high densities. Note that the wetlands in the Western and especially the NE subregions of Bellfrog Way, and the Ramsar Road west subregion of Cobban's Creek, did experience high levels of salinity in 2017-18 (Figure 3.2.5), although the degree to which this effect might be confined to dry/drought years such as 2017-18 is not clear.

Green and golden bell frogs are almost absent from the Hunter North River and School House subregions of the Northern zone. Within the Northern zone, numbers are currently highest in the Millam's Pond subregion (Table 3.9.4); these frogs are located in the NCIG CHEMP wetlands that have been established in that area. Note that only a small number of the NCIG CHEMP ponds were included in the current analysis, and the actual numbers of frogs in the Northern Zone is slightly higher than shown here.

Within the Industrial Zone, the Industrial Zone North region consistently has the highest numbers of frogs, although numbers in the Industrial Zone South have increased markedly in the last two seasons. Very high densities (**Search Sensitivity**; Table 3.9.3) were recorded in the Industrial Zone South in 2016-17, but overall numbers (**VES Detected** and **Total Detected**) have always been higher in the Industrial Zone North.

Abundance at Delta Ponds (K104) has generally been high, with very large numbers in 2015-16 following a large breeding event in 2014-15. Bell frog numbers in the KWIEF *K7* wetlands, which make up most of the northern rail corridor and include densely populated wetlands such as K29, usually have the highest numbers (VES Detected) and densities (Search Sensitivity) of any subregion on the island (2015-16 was an exception; frogs appeared to have dispersed from K29 into the surrounding landscape during that very wet summer).

In the last two seasons, numbers in all of the subregions of the southern industrial zone (except the RMS wetlands K100W and K100E along Cormorant Road, which are no longer being surveyed) have seen marked increases in bell frog abundance and density. This is attributed to the presence of *L. aurea* in newly constructed wetlands such as K111-114 (HDC; Rail loop *K10 Nth*), K115-116 (NCIG; NCIG rail central & east), K117-118 (HDC; KIWEF *K2*) and C2 and K121-123 (PWCS and HDC; NCIG rail south *K10 Sth*), which have augmented the existing wetlands in NCIG rail central & east (K102, K100A), NCIG rail south (K36, K49A, K49B), KIWEF K2 (K46), and the Rail loop K10 Nth (K108). The new wetlands in the southern industrial zone provide additional habitat and improve connectivity across this area. Moreover, the new wetlands provide a mix of hydroperiods; the resulting (positive) changes to the spatio-temporal habitat mosaic in this region have been a marked increase in the abundance and density of *L. aurea*. Comparing the values for 'All *L. aurea* and 'Adult *L. aurea* indicates a high number of juveniles in the Industrial Zone South Region, especially in 2016-17, linked to the success of the HDC constructed wetlands as breeding

	All *L. aurea* (not including mets)				Adult *L. aurea* only			
	2014-15	2015-16	2016-17	2017-18	2014-15	2015-16	2016-17	2017-18
Jurisdiction								
NPWS	44	29	27	13	35	20	14	4
NCIG_CHEMP	-	-	-	10	-	-	-	5
BHP_CHEMP	-	19	-	394	-	13	-	178
PoN	420	220	455	330	294	98	247	271
PWCS	534	922	2464	1918	316	410	1389	1130
NCIG	0	12	86	87	0	4	62	50
HDC	66	36	393	209	45	26	34	52
HDC (BHP)	11	2	48	68	7	0	18	39
RMS	0	2	6	-	0	2	3	-
Zone								
Nth	10	4	0	11	6	3	0	6
Central	454	264	482	736	323	128	261	452
Southern	611	974	2997	2282	368	442	1506	1271
Region								
Hunter North River	0	0	0	3	0	0	0	3
School House	10	4	0	8	6	3	0	3
Cobbans Creek	13	34	5	404	13	22	2	180
Bellfrog Way	441	230	477	332	310	106	259	272
Industrial Zone North	532	921	2420	1858	314	410	1362	1094
Industrial Zone South	79	53	577	424	54	32	144	177
Subregion								
Scott's Point	0	0	0	3	0	0	0	3
Riverside park	0	0	0	0	0	0	0	0
Wet meadow	10	3	0	1	6	3	0	1
Millam's Pond	0	1	0	7	0	0	0	2
Ramsar Road West	1	28	3	404	1	16	2	180
Ramsar Road East	12	6	2	0	12	6	0	0
Bellfrog Way West	4	2	7	2	3	2	2	1
Bellfrog Way NE	12	4	4	0	9	3	2	0
Bellfrog Way SE	425	224	466	330	298	101	255	271
Delta Ponds (K104)	209	859	718	559	38	364	372	236
KIWEF *K7*	321	57	1603	991	274	43	939	771
NCIG rail central & east	0	13	103	99	0	4	76	57
Rail loop *K10 Nth*	66	36	383	101	45	26	28	22
Cormorant Road	0	2	6	-	0	2	3	-
Rail loop SW *K10 Sth*	0	0	16	89	0	0	10	25
NCIG rail south	11	2	58	45	7	0	20	21
KIWEF *K2*	2	0	11	90	2	0	7	52
Deep pond	2	5	99	308	2	3	51	87

Table 3.9.4: Total Detected for the last 4 seasons, summed for Jurisdiction, Zone, Region, and Subregion Areas with high values indicate the location of the CMR wetlands. Across all four years, K22-23 in Bellfrog Way SE, and K29 in the KIWEF *K7* have been CMR locations. In 2014-15 K108 (in the Rail Loop *K10S*) was a CMR wetland, but was replaced by K104 (Delta Ponds) from 2015-16 onwards.

habitat (**Section 3.6**). Although the abundance of adults in the Industrial Zone South remains less than in the Industrial Zone North, adult numbers have increased in the southern region over the four year period. This is despite a sharp reduction in the number of *L. aurea* adults detected in K108 since 2014-15 (as indicated by the Total Detected adults in the Rail loop *K10 Nth* subregion; Table 3.9.4).

Numbers and densities in Deep Pond (K105A and K105B) have also increased over the four years. There appears to be two factors involved with this; firstly, the thickness of the emergent vegetation (i.e .reeds such as *Typha*, *Phragmites*, and *Schoenoplectus*) fringing K105A has steadily increased, providing larger extent of edge vegetation which *L. aurea* use and which appear to be an important habitat trait linked to abundance (**Section 3.7**). Secondly, the splitting of K105B from K105A (as result of the completion of the NCIG rail infrastructure) appears to have turned the southern part of Deep Pond (now K105B) into a highly suitable habitat for *L. aurea*. K105B has a large area of open water surrounded by a dense edge vegetation of emergent reeds (c.f. **Section 3.7**). Furthermore, its hydrology has now changed from permanent (when it was the southern part of Deep Pond) to semi-permanent; this led to K105B drying out during both the 2016-17 and 2017-18 seasons, eliminating *Gambusia* and encouraging the growth of Paspallum grass along large parts of the shallow muddy bottom of the wetland. In both years, late season rain provided a *Gambusia*-free wetland, with extensive areas of shallow flooded grass and open water, edged by thick reed beds; large breeding events were recorded in both seasons.

From a jurisdictional perspective, PWCS has at present the largest numbers of frogs in its wetlands. The PoN wetlands have always held high numbers of bell frogs, but HDC are now approaching those levels. *L. aurea* abundance in NPWS wetlands is low. The HDC (BHP) and NCIG rail (central and east) wetlands have markedly higher numbers in the last two seasons, likely as a result of the improved connectivity and habitat mosaic in the southern industrial zone discussed above. The BHP CHEMP wetlands support good numbers, but the NCIG CHEMP have yet to achieve these levels of *L. aurea* abundance.

4. Discussion

<u>Conservative biology of *L. aurea* on Kooragang Island</u>

1. **<u>Population size</u>**: The population size of *Litoria aurea* across surveyed wetlands is approximately 2,000-3,000 adult individuals. This is consistent with most recent annual (2014-15 season and later) estimates. It may represent an increase in population levels compared to the four seasons between 2010 and 2014, although the uncertainties inherent in generating the population estimates mean that this apparent trend may be affected by various sampling biases. Importantly, there does not appear to be any evidence for a long-term decrease in the *L. aurea* population of Kooragang Island since this research program commenced in 2010.

   When discussing these population estimates, it is important to consider the uncertainties inherent in using statistical models to produce those population estimates (Section 3.8):

   - *Detectability*: the probability of detected *L. aurea* during a survey depends on: (1) The abundance of frogs in a wetland (this is in turn connected with distribution of *L. aurea* across the landscape and is potentially affected by numerous factors - see point 4b below); (2) Behaviour of the frogs, i.e. whether they are in microhabitats that provide shelter (when they are very difficult to detect), or are instead foraging or engaged in breeding behaviours (when are often more detectable). These behaviours may be in response to time of year, seasonal climatic patterns, daily or weekly weather patterns, or other factors; (3) Search effort and the skill of individual surveyors; and (4) physical structure of the habitat (e.g. floristic and structural components on the vegetation community), can affect both abundance (e.g. dense stands of reeds may support large numbers of frogs) and detectability (it is difficult to see frogs in dense reeds).
   - *Population Estimation Models*: the population estimates for wetlands surveyed by CMR studies underpin the population estimate for the whole island. The statistical models used to produce those estimates from CMR surveys depend upon certain assumptions, for example no immigration or emigration, and births or deaths within primary survey periods (Section 2.6). In certain circumstances these assumptions may be reasonable, but at others (e.g. after significant rain, which stimulates adults to disperse to ephemeral wetlands) they are clearly not maintained within the survey period. Another challenge is determining the quantitative relationship between VES counts and the population estimates generated by CMR surveys; VES counts during the various secondary surveys within a primary CMR survey period can vary, even though the population size is approximately constant. This variation must somehow be related to detectability, but without a clear understanding of the factors that affect detectability it is difficult to know how best to correlate VES counts with calculations of population size at the CMR surveyed wetlands. This then feeds into the next sampling challenge:
   - *Extrapolating population estimates on the basis of VES counts*: most wetlands are surveyed using VES only and typically only a small proportion of bell frogs present at a wetland will be detected during VES. On the basis of the 2017-18 data, it appears that between 1/6 and 1/10 of frogs may be detected during a VES (Section 3.8). This may seem like a reasonable range of uncertainty; however, the process of extrapolating from small numbers (VES counts) to large numbers (population estimates for each wetland) greatly magnifies any uncertainty. Additionally, wetland physiognomy might be expected to alter the proportion of frogs present that are detected during VES - for instance, in a small open wetland with few emergent reeds, frogs may be much more detectable than a large densely vegetated wetland - but the extrapolations do not consider that factor. Also, there are some large wetlands that are not completely surveyed, and VES counts must be extrapolated to account for the unsurveyed portion.

Given these uncertainties inherent in the statistical modelling approach, we can use information on counts (estimates) to assess population level spatio-temporal trends (see Section 3.9). This avoids many of the assumptions inherent in modelled-based estimates, but is directly and strongly affected by search effort (which is an important source of bias). To minimise the effect of search effort we apply standardised survey methods with teams of experienced field ecologists. Both model-based estimates and counts need to be interpreted within a framework of understanding the biology of the species being investigated. For example, both the models and the counts indicate a low population size in 2015-16. However, that was a very wet year; and our observations of distribution indicate that bell frogs were dispersed widely across the landscape, leading to low detectability, and it is possible that the actual population number was high across that period. Subsequently, the breeding seasons of both 2016-17 and 2017-18 were relatively dry (i.e. spring and summer rainfall totals being below long-term averages). This had the effect of increasing detectability, since frogs contracted to a small number of wetlands that contained water (i.e., wetlands with a permanent hydrology), and which are targeted in our survey effort. However, there is no ecological reason to suppose that the population in these years was actually higher than in 2015-16. To enable a robust and repeatable absolute population estimation based on capture-mark-recapture methods it is necessary to have identified permanent wetlands that provide habitat for *L. aurea* over a long-time frame. It should be recognised that this puts a bias on the ecological value of permanent wetlands at the expense of considering the value of ephemeral wetlands.

At present, the factors that affect reliable estimates of population size are:

- Understanding the extent to which detectability affects survey counts,
- A quantitative understanding of the effect of habitat (e.g. wetland physiognomy) upon distribution/abundance (there is a qualitative exploration of this in Section 3.7), and
- Quantitative information on the extent of different wetland physiognomies across KI (for both surveyed and unsurveyed wetland areas).

Consider for example, wetland K105A. It is too large to survey completely, and we survey a smaller part of it (approximately 25%). The area surveyed incorporates stretches of thick *Typha* and/or *Phragmites* stands around the wetland edges, patches of *Schoenoplectus*, grassy banks with *Juncus*, and a rocky bank. Repeated experience with this survey indicates that the distribution of *L. aurea* across these zones is non-uniform. When extrapolating from survey counts to total estimates for this wetland, it would be preferable to weigh the extrapolation according to the extent of habitat structures in the unsurveyed part of the wetland; but these have not been measured.

2. **<u>Demography</u>**

   a. <u>Age/sex class structure</u>: For those frogs were age/sex class was identified, approximately half of the *L. aurea* detected in each round were juveniles. Of the individual adults captured and identified, 2/3 were males.

   Cohorts that were tadpoles at the start of the season were large juveniles or small adults by the autumn. Tadpoles that were spawned in the middle of the breeding season were juveniles by the end of the season.

   Most adult females were smaller than 70 mm (Figure 3.4.4), suggesting that they were in their second year. Although this is smaller (and, by inference, younger) than adult females in other populations, candling indicates that many of these were nevertheless gravid and thus sexually mature (see 2b below). The proportion of adult females with an SVL > 70mm is small; given the pattern of survivorship inferred from data on persistence (3a below), it appears that only a very small number of females survive until their 3rd year. Fortunately for the Kooragang

Island *L. aurea* population, the effective population size does not appear to depend entirely on those older adult females.

b. Recruitment: Within the Industrial Zone, breeding was documented mainly in the constructed HDC wetlands (K111-114, K117-118, K121-123); the other areas with significant breeding were K104 and K105B, and also K46. In all of these *Gambusia* density was low or zero.

For the wetlands monitored as part of the Island-wide Survey program, evidence of breeding was limited to two wetlands in the NCIG CHEMP and three wetlands in the BHP CHEMP. Note, however, that each CHEMP has many more wetlands than are included in this Island-wide survey program; they are each more completely investigated as part of separate research projects. Numerous additional breeding events and recruitment were recorded in these habitats, but this information is not included here. Clearly, the population of *L. aurea* in these habitats provide important wetland connectivity in the landscape of the island (as well as increasing the overall Kooragang Island population estimate).

For those events that are monitored as part of the island-wide surveys presented in the current report, cohort analysis (Section 3.4) indicated several episodes of breeding:

  i. After spawning following significant rain in the previous autumn, some tadpoles overwintered and metamorphosed in early spring, becoming mid-sized juveniles in late spring and large juveniles in mid-summer (e.g. K29, K104, K105B)
  ii. Early spring rain initiated a breeding event, tadpoles were detected (K114, K122), and very small juveniles (K111, K115, K121, K46), in early summer, and as larger juveniles in mid-summer.
  iii. Early summer rain resulted in further breeding; in mid-summer we detected tadpoles, metamorphs, and very small juveniles in K114, as well as very small juveniles in 105B.
  iv. Late summer/autumn rain stimulated a large breeding event with widespread chorusing throughout March, tadpoles detected in late March, and tadpoles and metamorphs detected in late April (K112-114, K121-123, K104).

Breeding is strongly linked with rain events and the absence of *Gambusia*. Significant breeding was observed in wetlands with hydroperiods ranging from ephemeral to semi-permanent and nearly permanent. Chorusing by males occurred in open water, at or close to the water surface, either in the middle part of the wetland or where they have access to flooded emergent vegetation at the wetland edge. The largest chorus observed in 2017-18 was in K105B, in part of the wetland that has a shallow sloping bottom and large areas of flooded grass.

c. Gravid females: 70%-80% of females between 64 and 70 mm SVL were identified as gravid: that proportion was higher for larger females, but decreased to between 10% and 40% for females smaller than 62 mm SVL. The smallest female considered to be gravid was 52 mm SVL (Figure 3.6.4).

Currently, candling is used to document gravity, but candling is an imperfect technique. Hormone analysis would be more reliable; nevertheless, available information suggests that female bell frogs reach reproductive maturity on KI earlier than has been described for other sites. This might be an artefact of sampling effort/technique, but if born out (by e.g. hormone analysis) may indicate a rapid evolutionary response to selection pressures on KI. The most obvious potential selection pressure is chytrid infection. Whatever the reason, it appears that the proportions of adult females present are higher than has been understood earlier in this project. Using 58 mm as a threshold between subadult and adult females, the proportion of adult females is 1/3 of all adults. Many of these were gravid. As 282 individual adult females (>= 58 mm SVL) were captured during surveys, the effective population size seems to be several hundred reproductively active females.

3. **Longitudinal data**
   a. Persistence: Persistence of marked frogs (and, by extension, survivorship) was low. Most marked frogs are never recaptured; of those that are, less than 10% are recaptured more than 12 months after the initial capture, and less than 2% were recaptured more than 2 years afterwards.

   Note that these times do not represent true ages, as frogs are not marked until they have a SVL greater than 40 mm. At the time that they are tagged, they may be at least 1 year old. Nevertheless, these numbers point to the high mortality rates of *L. aurea* on Kooragang Island.

   The low survivorship rates highlight the importance of *L. aurea* achieving reproductive maturity at a relatively early age, i.e. in their second year.

   b. Movement: Of the 2,551 frogs marked between 2012 and 2018 that were recaptured, only 243 were recaptured in a different wetland (Section 3.6: Table 3.6.3). At face value, this seems like a very low rate of movement and suggests high rates of philopatry in *L. aurea.*

   However, when considered along with the persistence data, a different picture emerges. Most recaptured frogs do not move between wetlands, but most recaptured frogs are recaptured less than six months after initial capture and very few are encountered more than a year afterwards. This is a short amount of time for movement to occur. Even though the number of *L. aurea* recaptured more than a year after initial capture is low, the proportion of these that have moved to a different wetland is relatively high: 22% of the frogs that are recaptured more than 2 years after initial capture have moved, and 44% of those that last 3 years are found in a different wetland (Table 3.5.6, Figure 3.5.3). It seems that, even though most frogs don't survive, those that do often move among wetlands.

   For the 243 movements detected, most were relatively small movements within NCIG CHEMP stages, within the BHP CHEMP ponds in Ramsar Rd west, or between K22 and K23. Of the remaining movements, most were less than 500 metres, but some were more than 1 km and one animal moved a minimum distance of 3.6 km between K9 and K108 (Tables 3.6.4 & 3.4.5).

   Movement among wetlands is related to wetland connectivity (see point 4 below). A large number of movements were between wetlands in the habitat mosaic centred upon K29, particularly the small deep wetlands adjacent to it (C1 and K106C). (Figures 3.5.1 & 3.5.2). It appears that these play an important role within that mosaic. Other movements centred around K29 involved K105A (a large permanent wetland), K106B (ephemeral; temporary), K22 (ephemeral; seasonal) and K23, K35, and K42 (small to medium size, semi-permanent to nearly permanent). The only detected movement between K29 and a wetland outside of this mosaic was from K100A.

   The information on movements around K29 - and K22 and K23 - results not just from the movement of frogs and mosaic of habitats close by, but also from the years of intensive sampling effort focused upon these wetlands. Nevertheless, the large number of detected movements speaks to the connectivity of wetland habitats in this part of the landscape. In other areas that seem to have a similar habitat mosaic - such as the southern region of the industrial zone - that connectivity has only recently been created (via the construction of wetlands by HDC and PWCS) and sampling effort has been low until recently; consequently, only small numbers of movements involving wetlands in the southern Industrial Zone have been detected (Figures 3.5.1 & 3.5.2). If frogs are now moving frequently across this landscape, we can expect some lag before we start to detect that movement in numbers.

Many movements require movements across roads and tracks, and *L. aurea* are often observed on or alongside these. These structures do not appear to impede movement. Several of the detected movements require movement across a rail line; sample sizes are too small for quantitative analysis and it is thus possible that rail lines hinder but do not completely prevent movement of *L. aurea*. From the small dataset available, however, it is evident that *L. aurea* do cross rail lines and the rail infrastructure in the Industrial Zone may not determine habitat connectivity.

Although comparative numbers are low, movement seems to be by males more than females. Note that detecting movement between surveyed wetlands is biased towards semi-permanent and permanent wetlands, and may under-detect short movements to ephemeral wetlands for breeding, especially if frogs subsequently return to the nearby permanent wetland.

4. Landscape use

a. Distribution: As has been the case for many years now, on Kooragang Island most frogs are found in the Industrial Zone; specifically, in the northern part of that Zone and in the wetlands adjacent to the PWCS rail corridor (Figure 3.3.7, Tables 3.9.2 & 3.9.4). However, in 2017-18 densities of *L. aurea* in the southern Industrial zone and in the Ramsar Road west subregion of Cobban's Creek were also high (Figure 3.3.2, Table 3.9.3). Although absolute numbers are lower than for the Northern Industrial Zone (Figure 3.9.2), these increased densities are linked to the construction of new wetlands; respectively, the HDC wetlands and the BHP CHEMP wetlands.

In contrast, both densities and absolute numbers in the **Northern Zone** of the island remain low, despite the construction of the NCIG CHEMP wetlands (Figures 3.3.2, 3.3.7, and Tables 3.9.2, 3.9.3). Note however, that the present study did not survey all of those new habitats; other observations (from Dean Lenga's PhD work) indicate that *L. aurea* are present in the those additional NCIG CHEMP wetlands. Thus, the actual pattern of bell frog distribution across the Northern Zone of the island may be better than our dataset suggests.

Within the **Central Zone**, the abundance of *L. aurea* along Bellfrog Way appears to have declined compared with observations from pre-2014; however, the reduction in search effort combined with the targeting of two wetlands that still have good number of *L. aurea* means that this pattern is not apparent in the VES counts from 2014-15 onwards (Table 3.9.2; see also description of results in Section 3.9).

In the southern part of the **Industrial Zone** both the density and abundance of *L. aurea* in this region have increased over the last four season. In particular, the K2 KIWEF, the NCIG rail south, and the rail loop SW (K10 South KIWEF) subregions appear to support more *L. aurea* in the last two seasons than was the case from 2014-16 (Tables 3.9.2, 3.9.3, 3.9.4). Like wise, the numbers detected in NCIG rail central and east subregion look to have increased since 2014-

15, although K100A in particular is known to have support large numbers of *L. aurea* in the years previous to the period shown in Section 3.9. Within the rail loop, K108 held large numbers prior to 2015-16; a decline in the *L. aurea* supported there since 2015-16 has been at least partially counteracted by increased numbers in other parts of the rail loop following the construction of new wetlands (see points 4b and 7 below). A large number of the wetlands known to support *L. aurea* breeding in the 2017-18 are located in the southern Industrial Zone.

Within the northern part of the **Industrial Zone**, K29 held large numbers of *L. aurea*, although not as much as the very large numbers detected in 2016-17. The other wetlands with large numbers of *L. aurea* were K104, and K105 (in particular K105AS and K105B). Densities at K106C were especially high. Bell frogs were also present at C1, K103, K34, K31, and K42, although at lower densities. They were absent from the ephemeral wetlands K106A and K106B throughout most of the season, but were found in K106B once that wetland held water following late season rain.

b. <u>Landscape factors affecting distribution, abundance, and recruitment</u>:
   i. **Habitat**: *L. aurea* make use of both aquatic and terrestrial habitats. Whilst the former are understood to be essential for the long term presence of *L. aurea* in an area, the later are used for foraging and for dispersal between wetlands. In some contexts, the availability of suitable terrestrial habitat could perhaps limit *L. aurea* distribution and abundance; however, on Kooragang Island there is no evidence that terrestrial habitat is limited and it is considered unlikely that the population is constrained by this component.

      Aquatic habitats are used by all stages of the *L. aurea* life cycle. They are obviously essential for successful breeding, and in this respect wetlands that provide suitable breeding habitat are a particular focus for conservation management of *L. aurea*. Wetlands are used for foraging, short-term occupancy, and with respect to connectivity of habitat, as 'stepping stones' across the landscape. However, the long-term occupancy of *L. aurea* in an area seems to depend on wetlands that consistently provide access to water (i.e. a nearly-permanent or permanent hydroperiod) and protection (usually through the presence of dense banks of emergent reed species fringing the wetland). Such wetlands are referred to as 'refuge' habitats (Clulow, 2014) and are typically (but not always) occupied by significant numbers of adult bell frogs (they may also provide breeding habitat as well). Note that our use of ‘refuge’ in this context is not in any way equivalent to the ecological concept of ‘refugia’ that is used connection with large scale habitat alteration and/or climate change. Rather, it refers simply to a permanent or semi-permanent wetland that consistently holds large numbers of adult *L. aurea* on Kooragang Island.

      In understanding the distribution of suitable habitat for *L. aurea* across a landscape, the spatio-temporal pattern of both **breeding** and **refuge** habitats appears to be an important consideration. The wetland physiognomies (i.e. the physical characteristics of habitat within a wetland) that appear to be linked to a role as a **refuge** habitat are explored in section 3.7; the wetlands that consistently held the largest numbers of adults tended to be large, have extended hydroperiods (i.e. permanent or nearly permanent), provide large extents of open water, and are fringed with dense edge vegetation and deep water close to at some of those edges (Figure 3.7.1). However, b**reeding** habitats are not necessarily large or of a long hydroperiod, as long as they have low densities of *Gambusia* (see below); as drying removes *Gambusia* from a wetland, shorter period wetlands appear to provide suitable breeding habitat. In addition, nearly all wetlands where breeding was detected have large proportions of open water, and most (but not all) have aquatic vegetation. Small to medium and ephemeral to semi-permanent wetlands are often used for breeding, especially if they are *Gambusia*-free. In some cases, significant breeding events have been detected at large wetlands that provide refuge habitat (e.g. K104, K105B), but only if *Gambusia* densities are low.

An additional wetland type may also play an important role in the mosaic of wetland habitats that support large numbers of *L. aurea*. Small, well vegetated permanent wetlands (K106C, C1, C2) do not support breeding but consistently support adult frogs and data on movement indicates that they are used by frogs moving in and out of nearby wetlands (including refuge wetlands). These small wetlands appear to act as 'stepping stones' within the habitat mosaic, and also provide aquatic habitat during dry periods. They may be natural, or constructed (the 'cluster ponds'), providing an additional opportunity for managers.

ii. ***Gambusia***: the presence of high densities of the invasive mosquitofish *Gambusia* appears to act as a major obstacle to successful breeding in *L. aurea* (Section 3.6; see Table 3.6.1 and Figure 3.6.4). Low levels of breeding have been observed in situations with high densities of Gambusia (e.g. K9C in 2015-16; K29 in 2016-17; K104 in 2015-16), but significant breeding only occurs when *Gambusia* is at a low density (usually, following near drying out of the wetland prior to a large rain event) or is completely absent (e.g. K113, K106A and K106B in 2015-16; K111, K114 and K104 in 2016-17 and 2017-18; K121, K122, K123 and K105B in 2017-18).

iii. **The habitat mosaic**: within the Industrial Zone, the areas with the highest abundance of *L. aurea* are areas with a spatial complex of wetlands that between them span a range of sizes and hydroperiods, with good connectivity amongst them. Perhaps the best example is based in the *K7* KIWEF subregion, where K29 provides important refuge habitat and is surrounded by 14 wetlands (9 of which were surveyed this season) of varying size and hydroperiod, all within a 500 metre radius. Although K29 itself has all of the habitat traits identified above as being characteristic of wetlands that support large numbers of adult *L. aurea*, the spatial complex of wetlands close to it is demonstrated to be an important component in maintaining those numbers.

A key aspect of the habitat mosaic is that the wetlands comprising it are of varying physiognomies, especially with respect to hydroperiods. As an illustration of how this variation can be important; in 2015-16, when summer rainfall was much higher than average, there was a large breeding event in K106A and K106B. Large numbers of small adults in K29 at the start of the following season show the importance of that event. During the unusually dry 2016-17 and 2017-18 seasons, K29 provided aquatic habitat to *L. aurea* in the area; it eventually dried out in late February 2018, just before heavy autumn rain in March. Prior to this drying event, K29 was infested with *Gambusia*; subsequently, *Gambusia* density was nil or very low (*Gambusia* could not be detected), and K29 may now provide potential breeding habitat. The variation in wetland hydroperiods mean that different wetlands may provide breeding and/or refuge habitat in different years. For the habitat mosaic that includes K29, the sequence of wet and then dry years meant that recruitment was high and then *Gambusia* was eliminated from much of the mosaic, whilst the variation in wetland physiognomies allowed *L. aurea* to persist and breed across this range of climatic conditions.

Following the recent construction of artificial wetlands (see point 7 below), the eastern part of the southern region of the industrial zone (encompassing the K10 South, rail loop, NCIG rail central and east, and Cormorant Road subregions), appears now to be close to offering a habitat mosaic similar to the one centred on K29. However, the changing hydroperiod of K108means that this area now lacks a large, central, permanent wetland that can act as refuge habitat. K100A and K102 lie on the edge, but K108 was previously a significant wetland in this area. In 2005, K108 was a permanent/ semi-permanent wetland with a large area of open water, edged by banks of emergent reed species (a wetland physiognomy understood to be suitable as refuge habitat for *L. aurea*). By 2017-18 it had become an ephemeral wetland which holds water for only a short time after heavy rain; furthermore, 'choking' of the wetland by reeds means that even when it does hold water, there is no area of open water present. Even though the number of frogs at K108 has declined, the population at other nearby (constructed) wetlands has increased and overall numbers of *L. aurea* within the rail loop have been steady over the last 4 seasons. In particular, the frequent breeding events within the rail loop are linked to these newly constructed habitats. However, the number of adults within the rail loop is less than in 2014-15 and earlier, which suggests that the current lack of a large refuge wetland within the habitat mosaic is inhibiting an increase in the abundance of adult *L. aurea* in this part of the island.

iv. **Northern end of island**: Do any of the factors listed above provide an insight into why the Northern Zone of the island is not supporting large numbers of bell frogs? Figure 3.2.7 shows the surveyed wetlands, mapped by hydroperiod. A notable feature of the wetlands in the Northern Zone is that they lack large permanent wetlands and that they are not spatially connected with the wetlands in the Central and Southern Zones. The factors affecting bell frog occupancy in this part of the island are undoubtedly complex, but it is possible that the large-scale landscape attributes are at least partially responsible. For example, most of the Northern Zone is in the upper catchment of the braided stream/wetland complexes on Kooragang. These areas would be expected to have lower salinity than wetlands lower in the catchment. It is also evident that historical land reclamation for agricultural purposes occurred mostly in this zone.

Specific management issues relevant to research partners

5. **Habitat corridor mitigation strategy**: The extent, connectivity, and variation in wetland hydroperiod (i.e. the' habitat mosaic') of the southern Industrial Zone has increased markedly in recent years, as a result of a large number of constructed wetlands (see point 7 below). This has resulted in an increase in density and abundance of *L. aurea* in that region (Section 3.9); in particular, frequent breeding now occurs in the southern part of the Industrial Zone (Section 3.6).

   The combination between new and old wetlands provide a range of the habitats that make an effective mosaic (Figure 4.5.1). However, the apparent decline of K108 as a refuge habitat (see point 4 above) means that the eastern part of the southern Industrial Zone lacks wetlands that support large numbers of adult *L. aurea*, especially within the rail loop itself. In the western part of that region, K105B, K46 and K49A appear to provide refuge habitat for adult *L. aurea*, in addition to the breeding habitats provided by K117 and K118 in addition to K46 and K105B.

As a large permanent / nearly permanent wetland located in the middle part of the Industrial area, K102 has the potential to play an important role in providing habitat and connectivity between the northern and southern regions of that zone. However, it does not appear to currently support large numbers of *L. aurea*; bell frogs are present, but not in high numbers. It is infested with *Gambusia*, and the eastern half of the wetland is choked with emergent aquatic vegetation; it is possible that these factors hinder *L. aurea* occupancy.

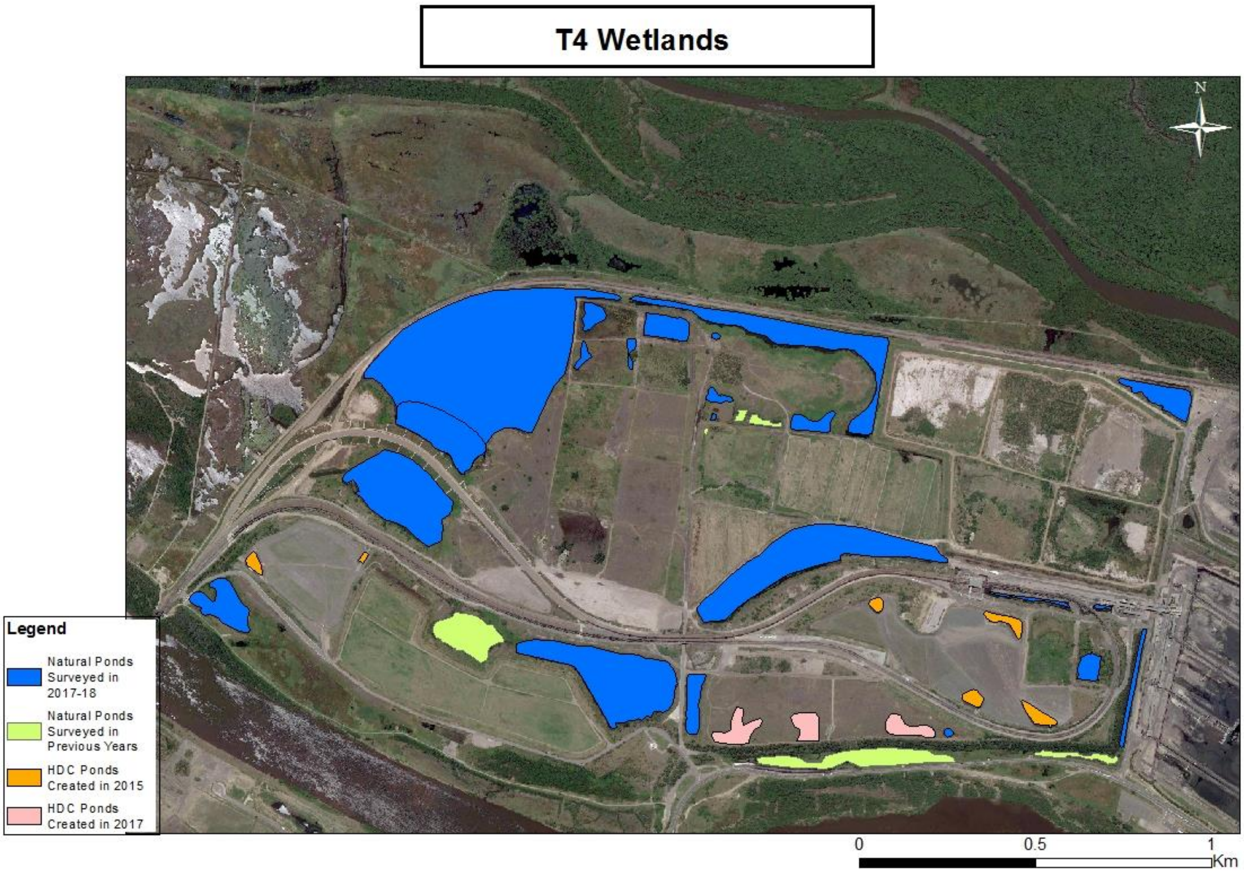


Figure 4.5.3: Wetlands in the Industrial Zone. Note that the creation of 'HDC' wetlands has increased the available habitat for *Litoria aurea* within the NCIG rail loop (orange) and in the subregion to the SW of the rail loop (pink). In concert with the connectivity between wetlands in those subregions, and their variation in hydroperiod (Figure 3.2.6), these new wetlands considerably improve the habiat mosaic in the SE corner of the Industrial Zone, compared with the situation prior to 2015.

At the NE corner of the Industrial Zone, K104 provides connectivity between the industrial zone and the 'natural' wetlands alongside mangrove-lined creeks in to the north-east. It continues to support significant numbers of adult *L. aurea* and regular large breeding events; but its distance from other surveyed wetlands means that its importance for connectivity across the Industrial Zone is difficult to judge. Confirmed movements between K104 and K23 and K115 indicate that bell frogs do move in and out of K104.

6. **Rail infrastructure mitigation strategy**: Although confirmed movements are small in number (see point 3b above), it is clear that *L. aurea* have dispersed across the rail loop following construction of K111-K114. The presence of frogs in ponds around the edge of the rail loop suggests potential connectivity between rail loop wetlands and surrounding wetlands. Confirmed movement of frogs

between wetlands within the rail loop (K111 and K115, and K108 and K9, K22, and K100A) shows that this connectivity is real. Dispersal of frogs into *K10 South* (C2) following construction of the HDC wetlands within the rail loop and *K10 South* suggests that connectivity of habitat is an important factor in *L. aurea* distribution, and that if habitat connectivity is present then railway lines do not prevent dispersal. Detected movements across the PWCS rail line in the northern region support this; multiple movements between K29 and K22/23, plus movements between K103 and K104 and K22/23, show that *L. aurea* regularly cross the rail infrastructure.

Although the population of K108 has declined since the NCIG rail loop was constructed, this appears to be linked to a change in wetland hydrology and vegetation at this wetland; it no longer provides the wetland physiognomy associated with refuge habitats elsewhere across the Industrial Zone. The apparent decline of this wetland as bell frog habitat does not appear to be linked to any change in habitat connectivity, as other wetlands within the rail loop are occupied by *L. aurea* and connectivity between these and surrounding wetlands is evident. It is possible that the change in hydrology of K108 since 2005 is at least partly a result of the construction of the rail infrastructure.

The other area where rail infrastructure has affected a wetland occupied by *L. aurea* is on the western side of the Industrial Zone; 'Deep Pond' (K105) is a very large wetland that has been divided into two by the construction of a rail line by NCIG (from 2010-2015); the northern section (K105A) is larger than the southern section (K105B). During installation of the rail infrastructure, large culverts were installed to allow *L. aurea* to move between the two sections, but it is unknown if bell frogs use these (30 m long large diameter concrete pipes), or whether any connectivity between the two is maintained by frogs moving over the top of the rail embankment (game cameras do not detect movement of frogs as these cameras are set off by temperature sensors at night, and frogs are ectotherms).

Leaving aside the question of connectivity between the two halves of K105, the construction of the rail infrastructure between them appears to have had benefits for the *L. aurea* population. Constructing the rail line involved creating a large embankment which now forms the southern shore of K105A (K105AS) and the northern shore of K105B; these new edges are now well vegetated by grass and dense stands of emergent reeds (mainly *Typha*) and are now occupied by large numbers of *L. aurea*. Furthermore, following separation from the larger water body, K105B is now a semi-permanent wetland; previously, Deep Pond was a permanent wetland and K105A is still permanent or nearly permanent. Although K105B usually holds water, in dry years (such as 2016-17 and 2017-18) it dried out, and this had the effect of removing *Gambusia* from this wetland. In addition, during the drying phase the shallow sloped bottom of the wetland was colonised by water couch (*Paspallum*). As a result, when the wetland is recharged by significant rain, it now provides large areas of flooded grass in a *Gambusia*-free wetland with extensive open water, fringed by dense stands of emergent reeds. Two significant breeding events in two seasons, in combination with large numbers of adults, indicate that K105B is now a suitable habitat for *L. aurea* and it has become an important wetland within the Industrial Zone. Although many of the features underlying this suitability were not necessarily planned as part of constructing the rail infrastructure, the net effect of the rail way appears to have been positive for *L. aurea*. Continued surveying of the area surrounding K105B will provide information on the connectivity between this new habitat and nearby wetlands (K105AS, K118).

7. **Constructed wetland strategy**: Over the last decade, there have been several phases of artificial wetland construction across the island:
    - The 'cluster ponds' installed by PWCS; one each in the northern and southern regions of the Industrial Zone (C1, C2).
    - The HDC wetlands constructed as part of closure works in the southern region of the Industrial Zone,
    - The NCIG CHEMP wetlands in the Northern Zone of the island, and
    - The BHP CHEMP wetlands in the Central Zone of the island.

    Each of these phases are now occupied by *L. aurea* at some level. *L. aurea* abundance is low in the NCIG CHEMP than for the others (see discussion in point 4b above).

    Both the **NCIG** and the **BHP CHEMP** wetlands are the focus of current research projects and detailed information is reported separately.

    For the **cluster ponds**; the northern set (C1) was established close to a number of wetlands that held large numbers of *L. aurea*, i.e. installed into an existing habitat mosaic. It was occupied by *L. aurea* shortly after construction. The southern set (C2) was established some distance (> 300 m) from wetlands with known high levels of *L. aurea* occupancy, and was not occupied until the year after construction of the HDC wetlands within the rail loop (see below); this apparently improved connectivity within the rail loop adjacent to C2. As further new HDC wetlands (K121-123) have been added to the habitat mosaic surrounding C2, the abundance of *L. aurea* at these cluster ponds has increased.

    The cluster ponds are small, deep, permanent wetlands containing emergent aquatic reeds (*Schoenoplectus*) within the tubs, surrounding by terrestrial ground plants (*Lomandra longifolia*) and small trees (*Acacia sp.*). This habitat structure is evidently suitable for *L. aurea* and they can be consistently detected at the cluster ponds. Although small, as deep permanent ponds they provide aquatic habitat during dry periods, and as each cluster is a set of water tanks they can be managed by topping-up with transported water. Because they are hydrologically isolated from the surrounding water table and wetlands, they can be maintained at a consistent desired level of salinity, and when located above ground level they cannot be invaded by *Gambusia* during flood events. As such, they potentially provide a valuable component of a successful habitat mosaic for *L. aurea*, particularly during extended dry periods.

    The nine **HDC wetlands** were constructed in three locations, from 2014-17. Located across the southern region of the Industrial Zone, these wetlands have increased both the total area of aquatic habitat and the connectivity between wetlands in the southern industrial zone.

    Of the first six to be constructed (K111-114 in the rail loop, K117-118 in the *K2* KIWEF), three were occupied by *L. aurea* within the first season following construction and the rest were occupied the following season. The three wetlands completed in the *K10 South* KIWEF subregion in 2017 (K121-123) were all occupied by *L. aurea* within the first season following completion.

    These wetlands evidently provide suitable breeding habitat, with breeding detected at all nine at some point between 2015-16 and 2017-18. They are all free of *Gambusia* and, given their positions in the landscape and height above the original estuarine wetland floor, it seems like that they will remain so. Breeding has been regularly detected at K114 since its construction, often in significant numbers. Breeding occurred in K121, K122, and K123 in their first season following completion (2017-18).

Connectivity between the HDC wetlands and nearby existing wetlands has been confirmed by two detections of movement: between K111 and K115, and K46 and K117 (Section 3.5).

As of the 2017-18 season, the HDC wetlands have evidently increased the amount of available breeding habitat and the connectivity within the southern Industrial Zone. However, the number of adults supported by these wetlands is low. Given the connections between wetland physiognomy and occupancy by adult *L. aurea*, this pattern may be at least partly determined by the size, hydroperiod, and vegetation structure of these wetlands. The first six wetlands created (K111-114, K117-118) are small to medium sized, but K121-123 are all medium-large in size. Assessing hydroperiod is complicated by the short span (thus far) of existence for these wetlands, but K117-118 seem to be permanent whilst K112 and K113 are temporary, K111, K114 and K121 are seasonal, and K122 and K123 are semi-permanent. For all of these wetlands, aquatic vegetation is being established naturally by dispersal of seeds from surrounding wetlands; the wetlands are thus undergoing an 'early succession' phase where aquatic plants are becoming established but do not yet form dense banks of vegetation.

If the wetlands most suited as *L. aurea* 'adult refuge' habitat are large, semi-permanent or permanent, with large areas of open water surrounded by dense edge vegetation (Section 3.7), then none of the HDC wetlands current provide this wetland physiognomy. K122 and K123 are both medium-large and semi-permanent / nearly permanent, but their very recent construction means that no edge vegetation is present. Once banks of reeds are established around the edges of these, they may potentially become refuge wetlands supporting large numbers of adult *L. aurea*, but this is not the case yet. Of the others, K117 and K118 are permanent and the extent of edge vegetation is rapidly increasing (whilst their depth ensures they will retain a large proportion of open water; however, they are smaller most other wetlands that support large numbers of adults (the exceptions are K23 and K106C). Nevertheless, they are close to two larger wetlands (K46 and K105B) that are known to support large numbers of adults, and one wetland that although currently not surveyed may well do (K49A). Within the rail loop, K112 and K113 are temporary and K111 and K114 are seasonal; they are small-medium sized and do not yet have extensive banks of reeds around the edge. Whether any of these might at one point provide 'refuge' habitat is not clear but it is possible that their hydroperiods are too short. At present, the closest wetland to the rail loop that may provide adult refuge habitat is K100A.

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Appendix A

Wetland sample sites: Wetlands are included within the Whole Island Monitoring Program if:

1. They have been surveyed since the establishment of early monitoring programs on the Island (i.e. a Hamer study site (Hamer 1998)), or
2. they have since been identified as providing habitat for *L. aurea*, or
3. are newly created within key areas (e.g. HDC constructed wetlands within the Terminal 4 industrial zone.

From the program's commencement (2010/2011) more than 50 additional wetlands had been added by the 2015-16 surveys, making a total of 76 wetlands surveyed in that season. The survey effort required for this number of wetlands was high and contributed (along with other logistical issues) to only two full surveys rounds being completed in the 2015-16 season. In 2016-17 we did not survey several of the wetlands that had been surveyed in the previous years (K6, K27, K30B, K44, K47, and K119; these had consistently had very low numbers of *L. aurea*). As the NWL wetland was now included in the BHP CHEMP, it was no longer on the island-wide survey schedule; the addition of K105B meant that a total of 71 wetlands were surveyed in 2016-17 (Figure 2.1.1).

With the completion of three new wetlands by HDC in mid 2017 (designated K121, K122, and K123) and an increasing focus on the changing habitat mosaic of the southern industrial zone, and the addition of K105B to the survey schedule (as part of the need to understand any effects of the NCIG rail infrastructure; see Aim #6 in Section 1.5 above), the logistics of survey effort were managed by removing a number of wetlands from the survey schedule. Some of these (K1, K2S, K7A, K8, K15, K16, K17, K18, K19, K58A) were (i) becoming 'choked' with vegetation and held very little water, with very few detections of GGBF in recent years, (ii) are located close to the new NCIG CHEMP habitats in the Northern Zone. Since significant search effort was being focused on the new habitats, we decided that we could remove those older wetlands from the survey schedule and whilst maintaining equivalent search effort in the Northern zone of the island. Similarly, construction of the BHP CHEMP habitats in the Central Zone meant that K10, K11, K12, K20, K24, K25, K45, K45A, and K107 could be removed from the survey schedule whilst maintaining levels of search effort in the Central Zone consistent with previous years. Within the Industrial Zone, several wetlands in the 'K30' area were removed from the survey schedule as survey effort was very high in these; K30, K30A, K32, K33, K35, and K41 were not surveyed this year, leaving K34, K31, and K42 from this part of the Industrial Zone in the survey schedule. K49A, K100E, and K100W were also removed from the schedule; these wetlands present considerably difficulties to survey and omitting them provided significant benefits for the management of survey logistics. In each case, nearby wetlands continued to be surveyed.

The removal of these 28 wetlands from the schedule was countered by the addition of three wetlands within the Industrial Zone, five wetlands from the BHP CHEMP, and eight wetlands from the NCIG CHEMP, as well as splitting surveys in the large Deep Pond wetland between the northern section (K105A) and southern edge (K105AS), leaving a total of 60 wetlands surveyed in the 2017-18 research program.

To maintain consistency, identification and sample site nomenclature follows Hamer's numbering scheme and has been extended to the additional wetlands; refer to Figure 2.1.2 and Figure 2.1.3 for details of and numbering.

Wetlands are grouped into three geographical zones; 1) North-Western, 2) Central, and 3) Southern.

1. North-western: this zone includes the National Park from the Sandgate bridge in the south to Scott's Point in the north, and has an area of 377 ha. Within this zone there are 14 wetlands sampled as part of the program this year. Overall the zone has experienced a range of disturbance

histories, including, grazing, clearing, draining, impounding, flood-gating and other types of human development.

2. Central: this zone also includes part of the National Park Estate. It ranges from the south where wetland sample sites are found adjacent to Bell Frog Track, to north at Milam Rd and terminating at the north arm of the Hunter River. Overall this zone has an area of 293 ha, of which 90% is mangrove forest community. Within this zone there are 22 wetlands sampled as part of this program. Compared to the North-western zone this zone has been less impacted by human activity. Nonetheless, there is evidence of historic disturbance, including clearing, draining, impounding, road construction, utility easements, and flood-gating.

Southern: Wetlands in this zone are located on industrial and commercial lands leased or owned by organisations undertaking a range of business activities on the site. Within this zone there are 38 wetlands sampled as part of this program, with a wide variety of types and sizes represented in the overall area of 346ha. As could be expected given the industrial/commercial nature of this zone it has both historically modified and continues to be a modified and disturbed part of the site. Nonetheless, the wetlands within this zone are easily delineated and in numerous cases removed from industrial activities. Compared to the rest of the site, this has undergone the greatest level of historical disturbance and continues to be impacted by human activity

APPENDIX 6

CHEMP QUARTERLY AND 6-MONTHLY REPORTS AND MINUTES

Compensatory Habitat and Ecological Monitoring Program – Quarterly Report (Quarters 2, 3 and 4 2017)

DATE: *4th January 2018*

AUTHOR: Philip Reid, Hayley Ardagh (NCIG), Michael Mahony, John-Paul King, John Clulow, Colin McHenry, Bede Moses, Cassandra Maynard, Simon Clulow (Amphibian Research Group/Uni of Newcastle), Will Glamore and Mahmood Sadat-Noori (UNSW), Greg Little, Conservation Volunteers Australia.

APPROVAL: Nathan Juchau

INTRODUCTION

This report provides an update of activities relating to the NCIG Compensatory Habitat and Ecological Monitoring Program since the previous Quarterly Report from April 2017. The report aims to provide information on key components of the program and how these are being implemented. Update reports will be provided to the Consultative Board every 6 months moving forward, which will coincide with Consultative Board meetings. This report brings together three Quarterly Reports (Quarter 2, 3 and 4 2017).

1. Kooragang Island Green and Golden Bell Frog Population Monitoring

The report "Research Program on the Green and Golden Bell Frog on Kooragang Island" conducted by the Amphibian Research Group, University of Newcastle, was finalised in August 2017. During the monitoring period 73 wetlands were surveyed in three rounds at each wetland between November 2016 and March 2017 (Monitoring locations in Figure 1). The monitoring suggests a healthy and stable population throughout the industrial area of the island.

More than 80% of the Green and Golden Bell frogs were detected in the industrial zone of the island, although the Compensatory Habitat also contains good (and growing) numbers. The largest numbers occur at permanent wetlands that are surrounded by a range of smaller semi-permanent and ephemeral wetlands. This mosaic of habitat types appears to provide the best conditions for persistence in good numbers at a given location.

Reproduction was detected at 8 of the sampled wetlands, with three sizeable breeding events detected; at K104, K111, and K114. It's possible that the autumn rain event (from the tropical cyclone Debbie) allowed a large breeding event. If so, this should be detectable as a cohort of mid-sized juveniles in November 2017.

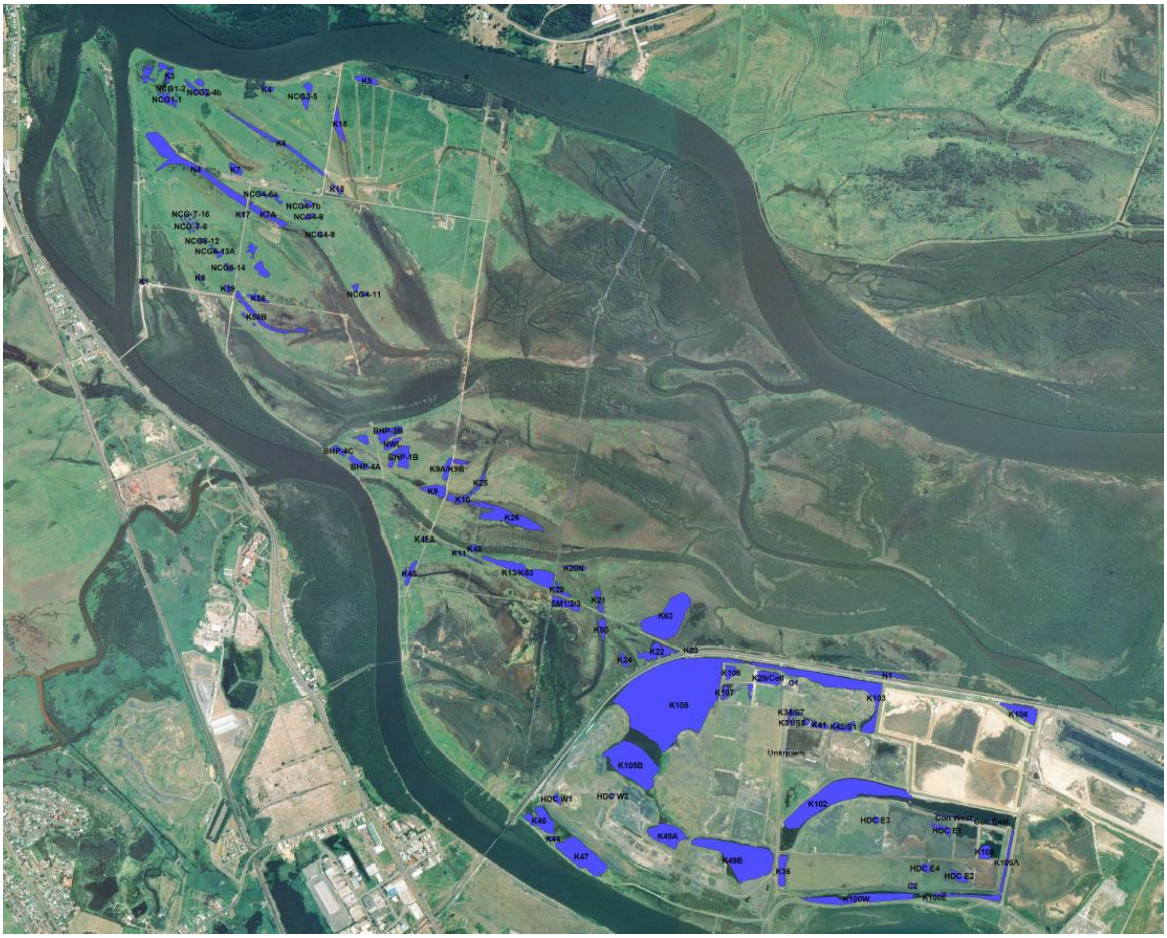


Figure 1: Kooragang Island Green and Golden Bell Frog Monitoring Survey Locations

2. Captive Breeding and Release Program

Following our third successful breeding event of the Green and Golden Bell frog, the Captive Breeding and Release Program has now ceased after five consecutive seasons.

3. NCIG Green and Golden Bell Frog Compensatory Habitat Monitoring

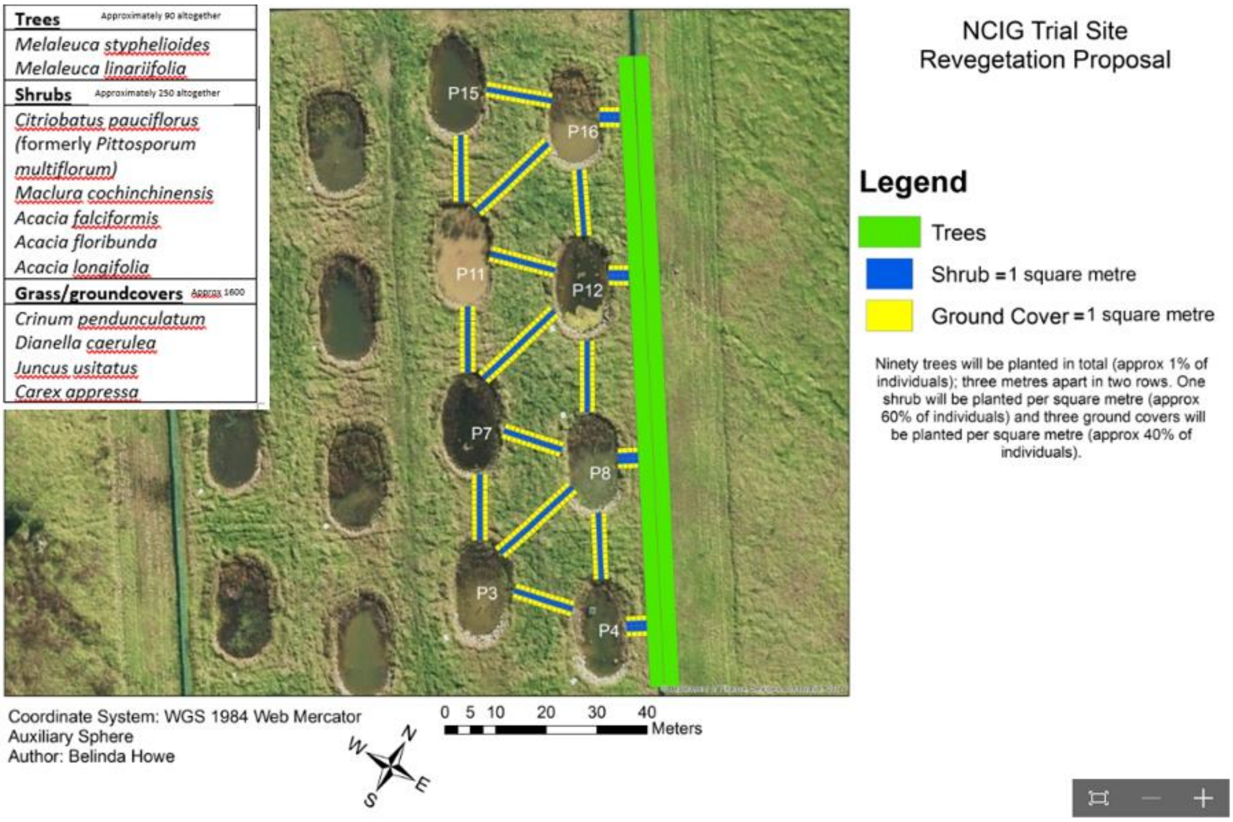
3.1. Compensatory Habitat Monitoring

There is currently no new data to report in relation to the monitoring of the Green and Golden Bell frog since the last quarterly report. A new PhD student from the University of Newcastle is commencing a project on the Green and Golden Bell frog, which will include the NCIG Compensatory Habitat. Monitoring of the Green and Golden Bell frog will increase further into the summer season as the project commences.

3.2. Compensatory Habitat Management

Conservation Volunteers Australia commenced another successful fox baiting program on behalf of NCIG at the Green and Golden Bell Frog Compensatory Habitat in December 2017. At the end of this reporting period 13 fox baits had been taken over 3 days of baiting, suggesting high fox activity in the area. The fox baiting program will continue into January 2018. This fox baiting program runs collaboratively with BHP, who manage a separate Green and Golden Bell Frog offset on Ash Island. The coverage of the baiting was also extended this season to include the NCIG Migratory Shorebird Habitat.

To improve the success of NCIG's Green and Golden Bell Frog Trial Ponds, Conservation Volunteers Australia revegetated the Trial Ponds on behalf of NCIG. The project involved the planting of approximately 1900 plants, comprising primarily of native grasses/ground cover in addition to shrubs and trees. This project concluded in late December 2017 and will now require ongoing maintenance in 2018 including watering and weed removal.



Ninety trees will be planted in total (approx 1% of individuals); three metres apart in two rows. One shrub will be planted per square metre (approx 60% of individuals) and three ground covers will be planted per square metre (approx 40% of individuals).

Figure 2: Green and Golden Bell Frog Trial Pond Revegetation Plan

Figure 4: Green and Golden Bell Frog Trial Pond

4. Shorebird Compensatory Habitat

4.1. Migratory Shorebird Habitat Management

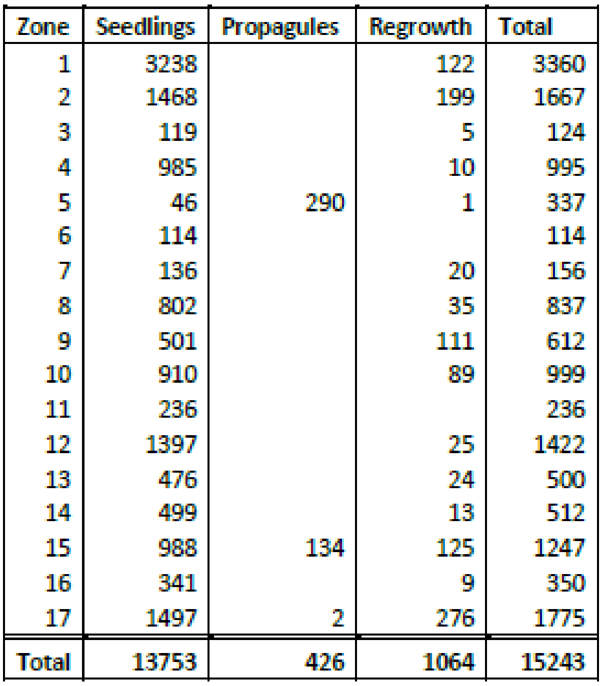
Since completion of the shorebird habitat creation in November 2016 a number of research and monitoring projects have commenced, including bird and vegetation surveys, hydrology and vegetation monitoring and mangrove regrowth management. These projects will continue into 2018 to ensure the shorebird habitat is adequately managed.

UNSW Water Laboratories were commissioned to develop hydrological controls for ongoing management of the SmartGate. Based on the modelling undertaken by UNSW, two possible Design Tidal Regimes were produced. The first option was to adopt a regime where water levels exceed 0.3 m AHD 2.8% of the time (equivalent to approximately 120 tides per year exceeding 0.3 m AHD), which is equivalent to a natural elevation of 0.75 m AHD (the median level of saltmarsh). The second option was to adopt a tidal regime where water levels exceed 0.3 m AHD 0.6% of the time (equivalent to approximately 50 tides per year exceeding 0.3 m AHD), which is equivalent to the natural elevation of 0.87 m AHD (95th percentile elevation of mangroves).

With the recommendation from UNSW Water Research Laboratory, the first option was adopted. This option provides more inundation area that is suitable for saltmarsh growth. However, if observed mangrove growth is found to be excessive, the second option may need to be reconsidered.

New mangrove growth was removed in December 2017 by CVA. The new growth was collected and counted separately by location and by growth (e.g. root shoots, seed growth or re-shoots from old mangroves), to determine the locations of highest density mangrove recruitment. These results will help to determine how the mangrove regrowth can be most effectively managed. The results can be seen below.

Table 1: Shorebird Compensatory Habitat Mangrove Removal, December 2017



Zone	Seedlings	Propagules	Regrowth	Total
1	3238		122	3360
2	1468		199	1667
3	119		5	124
4	985		10	995
5	46	290	1	337
6	114			114
7	136		20	156
8	802		35	837
9	501		111	612
10	910		89	999
11	236			236
12	1397		25	1422
13	476		24	500
14	499		13	512
15	988	134	125	1247
16	341		9	350
17	1497	2	276	1775
Total	13753	426	1064	15243

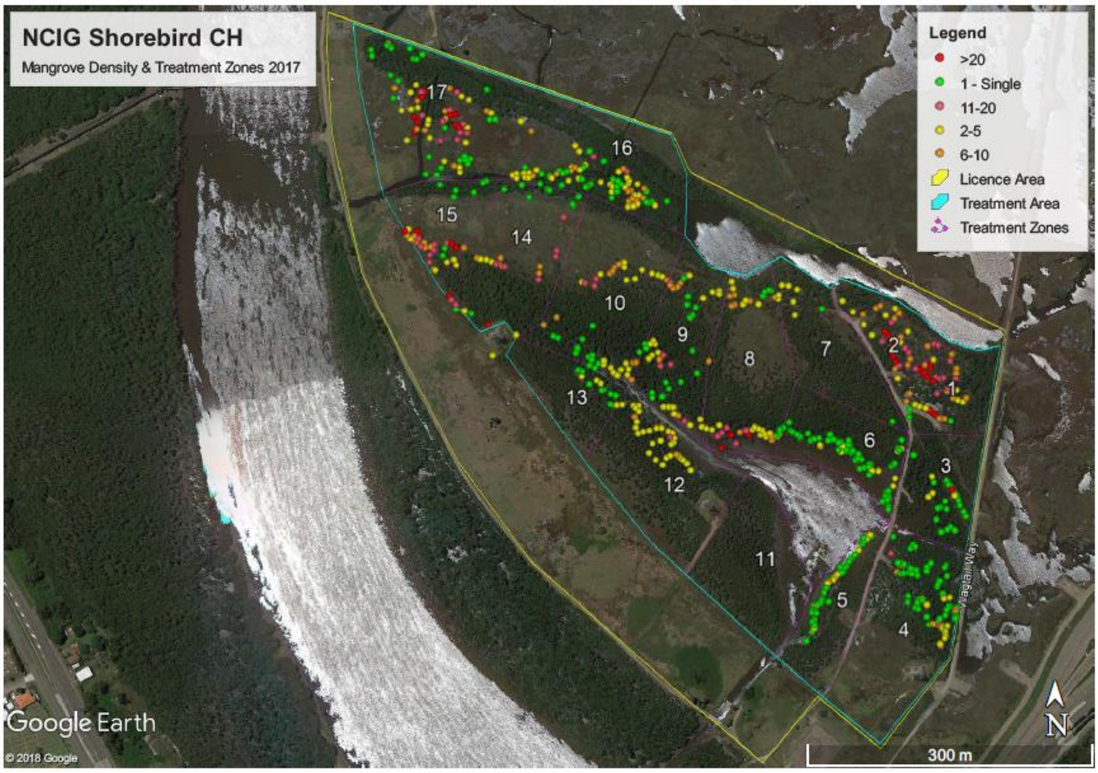


Figure 5: Mangroves removed from NCIG Shorebird Compensatory Habitat

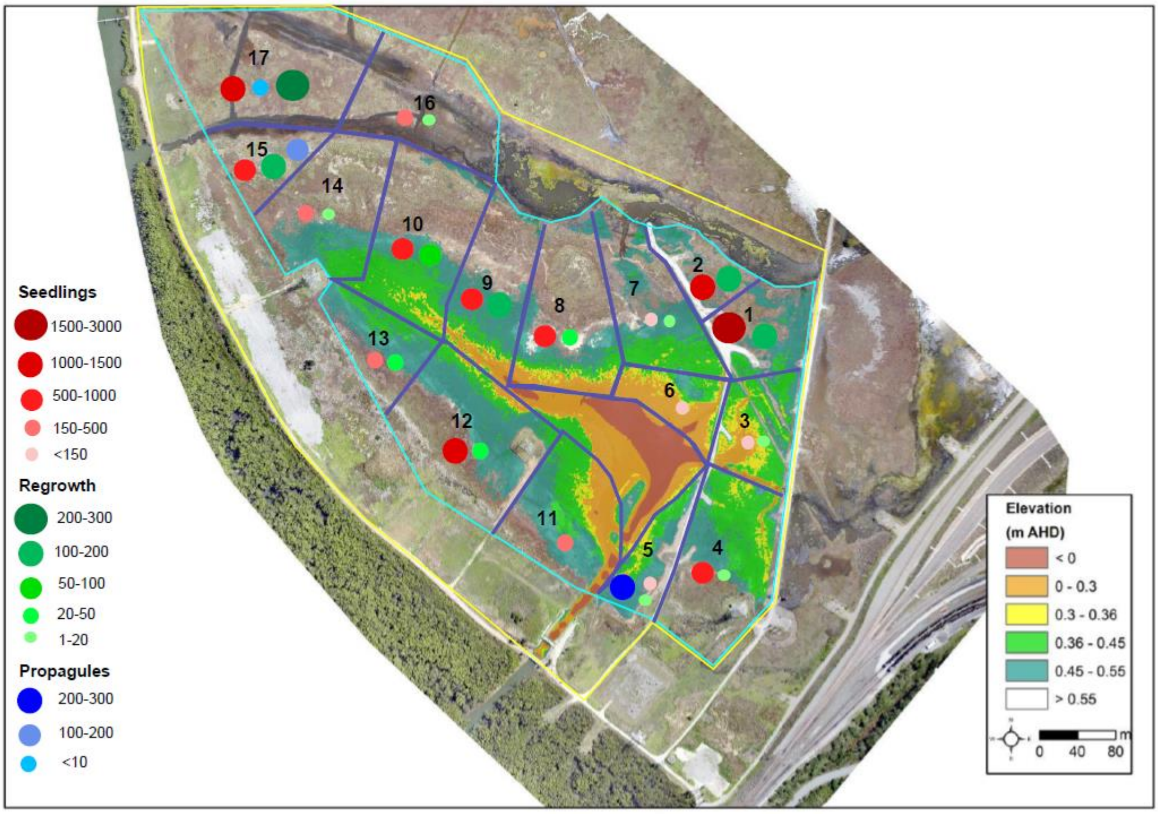
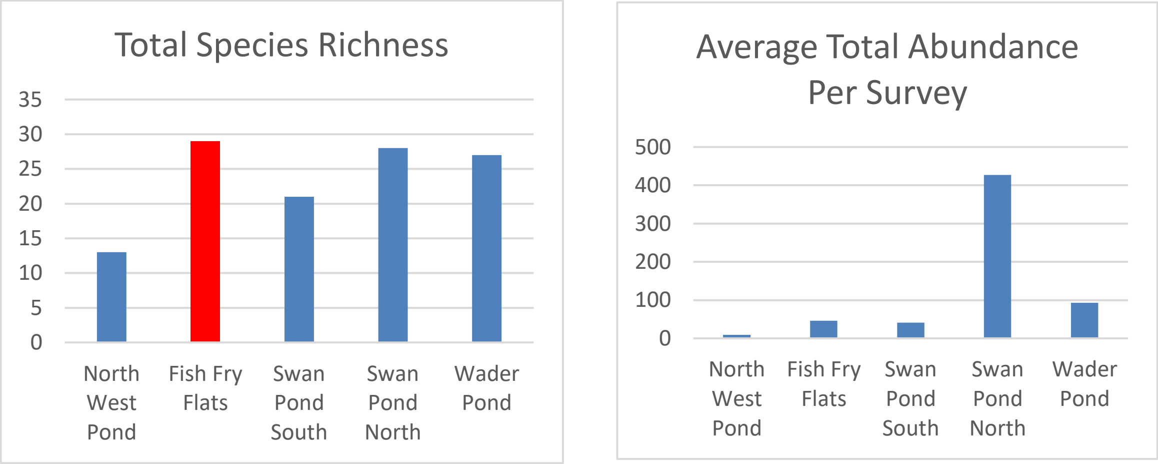


Figure 6: Total number of mangroves removed from each zone (by growth)

Figure 7: Conservation Volunteers Australia removing the mangroves

4.2. Migratory Shorebird Habitat Monitoring

Continuing in accordance with the Shorebird Monitoring Evaluation Reporting and Improvement (MERI) Plan – fortnightly surveys are taken in September-April (high tide, low tide and nocturnal roosting), and monthly in April-September (high tide and low tide). The 2017 bird survey results (January to December 2017) show that many shorebird species have been observed across all ponds, including Fish Fry Flats as well as neighbouring ponds such as Swan Pond, Wader Pond and North-West Pond. Additionally, the results show that a diverse range of birds are visiting Fish Fry Flats. Recent observations at Fish Fry Flats include the Red-capped Plover and the Eastern Curlew.



Figures 8 and 9: Total species richness and average abundance of birds from January-December surveys.

4.3. Area E Wetland Hydrology and Vegetation Monitoring (Water Research laboratory, UNSW).

NCIG continued its collaboration with the University of New South Wales (Water Research Laboratories) in undertaking a research project in alignment with the Shorebird Monitoring, Evaluation, Reporting and Improvement (MERI) Plan. A preliminary report was completed in December 2017.

The Objective of the research was to find relationships between saltmarsh and subsurface flows. There is an inverse relationship between surface water and ground water as ground water discharges into Fish Fry Flats on low tide**.** There was also a potential fresh water influence on low tides (pH relationship).

Comprehensive vegetation surveys in the shorebird habitat were completed in November 2017. An additional vegetation survey and an infauna survey will be completed in early 2018. Groundwater level monitoring will be tied in with the vegetation sampling to gain insight on the role subsurface hydrology plays in governing the behaviour of salt marshes, in particular, nutrient exchange, plant zonation and carbon cycling.

Elevation surveys were completed again in November 2017. The results of the elevation survey are currently being processed. Additionally, a drone survey was also completed. Data from the drone survey will be used to monitor vegetation cover and diversity in the shorebird habitat. This research will be continued into 2018.

Figure 10: Locations of the quadrat sampling on Fish Fry Flats

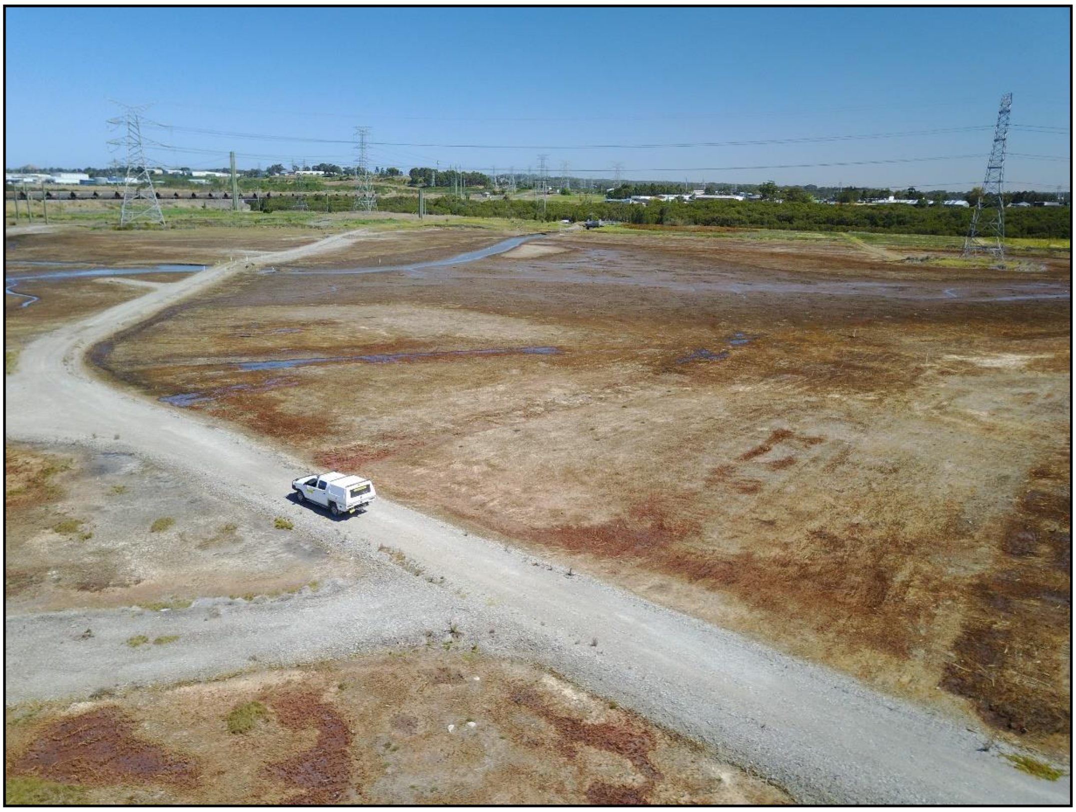


Figure 11: Aerial image of Fish Fry Flats using a drone (November 2017).

4.4. Benthic Survey Results

Benthic cores were taken during November by the University of Newcastle, although these have not yet been analysed. These will be analysed and interpreted in the future along with the following round of benthic sampling to be undertaken in early 2018

Appendix A – Shorebird Monitoring tabulated results (General Flora and Fauna)

Weather	
Temp (°C)	*recorded on site or from BoM*
Wind speed (K/h)	*from BoM*
Wind Direction	*from BoM*
Precipitation (mm)	*recorded on site or from BoM*

Activity (Ac) Codes

F = feeding
R = roosting
B = Breeding

Habitat (Ha) Codes

W = Shallow water
M = Exposed mud or sand
SM = Saltmarsh vegetation
A = Artificial structure

Date/Times																										
Date	4.1.17	4.1.17	6.1.17	14.1.17	20.1.17	20.1.17	6.2.17	9.2.17	9.2.17	11.2.17	23.2.17	23.2.17	5.3.17	6.3.17	6.3.17	25.3.17	25.3.17	25.3.17	4.4.17	4.4.17	6.4.17	12.4.17	20.4.17	20.4.17	2.5.17	2.5.17
Day	Wed	Wed	Fri	Sat	Fri	Fri	Mon	Thu	Thu	Sat	Thu	Thu	Sun	Mon	Mon	Sat	Sat	Sat	Tue	Tue	Thu	Wed	Thu	Thu	Tue	Tue
Time start	7.20am	1.50pm	9.30pm	10.30pm	9.20am	2.40pm	10.50pm	8.00am	2.30pm	10.10pm	7.10am	1.45pm	8.30pm	10.00am	4.10pm	6.45am	1.45pm	7.30pm	9.00am	3.00pm	10.30pm	9.20pm	9.30am	3.20pm	7.40am	2.00pm
Time end	8.15am	3.00pm	10.40pm	11.50pm	10.40am	4.30pm	11.50pm	9.00am	3.30pm	11.00pm	8.23am	2.45pm	9.40pm	11.00am	5.30pm	7.45am	2.45pm	8.30pm	10.00am	4.00pm	11.30pm	10.20pm	10.50am	4.30pm	8.40am	3.00pm
Weather																										
Temp (°C)	22	27	21	25	26	29	27	25	33	30	18	31	21	23	25	17	24	22	19	21	13	18	20	23	14	26
Wind speed (km/h)	20	24	31	24	20	11	22	13	19	13	15	26	13	24	46	7	17	17	15	31	17	24	2	19	13	15
Wind Direction	ESE	SSE	ESE	SE	N	NNW	SE	NNE	ENE	WSW	NNE	ENE	SW	SW	SSW	WSW	ESE	ESE	SSE	SE	SE	S	NNW	ESE	NW	W
Precipitation (mm)	0	0	0	0	0	0	0	0	0	0	0	0	14	0.4	0.4	0	0	0	15	15	11	33	0	0	0	0
Tide																										
Day/Night	Day	Day	Night	Night	Day	Day	Night	Day	Day	Night	Day	Day	Night	Day	Day	Day	Day	Night	Day	Day	Night	Night	Day	Day	Day	Day
High/Low	Low	High	Low	High	Low	High	Low	High	Low	High	High	Low	Low	Low	High	High	Low	High	Low	High	Low	High	Low	High	Low	High
Time	7.18am	1.33pm	9.59pm	11.36pm	9.34am	3.20pm	11.37pm	8.13am	2.53pm	10.28pm	7.20am	2.01pm	9.06pm	10.24am	4.28pm	7.28am	2.00pm	8.08pm	9.16am	3.29pm	11.30pm	9.41pm	9.42am	3.57pm	7.52am	2.05pm
Height	0.65m	1.66m	0.45m	1.5m	0.79m	1.31m	0.55m	1.9m	0.3m	1.55m	1.64m	0.53m	0.56m	0.58m	1.31m	1.69m	0.46m	1.52m	0.54m	1.35m	0.69m	1.75m	0.67m	1.32m	0.47m	1.42m
Other																										
Observers	GL	GL	GL, JL	GL, JL	GL	GL	GL, JL	GL	GL	GL, JL	GL	GL	GL, JL	GL	GL	GL	GL	GL & JL	GL	GL	GL& JL	GL & JL	GL	GL	GL	GL

Area F sub sites listed below

North West Pond	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
0 = nothing																																																							0																		0					
White-fronted Chat																																																																														
Avocet, Red-necked																																																												2	F	W	11	F	W												
Cormorant, Great																																																																														
Cormorant, Little Black																																																																														
Cormorant, Little Pied																																																																														
Cormorant, Pied																																																																														
Curlew, Eastern																																																																														
Darter																																																																														
Dotterel, Black-fronted																																																																														
Dotterel, Red-kneed																																																																														
Duck, Mallard/hybrid																																																																														
Duck, Pacific Black																																																																														
Duck, Pink-eared																																																																														
Egret, Cattle																																																																														
Egret, Eastern Great																																																										1	F	W																		
Egret, Intermediate																																																																														
Egret, Little																																																																														
Godwit, Bar-tailed																			45	F	W																																																										
Godwit, Black-tailed																																																																														
Greenshank, Common																																																																														
Gull, Silver																																																																														
Heron, Striated																																																																														
Heron, White-faced													1	F	M										3	F	SM				1	F	W							2	F	SM	4	F	SM				6	F	W																5	F	W	12	F	W				16	F	W
Ibis, Australian White	2	F	W										3	F	SM	1	F	SM							2	F	SM				5	F	SM	1	F	W																																										3	F	SM
Ibis, Straw-necked																																																																															
Knot, Great																																																																														
Knot, Red																																																																														
Lapwing, Masked				2	F	SM	2	F	SM							2	F	W	4	F	SM				2	F	SM	2	F	SM				2	F	SM	2	F	SM													2	F	SM							2	F	SM	2	F	SM				4	F	SM				4	F	SM
Night Heron, Nankeen																																																																														
Oystercatcher, Pied																																																																														
Oystercatcher, Sooty																																																																														
Pelican, Australian																																																																														
Plover, Double-banded																																																																														
Plover, Grey																																																																														
Plover, Lesser																																																																														
Plover, Pacific Golden																																																																														
Plover, Red-capped																																																																														
Rail, Buff-banded																																																																														
Sandpiper, Common																																																																														
Sandpiper, Curlew																																																																														
Sandpiper, Marsh																																																																														
Sandpiper, Sharp-tailed																																																																														
Sandpiper, Terek																																																																														
Shoveller, Australian																																																																														
Spoonbill, Royal													1	F	W							1	F	W																						1	F	W																												2	F	W
Stilt, Black-winged																			1	F	W							1	F	W							6	F	W													2	F	W										6	F	W												
Stint, Red-necked																																																																														
Stork, Black-necked																																																																										1	F	SM
Swan, Black																																																																														
Tattler, Grey-tailed																																																																														
Teal, Chestnut							17	F	S	9	F	W																2	F	W				2	F	W	12	F	W													10	F	W							17	F	W	10	F	W												
Teal, Grey																			6	F	W																																																									
Tern, Caspian																																																																														
Tern, Common																																																																														
Tern, Crested																																																																														
Tern, Gull-billed																																																																														
Tern, Little																																																																														
Tern, Whiskered																																																																														
Tern, White-winged Black																																																																														
Turnstone, Ruddy																																																																														
Whimbrel																																																																														
Species richness -	1			1			2			1			3			2			4			1			3			3			2			3			3			1			1			1			1			3			0			1			3			4			1			2			0			5		
Total abundance -	2			2			19			9			5			3			56			1			7			5			6			5			20			2			4			1			6			14			0			1			21			29			5			16			0			26		

Fish Fry Flat	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
0 = nothing																																																																														
White-fronted Chat																																																																														
Avocet, Red-necked																																																															10	F	W							3	F	W	14	F	W
Cormorant, Great																																																																														
Cormorant, Little Black																1	R	A																																																				2	R	A						
Cormorant, Little Pied				1	R	A																1	R	A																																		2	R	A																		
Cormorant, Pied																																																																														
Curlew, Eastern																						2	F	SM							2	F	M	3	F	M				2	F	M	1	F	M	1	F	M							1	F	M																					
Darter																																																																														
Dotterel, Black-fronted																																																															4	F	M												
Dotterel, Red-kneed																																																																															
Duck, Mallard/hybrid																																																																															
Duck, Pacific Black																																																																														
Duck, Pink-eared																																																																														
Egret, Cattle																																																																														
Egret, Eastern Great	1	F	M	5	R	SM																									11	F	W							1	F	M				1	F	M	1	F	M							1	F	M							5	F	M	1	F	W	2	F	W	2	F	W
Egret, Intermediate																																																																														
Egret, Little																																														1	F	M																														
Godwit, Bar-tailed																																																																														
Godwit, Black-tailed																																																																														
Greenshank, Common																																																													4	F	W															
Gull, Silver																															6	F	W																																													
Heron, Striated																			1	F	M																																																									
Heron, White-faced	2	F	M	2	F	SM							1	F	M	4	F	SM				9	F	SM	13	F	M				25	F	M	4	F	M				6	F	M	11	F	M	44	F	M	3	F	M				25	F	M	19	F	M							22	F	M	7	F	M	17	F	M	17	F	M
Ibis, Australian White	28	F	M	1	F	SM										8	F	M				21	F	SM	16	F	M				13	F	M							7	F	SM	10	F	SM	5	F	M							11	F	SM										3	F	M	1	F	M	66	F	M	45	F	M
Ibis, Straw-necked																																																																														
Knot, Great																																																																															
Knot, Red																																																																														
Lapwing, Masked							2	F	SM	2	F	SM													2	F	SM	4	F	SM							6	F	SM																						4	F	SM										4	F	SM	4	F	M
Night Heron, Nankeen																																																				1	F	M																								
Oystercatcher, Pied																																																																															
Oystercatcher, Sooty																																																																															
Pelican, Australian																						11	R	A							3	F	W																			1	F	W													11	F	W									
Plover, Double-banded																																																																									3	F	M			

North West Pond		No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
Plover, Grey
Plover, Lesser
Plover, Pacific Golden										1	F	M																									4	F	SM													2	F	SM
Plover, Red-capped
Rail, Buff-banded
Sandpiper, Common
Sandpiper, Curlew
Sandpiper, Marsh
Sandpiper, Sharp-tailed																																						8	F	SM																						13	F	M	9	F	M
Sandpiper, Terek
Shoveller, Australian
Spoonbill, Royal								1	F	S										1	F	W	1	R	A							8	F								6	F	W	2	F	W										5	F	W							1	R	SM	7	R	M				2	F	W
Stilt, Black-winged																				1	F	W																10	F	W													30	F	W							4	F	W	9	F	W	12	F	M				10	F	W	22	F	W
Stint, Red-necked
Stork, Black-necked
Swan, Black																										1	F	W
Tattler, Grey-tailed
Teal, Chestnut											1	F	W																									12	F	W													14	F	W							25	F	W	68	F	W	67	F	W	12	F	W	25	F	W	170	F	W
Teal, Grey																																																						2	F	W										28	F	W	23	F	W				65	F	W	50	F	W
Tern, Caspian
Tern, Common
Tern, Crested
Tern, Gull-billed																																																									6	R	M	6	F	M													6	R	M	13	R	M
Tern, Little
Tern, Whiskered
Tern, White-winged Black
Turnstone, Ruddy
Whimbrel
Species richness -		3			4			2			3			1			3			3			6			4			1			7			2			5			4			4			5			3			6			5			4			5			7			8			5			11			9		
Total abundance -		31			9			3			4			1			13			3			45			32			4			68			7			40			20			25			52			5			50			48			28			50			129			150			23			203			337		
Swan Pond South		No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
0 = nothing
White-fronted Chat
Avocet, Red-necked																																																														8	F	W	7	F	W	5	F	W	4	F	W	5	F	W	2	F	W
Cormorant, Great
Cormorant, Little Black
Cormorant, Little Pied																																1	F	W
Cormorant, Pied
Curlew, Eastern
Darter
Dotterel, Black-fronted																																						3	F	M	1	F	M	1	F	M							4	F	M	1	F	M	2	F	M							2	F	M
Dotterel, Red-kneed																																																																														4	F	M
Duck, Mallard/hybrid
Duck, Pacific Black
Duck, Pink-eared
Egret, Cattle
Egret, Eastern Great																																1	F	W	1	F	SM				1	F	W	1	F	W																												1	F	W
Egret, Intermediate
Egret, Little																				1	R	W																																																1	F	W	2	F	W
Godwit, Bar-tailed
Godwit, Black-tailed
Greenshank, Common																																																									1	F	W
Gull, Silver
Heron, Striated
Heron, White-faced		1	F	S	1	F	S							1	F	SM	3	F	SM							2	F	SM				1	F	W	6	F	M				1	F	SM	7	F	SM	1	F	SM	8	F	W				1	F	SM	2	F	SM							1	F	W	2	F	W				1	F	SM
Ibis, Australian White		10	F	SM	12	F	SM																10	F	SM	3	F	SM				7	F	W	2	R	A							12	F	SM	3	F	SM	12	F	SM																2	F	SM				6	F	SM	2	F	SM
Ibis, Straw-necked
Knot, Great
Knot, Red
Lapwing, Masked		5	F	SM	2	F	SM	2	F	SM				3	F	SM	5	F	SM	2	F	SM	5	F	SM	4	F	SM				3	F	SM				4	F	SM	3	F	SM				3	F	SM	5	F	SM				6	F	SM	5	F	SM				2	F	SM	3	F	SM	2	F	SM				2	F	SM
Night Heron, Nankeen																				1	F	W
Oystercatcher, Pied
Oystercatcher, Sooty
Pelican, Australian																																																		1	F	W																									3	R	SM
Plover, Double-banded
Plover, Grey
Plover, Lesser
Plover, Pacific Golden
Plover, Red-capped																																																																		2	F	M
Rail, Buff-banded
Sandpiper, Common
Sandpiper, Curlew
Sandpiper, Marsh
Sandpiper, Sharp-tailed																																																														6	F	M
Sandpiper, Terek
Shoveller, Australian
Spoonbill, Royal																													2	F	W													4	R	M										1	F	W										1	F	W				1	F	W
Stilt, Black-winged																				9	F	W							15	F	W	5	F	W	7	F	W																18	F	W	5	F	W				2	F	W	17	F	W	77	F	W	64	F	W	27	F	W	38	F	W
Stint, Red-necked
Stork, Black-necked
Swan, Black
Tattler, Grey-tailed
Teal, Chestnut		3	F	S				13	F	S	5	F	W				12	F	W							2	F	W	40	F	W							8	F	W													4	F	W	2	F	W	2	F	W	3	F	W	12	F	W	127	F	W	94	F	W	45	F	W	53	F	W
Teal, Grey								1	F	S				10	F	W	4	F	W	3	F	W							5	F	W																																								44	F	W	20	F	W	150	F	W	12	F	W
Tern, Caspian
Tern, Common
Tern, Crested
Tern, Gull-billed																																																																									9	F	M	4	F	W
Tern, Little
Tern, Whiskered
Tern, White-winged Black
Turnstone, Ruddy
Whimbrel
Species richness -		4			3			3			1			3			4			5			2			4			4			6			4			3			4			5			3			4			3			7			4			4			5			9			7			9			10		
Total abundance -		19			15			16			5			14			24			16			15			11			62			18			16			15			6			25			7			26			26			17			11			19			40			262			187			246			121		
Swan Pond North		No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
0 = nothing
White-fronted Chat																																																									2	F	SM
Avocet, Red-necked																																						22	F	W	5	F	W	5	R	W										180	R	W	220	R	W	5	F	W	15	F	W	140	F	W	110	R	W	300	R	W	135	F	W
Cormorant, Great
Cormorant, Little Black
Cormorant, Little Pied		2	F	S	2	R	A							2	F	W	2	F	W				3	R	A							1	R	A													1	F	W
Cormorant, Pied
Curlew, Eastern
Darter
Dotterel, Black-fronted																																																																		2	F	M
Dotterel, Red-kneed

North West Pond		No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
Duck, Mallard/hybrid																																								
Duck, Pacific Black																																								
Duck, Pink-eared																																								
Egret, Cattle																																								
Egret, Eastern Great														1	F	W	2	F	W							1	F	W												
Egret, Intermediate																																								
Egret, Little																																								
Godwit, Bar-tailed																																								
Godwit, Black-tailed																																								
Greenshank, Common																											4	F	W												
Gull, Silver														18	F	W	28	F	W				18	F	W	16	F	W				12	F	W	6	F	W			
Heron, Striated																																								
Heron, White-faced																							1	F	SM													2	F	W
Ibis, Australian White																																								
Ibis, Straw-necked																																								
Knot, Great																																								
Knot, Red																																								
Lapwing, Masked		2	F	SM	6	F	SM	5	F	SM	4	F	SM	4	F	SM	8	F	SM				8	R	SM	9	F	SM							7	F	SM			
Night Heron, Nankeen																																								
Oystercatcher, Pied																																								
Oystercatcher, Sooty																																								
Pelican, Australian																																	15	R	SM	10	R	SM			
Plover, Double-banded																																								
Plover, Grey																																								
Plover, Lesser																																								
Plover, Pacific Golden																																								
Plover, Red-capped																																								
Rail, Buff-banded																																								
Sandpiper, Common																																								
Sandpiper, Curlew																																								
Sandpiper, Marsh																																								
Sandpiper, Sharp-tailed																	20	R	SM																					
Sandpiper, Terek																																								
Shoveller, Australian																																								
Spoonbill, Royal								1	F	S																														
Stilt, Black-winged																	29	F	W	8	F	W							100	F	W	108	F	W	210	F	W	45	F	W
Stint, Red-necked																																								
Stork, Black-necked																																								
Swan, Black																																				2	R	SM			
Tattler, Grey-tailed																																								
Teal, Chestnut		2	F	S				6	F	S	40	F	W				80	F	W										50	F	W	40	F	W				24	F	W
Teal, Grey																	140	F	W	65	F	W							70	F	W	280	F	W	35	F	W			
Tern, Caspian																																								
Tern, Common																																								
Tern, Crested																																								
Tern, Gull-billed																																								
Tern, Little																																								
Tern, Whiskered														1	R	A	1	F	W																					
Tern, White-winged Black																																								
Turnstone, Ruddy																																								
Whimbrel																																								
Species richness -		3			2			3			2			5			9			2			4			4			3			6			6			4		
Total abundance -		6			8			12			44			26			310			73			30			30			220			456			270			93		

North West Pond	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
Duck, Mallard/hybrid																																							
Duck, Pacific Black							3	F	W																														
Duck, Pink-eared																																							
Egret, Cattle																																							
Egret, Eastern Great										4	F	W																	1	F	M								
Egret, Intermediate																																							
Egret, Little																																							
Godwit, Bar-tailed																																							
Godwit, Black-tailed																																							
Greenshank, Common				1	F	W																																	
Gull, Silver				28	R	SM	7	F	W																										6	F	W	24	R	SM
Heron, Striated																																							
Heron, White-faced										2	F	SM																									1	F	SM
Ibis, Australian White																													1	F	SM	4	R	SM				1	F	SM
Ibis, Straw-necked																																							
Knot, Great																																							
Knot, Red																																							
Lapwing, Masked	5	R	SM	8	F	SM	2	F	SM	6	F	SM	2	F	SM	27	R	SM	8	R	SM							8	F	SM	6	F	SM	4	F	SM	2	F	SM
Night Heron, Nankeen																																							
Oystercatcher, Pied																																							
Oystercatcher, Sooty																																							
Pelican, Australian													16	R	SM							3	R	W				1	R	SM	3	R	SM	6	F	W			
Plover, Double-banded																																							
Plover, Grey																																							
Plover, Lesser																																							
Plover, Pacific Golden																																							
Plover, Red-capped																																							
Rail, Buff-banded																																							
Sandpiper, Common																																							
Sandpiper, Curlew																																							
Sandpiper, Marsh																																							
Sandpiper, Sharp-tailed																			5	F	W																		
Sandpiper, Terek																																							
Shoveller, Australian																19	F	W	120	F	W							24	F	W	35	F	W				4	F	W
Spoonbill, Royal																												1	R	SM	7	R	SM						
Stilt, Black-winged	220	R	W	110	R	W	430	F	W				303	F	W	220	R	W	280	R	W	13	F	W	50	F	W	120	F	W	410	R	W	80	F	W	85	F	W
Stint, Red-necked																																							
Stork, Black-necked																																							
Swan, Black							1	F	W																			12	R	SM	3	R	W						
Tattler, Grey-tailed																																							
Teal, Chestnut							4	F	W				52	F	W	80	F	W	110	F	W	50	F	W	100	F	W	350	F	W	450	F	W	340	F	W	180	F	W
Teal, Grey																320	F	W	90	F	W	50	F	W	400	F	W	280	F	W	150	F	W	160	F	W	45	F	W
Tern, Caspian																												1	R	SM							2	R	SM
Tern, Common																																							
Tern, Crested																																							
Tern, Gull-billed																															1	R	SM	4	F	W	7	R	SM
Tern, Little																																							
Tern, Whiskered																																							
Tern, White-winged Black																																							
Turnstone, Ruddy																																							
Whimbrel																																							
Species richness -	3			5			7			3			4			7			7			5			5			12			11			8			11		
Total abundance -	230			152			448			12			373			848			833			121			567			939			1179			900			486		

Wader Pond		No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
0 = nothing																																								
White-fronted Chat																																								
Avocet, Red-necked																																								
Cormorant, Great																																								
Cormorant, Little Black																																								
Cormorant, Little Pied																							1	F	W										1	R	A			
Cormorant, Pied																																								
Curlew, Eastern																										1	F	SM												
Darter																																								
Dotterel, Black-fronted											2	F	M																											
Dotterel, Red-kneed																																								
Duck, Mallard/hybrid																																								
Duck, Pacific Black																																								
Duck, Pink-eared																																								
Egret, Cattle																																								
Egret, Eastern Great																																				3	R	SM			
Egret, Intermediate																																								
Egret, Little																																								
Godwit, Bar-tailed																																								
Godwit, Black-tailed																																								
Greenshank, Common		1	F	S																																				
Gull, Silver																																32	F	W	8	F	W			
Heron, Striated																																								
Heron, White-faced														6	F	SM																12	F	W	2	F	SM			
Ibis, Australian White		1	F	SM																			1	F	SM	1	F	SM				2	F	SM	2	F	SM			
Ibis, Straw-necked																																								
Knot, Great																																								
Knot, Red																																								
Lapwing, Masked		6	F	SM	4	F	SM	2	F	SM				3	F	SM	6	F	SM				13	F	SM	6	F	SM				4	F	SM	6	F	SM			
Night Heron, Nankeen																																								
Oystercatcher, Pied																																								
Oystercatcher, Sooty																																								
Pelican, Australian																																								
Plover, Double-banded																																								
Plover, Grey																																								
Plover, Lesser																																								
Plover, Pacific Golden																																								
Plover, Red-capped																																								
Rail, Buff-banded																																								
Sandpiper, Common																																								
Sandpiper, Curlew																																								
Sandpiper, Marsh																																								
Sandpiper, Sharp-tailed																																								
Sandpiper, Terek																																								
Shoveller, Australian																	4	F	W																					
Spoonbill, Royal																													1	F	W	7	F	W	1	F	W			
Stilt, Black-winged																				19	F	W							25	F	W	280	F	W	140	F	W	43	F	W
Stint, Red-necked																																								
Stork, Black-necked																																								
Swan, Black																																								
Tattler, Grey-tailed																																								
Teal, Chestnut								6	F	S	44	F	W				60	F	W	13	F	W							61	F	W	24	F	W				43	F	W
Teal, Grey																	180	F	W	15	F	W							20	F	W	120	F	W	81	F	W			
Tern, Caspian																																								
Tern, Common																																								
Tern, Crested																																								
Tern, Gull-billed																																								
Tern, Little																																								
Tern, Whiskered																																								
Tern, White-winged Black																																								
Turnstone, Ruddy																																								
Whimbrel																																								
Species richness -		3			1			2			2			2			4			3			3			3			4			8			9			2		
Total abundance -		8			4			8			46			9			250			47			15			8			107			481			244			86		

Wader Pond	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
0 = nothing																																							
White-fronted Chat				2	F	SM	2	F	SM																														
Avocet, Red-necked																						26	F	W	1	F	W	9	F	W	140	F	W	8	F	W	33	F	W
Cormorant, Great																																							
Cormorant, Little Black																																							
Cormorant, Little Pied																																							
Cormorant, Pied																																							
Curlew, Eastern																																							
Darter																																							
Dotterel, Black-fronted							5	F	M	6	F	M	5	F	M	2	F	M	2	F	M	2	F	M	8	F	M				6	F	M	6	F	M	12	F	M
Dotterel, Red-kneed																																							
Duck, Mallard/hybrid																																							
Duck, Pacific Black																																							
Duck, Pink-eared																																							
Egret, Cattle																																							
Egret, Eastern Great				1	F	W	1	F	W																														
Egret, Intermediate																																							
Egret, Little																																							
Godwit, Bar-tailed																																							
Godwit, Black-tailed																																							
Greenshank, Common																																							
Gull, Silver	29	F	W	9	F	W	4	F	W	14	F	W																											
Heron, Striated																																							
Heron, White-faced				1	F	SM				3	F	W							1	F	SM	1	F	SM							17	F	W	1	F	SM			
Ibis, Australian White	1	F	SM	2	F	SM	1	F	SM																									2	F	SM	3	F	SM
Ibis, Straw-necked																																							
Knot, Great																																							
Knot, Red																																							
Lapwing, Masked	2	F	SM	9	F	SM	11	F	SM	24	F	SM	2	F	SM				4	F	SM							3	F	SM	9	F	SM	6	F	SM	4	F	SM
Night Heron, Nankeen																																							
Oystercatcher, Pied																																							
Oystercatcher, Sooty																																							
Pelican, Australian										5	F	W																											
Plover, Double-banded																																							
Plover, Grey																																							
Plover, Lesser																																							
Plover, Pacific Golden																																							
Plover, Red-capped																									2	F	M												
Rail, Buff-banded																																							
Sandpiper, Common																																							
Sandpiper, Curlew																																							
Sandpiper, Marsh																																							
Sandpiper, Sharp-tailed							6	F	M										2	F	W				1	F	W							1	F	W			
Sandpiper, Terek																																							
Shoveller, Australian																																							
Spoonbill, Royal																																							
Stilt, Black-winged							380	F	W				208	F	W							21	F	W	45	F	W	153	F	W	80	F	W	76	F	W	53	F	W
Stint, Red-necked																																							
Stork, Black-necked																																							
Swan, Black																			2	F	W																		
Tattler, Grey-tailed																																							
Teal, Chestnut													8	F	W										70	F	W	33	F	W	90	F	W	6	F	W	40	F	W
Teal, Grey													2	F	W							5	F	W	30	F	W	90	F	W	120	F	W	25	F	W	8	F	W
Tern, Caspian																																							
Tern, Common																																							
Tern, Crested																																							
Tern, Gull-billed																																					2	F	W
Tern, Little																																							
Tern, Whiskered																																							
Tern, White-winged Black																																							
Turnstone, Ruddy																																							
Whimbrel																																							
Species richness -	3			6			8			5			5			2			5			4			7			5			7			9			8		
Total abundance -	32			24			410			52			225			3			11			54			157			288			462			131			155		

Weather
Temp (°C)
Wind speed (K/h)
Wind Direction
Precipitation (mm)

Date/Times																														
Date	16.6.17	16.6.17	17.7.17	17.7.17	15.8.17	15.8.17	5.9.17	5.9.17	8.9.17	14.9.17	21.9.17	21.9.17	5.10.17	5.10.17	5.10.17	20.10.17	20.10.17	27.10.17	8.11.17	8.11.17	10.11.17	17.11.17	24.11.17	24.11.17	4.12.17	4.12.17	9.12.17	17.12.17	18.12.17	18.12.17
Day	Fri	Fri	Mon	Mon	Tue	Tue	Tue	Tue	Fri	Thu	Sat	Sat	Thu	Thu	Thu	Fri	Fri	Fri	Wed	Wed	Fri	Fri	Sun	Sun	Mon	Mon	Sat	Sun	Mon	Mon
Time start	6.45am	1.15pm	8.00am	2.50pm	7.40am	2.00pm	7.30am	1.30pm	9.20pm	9.30pm	8.45am	2.45pm	8.40am	2.35pm	9.00pm	09.20am	3.30pm	9.50pm	5.50am	12.06pm	8.50pm	8.42pm	6.04am	12.35pm	9.20am	3.55pm	8.40pm	9.00pm	9.15am	3.40pm
Time end	7.45am	2.00pm	8.45am	3.50pm	8.40am	3.00pm	8.45am	2.40pm	10.15pm	10.35pm	10.00am	4.00pm	9.40am	3.35pm	10.05pm	10.30am	4.40pm	10.50pm	7.05am	12.58pm	9.45pm	9.34pm	7.08am	1.37pm	10.15am	4.53pm	9.35pm	9.36pm	10.05am	4.17pm
Weather																														
Temp (°C)	10	17	7	18	12	17	13	21	13	17	15	24	19	27	22	19	18	16	15	18	21	20	12	29	22	20	18	23	25	32
Wind speed (km/h)	19	15	15	9	19	9	44	44	28	41	13	17	9	19	19	11	28	31	13	22	22	30	6	20	20	28	24	13	11	20
Wind Direction	WNW	SSW	NW	NNE	NW	NNE	WNW	WNW	W	W	NW	ESE	SW	ESE	ESE	WSW	SW	S	SW	ESE	SE	NE	NW	E	SSW	S	SSE	S	SSE	SE
Precipitation (mm)	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	1.2	1.2	38.8	29	29	0	1.6	0	0	0	0	0.2	0	0	0
Tide																														
Day/Night	Day	Day	Day	Day	Day	Day	Day	Day	Night	Night	Day	Day	Day	Day	Night	Day	Day	Night	Day	Day	Night	Night	Day	Day	Day	Day	Night	Night	Day	Day
High/Low	Low	High	Low	High	Low	High	High	Low	High	Low	High	Low	High	Low	High	High	Low	Low	Low	High	Low	High	Low	High	High	Low	Low	High	High	Low
Time	7.21am	1.39pm	8.25am	3.00pm	7.53am	2.31pm	8.01am	1.41pm	10.04pm	10.07pm	9.20am	3.17pm	9.08am	3.04pm	9.18pm	9.51am	4.03pm	9.25pm	6.03am	12.33pm	9.25pm	9.02pm	6.30am	12.58pm	9.44am	4.18pm	8.57pm	9.20pm	9.32am	4.07pm
Height	0.56m	1.42m	0.50m	1.58m	0.5m	1.6m	1.45m	0.47m	1.75m	0.49m	1.65m	0.38m	1.64m	0.37m	1.74m	1.72m	0.39m	0.6m	0.48m	1.91m	0.39m	1.46m	0.72m	1.63m	2.05m	0.18m	0.37m	1.35m	1.80m	0.42m
Other																														
Observers	GI	GI	GI	GI	GI	GI	GI	GI	GI, JJ	GI, JJ	GI	GI	GI	GI	GI, JJ	GI	GI	GI, JJ	GI	GI	GI, JJ	GI, JJ	GI	GI	GI	GI	GI	GI, JJ	GI	GI

Area F sub sites listed below

North West Pond	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No
0 = nothing																			0											0		0																							0																													
White-fronted Chat																																																																																								
Avocet, Red-necked																									9	F	W	4	F	W													5	F	W							4	F	W							8	F	W	3	F	W													2	F	W	1	F	W				
Cormorant, Great																																																																																								
Cormorant, Little Black																																																																																								
Cormorant, Little Pied																																																																																								
Cormorant, Pied																																																																																								
Curlew, Eastern																																																																																								
Darter																																																																																								
Dotterel, Black-fronted																																																																																								
Dotterel, Red-kneed																																																																																								
Duck, Mallard/hybrid																																																																																								
Duck, Pacific Black																																																							3	R	W																															
Duck, Pink-eared																																																																																								
Egret, Cattle																																																																																								
Egret, Eastern Great							1	F	W																																																																															
Egret, Intermediate																																																																																								
Egret, Little																																																																																								
Godwit, Bar-tailed																																																																																								
Godwit, Black-tailed																																																																																								
Greenshank, Common																																																																																								
Gull, Silver																																																																																								
Heron, Striated																																																																																								
Heron, White-faced	3	F	SM	3	F	SM				1	F	W	1	F	W	1	F	W																						1	F	M				1	F	M							1	F	SM										1	F	M																			
Ibis, Australian White							19	F	SM	11	F	SM										1	F	W																						2	F	M																									4	F	SM	3	F	SM							1	F	SM	
Ibis, Straw-necked																																																																																								
Knot, Great																																																																																								
Knot, Red																																																																																								
Lapwing, Masked				2	F	SM	2	F	SM				2	F	SM													1	F	SM																						2	F	SM							2	F	SM	2	R	SM				4	F	W							2	R	SM							1
Night Heron, Nankeen																																																																																								
Oystercatcher, Pied																																																																																								
Oystercatcher, Sooty																																																																																								
Pelican, Australian																																																																																								
Plover, Double-banded																																																																																								
Plover, Grey																																																																																								
Plover, Lesser																																																																																								
Plover, Pacific Golden																																																																																								
Plover, Red-capped																																					5	F	M																																																	2	F	M							
Rail, Buff-banded																																																																																								
Sandpiper, Common																																																																																								
Sandpiper, Curlew																																																																																								
Sandpiper, Marsh																																																																																								
Sandpiper, Sharp-tailed																																																																																								
Sandpiper, Terek																																																																																								
Shoveller, Australian																																																																																								
Spoonbill, Royal																																																																																								
Stilt, Black-winged																									4	F	W	2	F	W													1	F	W							2	F	W																									5	F	W							
Stint, Red-necked																																																																																								
Stork, Black-necked																																																																																								
Swan, Black																																																																																								
Tattler, Grey-tailed																																																																																								
Teal, Chestnut																												4	F	W																									4	F	W							10	F	W										2	F	W										
Teal, Grey																																											6	F	W				6	R	W	8	F	W	8	F	W				20	F	W	12	F	W													4	F	W							
Tern, Caspian																																																																																								
Tern, Common																																																																																								
Tern, Crested																																																																																								
Tern, Gull-billed																																																																																								
Tern, Little																																																																																								
Tern, Whiskered																																																																																								
Tern, White-winged Black																																																																																								
Turnstone, Ruddy																																																																																								
Whimbrel																																																																																								
Species richness -	1		2		3		2		2		1		0		1		2		4		0		0		1		1		3		2		1		4		4		0		3		4		1		1		1		2		5		1		1		1
Total abundance -	3		5		22		12		3		1		0		1		13		11		0		0		5		1		12		3		6		16		16		0		30		27		1		4		4		5		15		1		1		1

Fish Fry Flat	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No
0 = nothing																																																																																								
White-fronted Chat																																																																																								
Avocet, Red-necked																									7	F	W	10	F	W				1	F	W							6	F	W				1	F	W	7	F	W	3	F	W	4	F	W	19	F	W	6	F	W													1	F	W	8	F	W				
Cormorant, Great																																														1	R	A																																								
Cormorant, Little Black							2	F	W				1	R	A				1	R	A										7	R	A																																																							
Cormorant, Little Pied							1	F	W				2	R	M				2	F	W	1	R	A																						1	R	A							2	F	W	1	F	W							1	F	W				1	R	A													
Cormorant, Pied																																																																																								
Curlew, Eastern																																																																																								
Darter																																																																																								
Dotterel, Black-fronted				9	F	M																																																																																		
Dotterel, Red-kneed				5	F	M																			6	F	M	2	F	M													1	F	M							6	F	M				12	F	M	10	F	M	13	F	M																						
Duck, Mallard/hybrid																																																																																								
Duck, Pacific Black																																																																																								
Duck, Pink-eared																																																																																								
Egret, Cattle																																																																																								
Egret, Eastern Great	1	F	M	1	F	M	1	F	W	2	F	W	1	R	M	2	F	W																1	F	W	1	F	W	2	F	W				1	F	M	1	F	M				1	F	W	1	F	W							1	F	W	3	F	W	5	R	M	1	F	W							1	F	W	
Egret, Intermediate																																																																			1	F	M																			
Egret, Little				1	F	M										1	F	W													1	F	W													1	F	W							1	F	W	1	F	W							1	F	W	1	F	W	1	F	W										1	F	W	
Godwit, Bar-tailed																																																																																								
Godwit, Black-tailed																																																																																								
Greenshank, Common																																																																																								
Gull, Silver																																																																																								
Heron, Striated																																											1	F	M																																											
Heron, White-faced	9	F	M	15	F	M	8	F	M	19	F	M	5	F	M	11	F	M	19	F	M	2	F	M							10	F	M	8	F	M	5	F	M	8	F	M				4	F	M	2	F	M				5	F	M	3	F	M							7	F	M	4	F	M	8	F	M	1	F	M							4	F	W	10
Ibis, Australian White							5	F	M	9	F	M	6	F	M				9	F	M	1	F	W							15	F	M	2	F	M	12	F	M	2	F	M				10	F	M							1	F	M	5	F	M							18	F	M	2	F	W	38	F	M	3	F	M							32	F	M	8
Ibis, Straw-necked																																																																																								
Knot, Great																																																																																								
Knot, Red																																																																																								
Lapwing, Masked				4	F	M										3	F	SM										5	F	SM				2	F	M				2	F	SM	3	F	M							4	F	M							2	F	M	2	R	M													2	F	M							
Night Heron, Nankeen																																																																1	F	W																						
Oystercatcher, Pied																																																																																								
Oystercatcher, Sooty																																																																																								
Pelican, Australian																																					1	F	W							1	R	A																																								
Plover, Double-banded																																																																																								

North West Pond	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No
Plover, Grey																																																																																									
Plover, Lesser																																																																																										
Plover, Pacific Golden																												1	F	M																																																						
Plover, Red-capped													2	F	M				1	F	M							1	F	M							1	F	M	1	F	M	2	F	M	1	F	M	2	F	M	1	F	M	2	F	M	10	F	M	1	F	M	5	F	M	2	F	SM	4	F	M	2	F	M	4	F	M	12	F	M	8	F	M	6	F	M	8
Rail, Buff-banded																																																																																									
Sandpiper, Common																																																																																									
Sandpiper, Curlew																																																																																								
Sandpiper, Marsh																																																																																								
Sandpiper, Sharp-tailed																																																																														15	F	M	15	F	M				
Sandpiper, Terek																																																																																								
Shoveller, Australian																																																																																								
Spoonbill, Royal							1	F	W	2	F	W							1	F	W																												1	F	W	1	F	W	1	F	W	3	F	W	1	F	W	3	F	W							1	R	A	2	F	W										
Stilt, Black-winged																									9	F	W	1	F	M																1	F	W							2	F	W	6	F	W	1	F	W				6	F	W																1	F	W	10	F	W				
Stint, Red-necked																																																																																						4	R	M	
Stork, Black-necked																																																																																								
Swan, Black																																																																																								
Tattler, Grey-tailed																																																																																								
Teal, Chestnut							7	F	W				23	F	W				14	F	W	1	F	W	10	F	W	6	F	W							4	R	M	2	R	M				6	F	W	19	F	W	3	F	W	5	R	M	21	F	W							12	F	W							12	R	M	3	F	W							
Teal, Grey				4	F	W																			11	F	W										16	F	W				12	F	W	11	F	W	31	F	W	15	F	W				3	F	W	25	F	W	70	F	W													28	F	W	50	F	W				
Tern, Caspian																																																																																					1	F	W	
Tern, Common																																																																																									
Tern, Crested																																																																																								
Tern, Gull-billed																	2	F	W																																																																						
Tern, Little																																																																																								
Tern, Whiskered																																																																																									
Tern, White-winged Black																																																																																									
Turnstone, Ruddy																																																																																									
Whimbrel																																																																																									
Species richness -	2			7			7			4			7			5			7			4			5			7			4			5			7			6			7			10			7			8			10			12			6			8			8			5			7			6			7			5			7			3
Total abundance -	10			39			25			32			40			19			47			5			43			26			33			14			40			17			26			37			57			39			27			65			58			106			43			14			56			23			62			91			49			26
Swan Pond South	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No
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Teal, Grey										4	F	W	48	F	W	60	F	W	240	F	W	33	F	W	100	F	W	100	F	W	223	F	W	302	F	W	350	F	W	320	F	W	350	R	W	290	F	W	310	F	W	200	F	W	130	F	W	130	F	W	250	F	W	300	F	W	350	R	W	850	R	W				84	R	W	2	F	W	80	F	W				
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Total abundance -	191			177			52			75			707			646			1165			435			170			728			676			830			681			494			574			841			754			262			350			536			317			398			1557			1497			436			500			39			188			0			2

Wader Pond	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No
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Teal, Grey							52	F	W							60	F	W				22	F	W	40	F	W				68	F	W	51	F	W	48	F	W	26	F	W	10	F	W	14	F	W	19	F	W				82	F	W	58	F	W	15	F	W	45	F	W	6	F	W	32	F	W																
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Total abundance -	23			109			86			24			13			100			22			37			98			86			93			72			58			63			21			80			81			3			190			145			22			53			124			106			39			0			4						0			

Appendix B – Area E Wetland Hydrology and Vegetation Monitoring Report (Mahmood Sadat-Noori and William Glamore)

Area E Wetland Hydrology and Vegetation Monitoring Report

Prepared by:

Mahmood Sadat-Noori, William Glamore

Water Research laboratory, UNSW

December 2017

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Introduction

The Newcastle Coal Infrastructure Group (NCIG) shorebirds project focuses on the creation of habitat suitable for migratory wader birds in the lower Hunter River estuary. This primarily relates to the removal of mangroves and expansion of existing saltmarsh communities at the NCIG shorebirds site, referred to as Area E (Figure 1). The Water Research Laboratory (WRL), School of Civil & Environmental Engineering at UNSW Sydney has previously provided advice and recommendations on this project in the report "Shorebirds Compensatory Habitat Area – Hydrological Controls for Ongoing Management". This report provides an update on the on-ground work accomplished in 2017 and plans to be carried out in 2018.

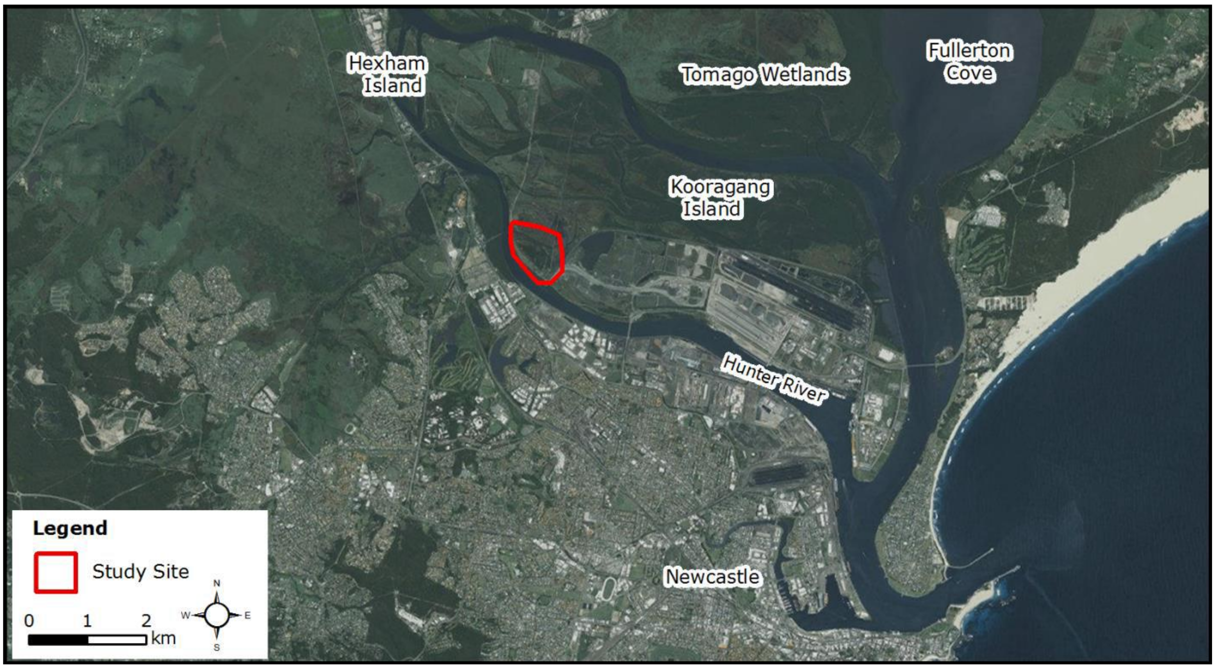


Figure1. The study site

Expert Recruitment

Dr. Mahmood Sadat-Noori was recruited in September 2017 as a Research Associate to lead this project. Mahmood was selected out of a pool of over 50 applicants from Australia and overseas to join the WRL, School of Civil & Environmental Engineering at UNSW. Mahmood is an expert in subsurface hydrology in coastal wetlands and brings over five years' research experience in the field of environmental science and engineering.

Additionally, he possesses a strong skillset in field investigations and on-ground monitoring.

Hydrology Monitoring

Introduction

Tides play an important role in the water balance and functioning of coastal wetlands. Therefore, any change in the tidal regime of a coastal wetland may affect their surface water hydrology, sediment characteristics and subsequently vegetation patterns. As surface and groundwater are closely linked in tidal wetlands, variations in surface water hydrology can also cause groundwater levels to fluctuate. To investigate these potential changes, we have installed monitoring piezometers within the wetland.

Groundwater Level monitoring

Fifteen piezometers have been installed through three transects at the site as shown in Figure 2. Table 1 presents the piezometer coordinates which are also well aligned with the vegetation survey plans (shown later in the report). A hand-held auger was used to dig holes down to the water table (average 0.4 m from ground level) and 2 m PVC pipes with 50 cm long screens attached to the end were installed to allow groundwater to infiltrate into the pipes. The slotted section of the pipe was covered with geo-fibre to prevents soil particles blocking the slots. The installation was done with minimal disturbance to the environment. Data obtained by these piezometers will be used to create groundwater level maps and assess groundwater temporal and spatial variations within the wetland tidal flats. In addition to groundwater depth, these piezometers will be used to sample groundwater quality including dissolved organic and inorganic carbon, nitrate, ammonium, phosphate and trace metals. These will then be compared with concentrations in surface water to assess how groundwater level fluctuation affects surface water quality over diurnal tidal cycles.

Subsurface flow is expected to significantly affect the ecological environment and ecosystem function of Area E wetland. Therefore, the piezometer work and groundwater level monitoring will be tied in with the vegetation sampling to gain insight on the role subsurface hydrology plays in governing the behaviour of salt marshes, in particular, nutrient exchange, plant zonation and carbon cycling.

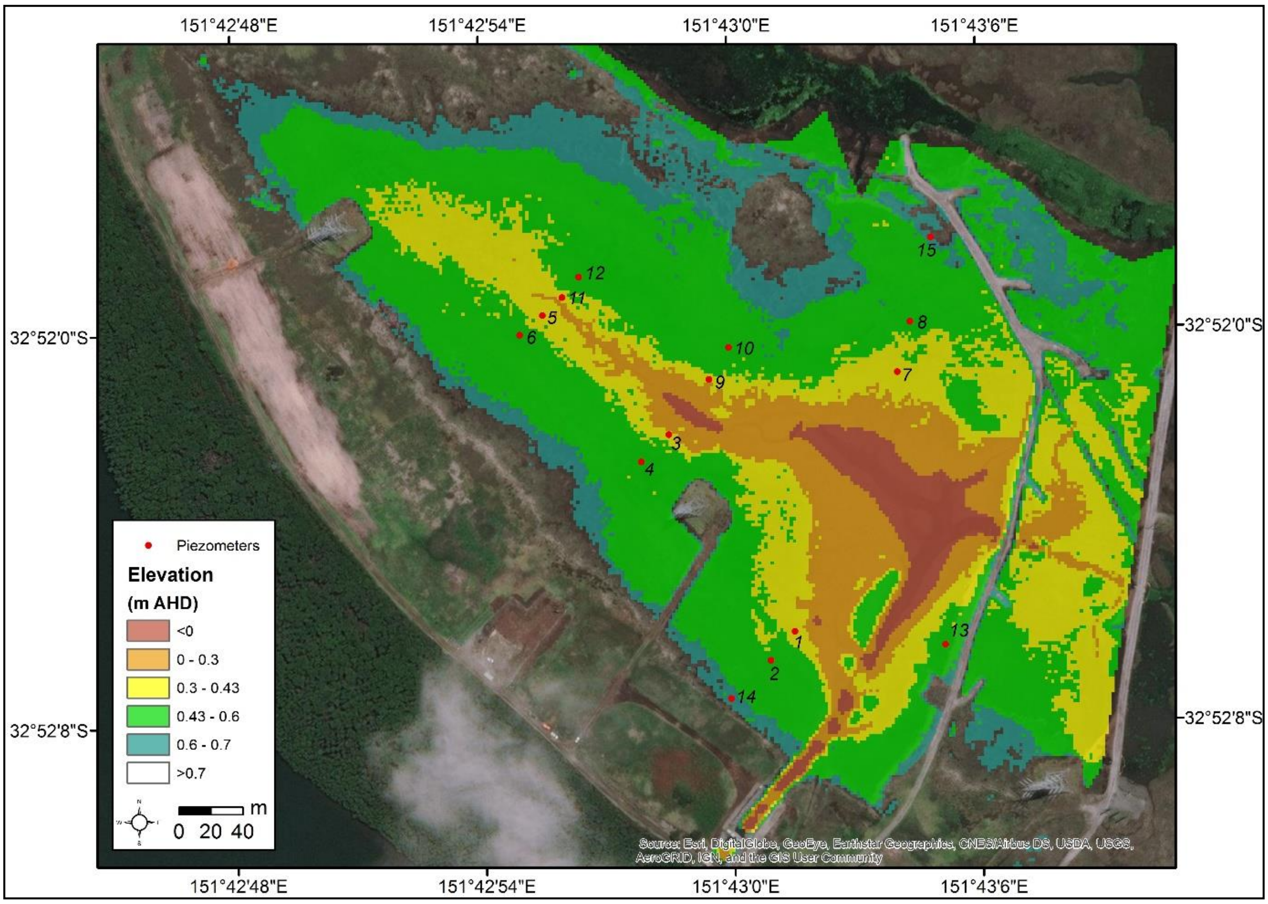


Figure 2. Piezometer location at Area E

Table 1. Piezometer coordinates

Number	Lat	Long
1	-32.8684	151.7171
2	-32.8685	151.717
3	-32.8673	151.7163
4	-32.8674	151.7161
5	-32.8666	151.7155
6	-32.8667	151.7153
7	-32.8669	151.7178
8	-32.8666	151.7179
9	-32.8685	151.7181
10	-32.8665	151.7156
11	-32.8664	151.7157
12	-32.8669	151.7166
13	-32.86845	151.71814
14	-32.86873	151.71668
15	-32.86615	151.71807

To investigate the spatial and temporal variations of salinity and water level oscillation due to diurnal, spring/neap tidal cycles and hydrological events six (6) Conductivity/Temperature/Depth (CTD) water loggers were installed in piezometers 1, 2, 7, 8, 14, and 15. The remaining piezometers have been equipped with water level sondes which records a measurement every fifteen minutes (Figure 3). The placement and design of the piezometers will provide insights into the movement and direction of groundwater flow towards the wetland (Fish Fry Flats) and out of the wetland towards Hunter River. These piezometers will be used for long term groundwater level monitoring which will then allow us to assess how groundwater interacts with surface waters and influences its quantity and quality.

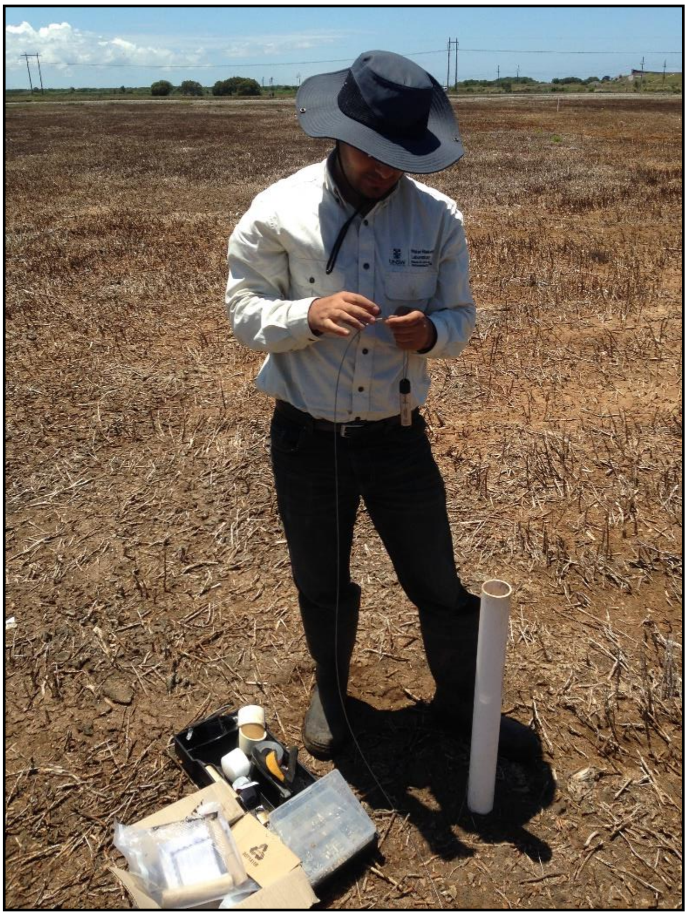


Figure 3. A water level logger being installed in a piezometer at Fish Fry Flats

Groundwater – surface water interactions

To gain insight on the groundwater-surface water connectivity in the wetland, we plan to qualitatively and quantitively assess the role of groundwater seepage into the wetland (Fish fry creek and flats) and its potential effects on the surface water quality of Fish Fry creek. This will be done using a combination of natural groundwater tracer technique, surface water time series measurements and groundwater and surface water quality testing.

Initial investigations carried out recently at Fish Fry creek showed considerable amount of groundwater (detected by radon, natural groundwater tracer) discharging into the Creek. Data collection started at low tide (9:00 am) and finish at tight tide time (3:00 pm). Figure 4 illustrates the equipment set up during the sampling campaign (28/11/17). Figure 5 shows water level, salinity, pH and radon concentrations during this time.

Figure 4. Equipment set up during a sampling campaign on 28/11/17.

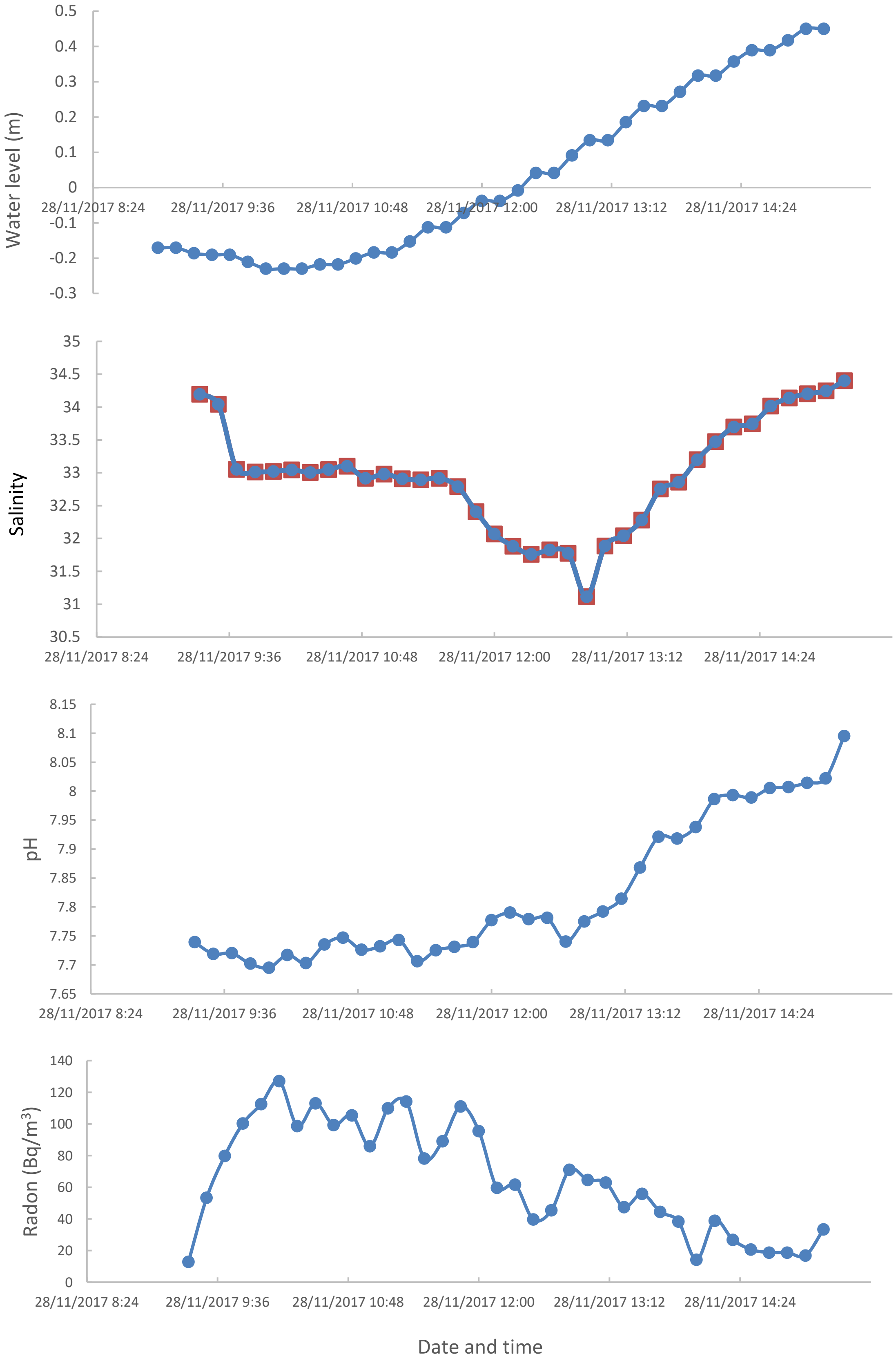


Figure 5. Six-hour time series data of water level, salinity, pH and radon (natural groundwater tracer) at Fish Fry Creek

An inverse relationship between surface water levels and radon tracer concentration was observed with radon being 6-fold higher at low tide compare to high tide. This indicates groundwater discharging into Fish Fry Creek at low tide and thus increasing radon activities (Figure 5). Additionally, lower salinity levels were observed during low tide and higher at high tide. This variation in salinity (although narrow) may indicate a source of fresh water to creek surface waters during low tide. Further investigations need to be carried out to confirm and identify this source. pH was recorded 7.65 at ebb tide an increased to 8.01 at flood tide. This pH variation was further examined by investigating the relationship between radon and pH during our 6 hour-time series measurement. A significant correlation (R^2 = 0.76) was found between radon and pH, indicating low pH groundwater is discharging into the Creek during low tide periods and changing surface water pH considerably (Figure 6). Longer and more specific observations and sampling will be conducted in 2018 to confirm these findings. Additionally, we plan to perform surface water timeseries measurements and collect surface water and groundwater grab samples under contrasting hydrological conditions to investigate how tidally restricting a coastal wetland will influence its surface and groundwater connectivity compared to natural conditions (i.e. gates remaining open for a short period of time).

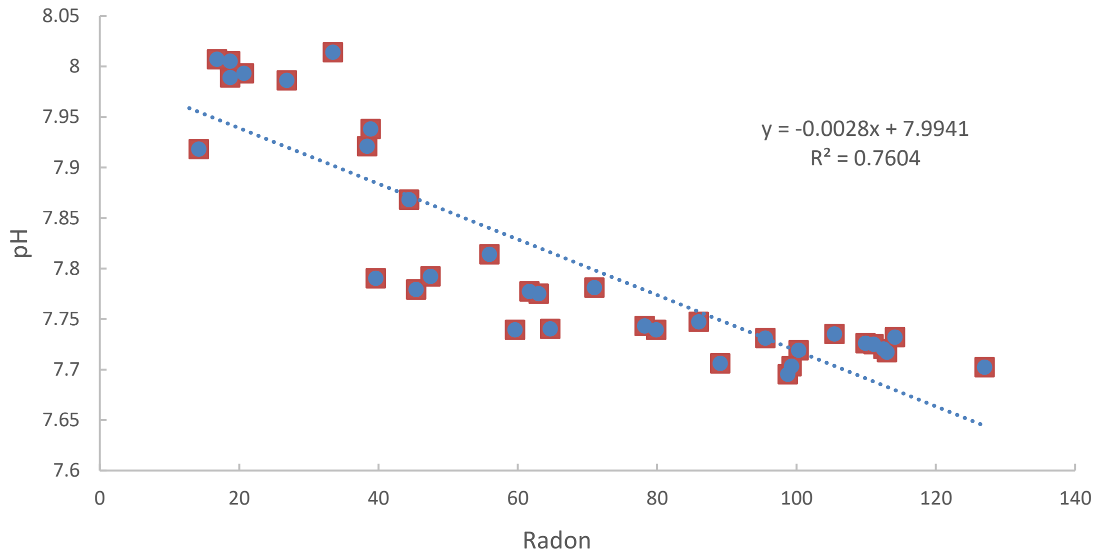


Figure 6. Radon (groundwater tracer) correlation with surface water pH at Fish Fry Creek

Vegetation Survey

In November 2017, a field investigation was undertaken to collect base line data on vegetation cover and diversity within the Area E site. During this investigation, more than 100 points were surveyed. Desktop analysis on the data collected are currently in progress. We plan to carry out additional filed campaigns in 2018 for ongoing monitoring of vegetation and infauna. Parameters measured that will be measured are:

1. Vegetation cover and diversity
    - Random fixed 1 x1 m quadrates
    - Separate high and low marsh transects
    - Some quadrates next to piezometers
    - Drone footage
2. Epifauna
    - Crab burrows counted in vegetation quadrates
    - Pit traps
3. Bird usage
    - Volunteer bird surveys
4. Fish usage
    - Ultrasound for fish entering and leaving the marsh
    - Nets for quantitative analysis of transient and resident fish
5. Sediment analysis
    - Cores taken from below marsh, low marsh, and high marsh
    - Particle size
    - Organic matter percentage and composition

Data from the measured parameters at Area E wetland will be correlated with drone Multispectral camera footage, and ground water maps from piezometer data.

Vegetation survey method selection

Stalker (2011) found there is no standard sampling method for saltmarsh vegetation in Australia or overseas and the quadrat size used varies from 0.25m^2 to 16 m^2. Stalker compared three different sampling methods (random 1 x 1 m quadrats, random 4 x 4 m quadrats and Outhired nested quadrats) in the Brisbane water estuary and found that:

- 4 x 4 m quadrats were most efficient in detecting differences in species richness between locations;
- 1 x 1 m quadrats were *generally* most efficient in detecting differences in species, percent cover and frequency between locations, but was dependent on the species;
- On average, six 1 x 1 m quadrats can be completed in about 20 minutes, whilst six 4 x 4 m quadrats take 40 minutes. Completing six Outhired quadrats takes 55 minutes.
- 54 quadrats produce acceptable error bars for species cover and frequency for the dominant saltmarsh species analysed, irrespective of whether a 1 x 1 m or a 4 x 4 m quadrat is used. However, power analysis for *Sarcocornia quinqueflora* suggests that 100 number of quadrats would only have an acceptable level of power to detect a large effect size (>0.4). Power analysis for the cover of *Sporobolus virginicus* in 1 x 1 m quadrats suggests 350 quadrats are needed to detect a small/medium effect size (0.2).
- It is often the case that fewer quadrats may be needed for the same level of power for frequency compared to cover. However, this is species dependent and frequency has the further problem of being dependent on quadrats size and therefore studies using different sized quadrats cannot be compared easily.
- Frequency of *Sarcocornia quinqueflora* in 4 x 4 m quadrats was 100%, making this sampling strategy unsuitable for this species. However, frequency in 4 x 4 m quadrats was the strategy that required the least number of quadrats (i.e. 60) for an acceptable level of power for *Sporobolus virginicus*.

Quadrat size, numbers and measure of abundance

1 x 1 m quadrats will be used to survey vegetation at Area E wetland as these quadrats have the advantage of being easier to place because of their rigid nature and can be stringed to improve accuracy of cover estimates. Our strategy is to estimate cover of all species in a 1 x 1 m quadrat and then embed this smaller quadrat in a 4 x 4 m quadrat in which only presence/absence is recorded. However, given time constraints, cover in 1 x 1 m quadrats is probably more feasible. Between 50 and 100 quadrats will be placed and surveyed. This number is also consistent with that "saltmarsh recovery study" by Laegdsgaard (2002), which used four randomly placed permanent belt transects (5 m wide) - from mangroves to

terrestrial vegetation – with six quadrats (25 cm × 25 cm) randomly placed at three “levels”: low marsh directly behind the mangrove fringe, middle marsh and high marsh (transition to terrestrial vegetation).

Quadrat Placement

Traditionally, a saltmarsh gradient would be studied using a stratified random approach as used by Laegdsgaard (2006). However, Area E is not a natural saltmarsh and does not have one neat zonation from low, middle to high marsh and further the eastern portion of it is bisected by an access road. As the waterbody is not linear, but rather T-shaped, the placement of transects perpendicular to the gradient will only work well in the western two thirds of the study area. Therefore, we will use five or six randomly placed permanently pegged transects with five quadrats (1 m ×1 m) randomly placed at three “levels”: low marsh (where mangroves removed), middle marsh and the high marsh/terrestrial vegetation. The quadrats will be temporarily pegged until a differential GPS has been used to determine its exact location. Based on air photo, some transects will be placed on a northern orientation, whilst will have a north-easterly orientation. The transects will vary in length as will the width of each zone (i.e. “level”). As the transects are only being used to place the quadrats, trampling is expected to be minimized. This sampling strategy will be replicated at any of the other Kooragang/Tomago areas. Quadrats will be placed adjacent to the installed piezometers so that groundwater levels can be used as direct complementary data rather than using modelled groundwater data (Figure 5).

Figure 5. Quadrats transect sampling locations

Drone Survey

On November 2017, an eBee RTK survey grade aerial drone was flown over the site and the data is being processed using a Pix4D advanced photogrammetry software to develop a digital elevation map (DEM). A total of 6 (six) ground control points were distributed around the site to increase the accuracy of the drone survey. Using the same software, a high resolution, georectified ortho-mosiac was also produced. Below is an aerial image of the Fish Fry Creek and Flats obtained from the drone flight (Figure 6). Data from the drone survey will be used to monitor vegetation cover and diversity within the wetland and examine saltmarsh recruitment compared with the results from the previous drone imagery.

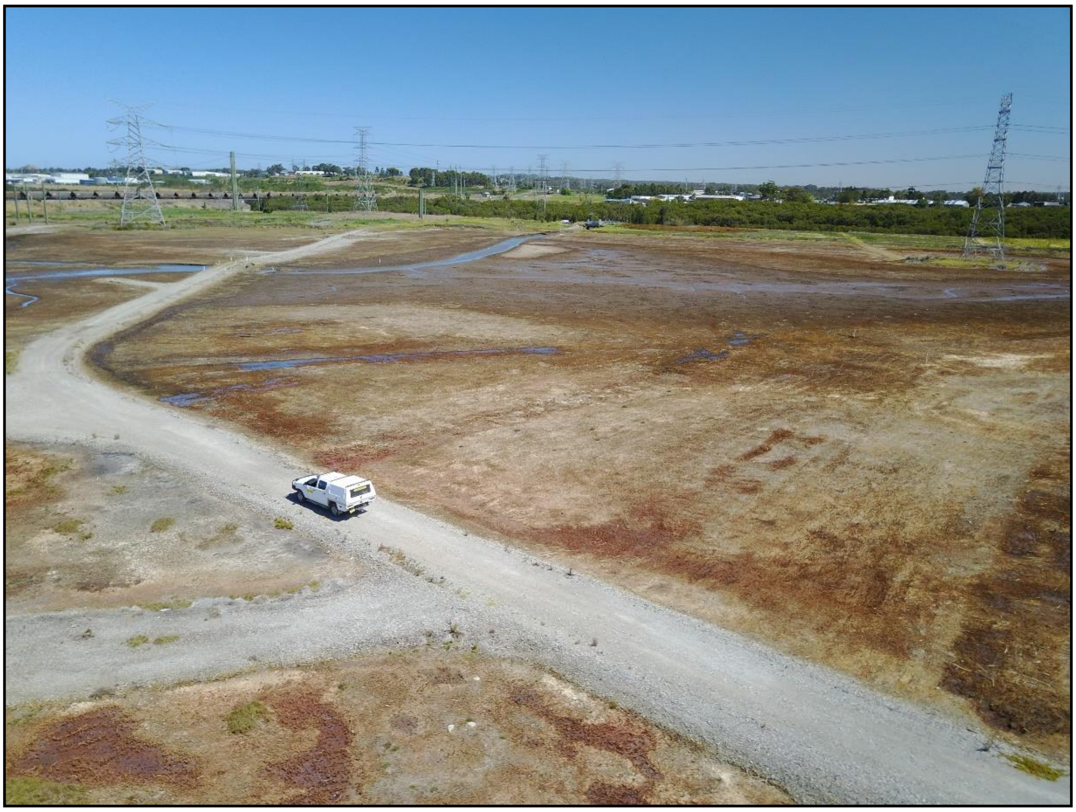


Figure 6. Aerial image of Fish Fry Flats (November 2017)

Objectives for 2018

Based on our accomplished on-ground surveys and data collection in 2017, we highlight the following objectives to be carried out in 2018. We plan to determine the:

(1) effect of restricted tidal exchange on the surface and groundwater connectivity of the wetland

(2) long-term groundwater level fluctuations using piezometers

(3) effect of water table oscillation on the physical and chemical characteristic of the wetland sediment and

(4) influence of tidal restriction on vegetation (saltmarsh) recruitment over spatial and temporal patterns.

Summary

Preliminary results indicate that groundwater significantly influences the hydrology of the wetland. To investigate this in more detail, we propose to carry out additional groundwater tracer time series measurements to quantify groundwater discharge into Fish Fry Creek.

This will be used to estimate the percentage of groundwater contributing to the surface water body of the wetland. Additionally, long term monitoring will be carried out to compare these results with direct water inputs from precipitation. We also propose to investigate how the installed tidal control gates will change the groundwater - surface water interactions at the site. To address this, we plan to carry out data collection field campaigns under two contrasting scenarios: 1) open gates – wetland under natural hydrology conditions and 2) closed gates – wetland under tidally restricted surface water condition. Additionally, long-term groundwater level monitoring using the installed piezometers will complement our tracer study and provide us with a greater understanding of the groundwater - surface water dynamics with in the wetland. These changes in the hydrology may affect vegetation growth in the area. We therefore, plan to carry out spatial and temporal vegetation surveys and identify any links between groundwater level fluctuations in Area E with saltmarsh development and growth.

References

Laegdsgaard, Pia, 2006. Ecology, disturbance and restoration of coastal saltmarsh in Australia: a review, Wetlands Ecology and Management14, 5, 379.

Laegdsgaard, Pia, 2002. Recovery of small denuded patches of the dominant NSW coastal saltmarsh species (Sporobolus virginicus and Sarcocornia quinqueflora) and implications for restoration using donor sites. Ecological Management and Restoration, DOI: 10.1046/j.1442-8903.2002.00113.x.

Appendix C – Area E Shorebird Monitoring Report 2017 (Greg Little)

Introduction

This report documents the 2017 results of regular monthly bird surveys of ponds at Area E on Kooragang Island. In particular this survey monitors changes in shorebird use of the Fish Fry Flat area (**Fig-1**) after clearing of mangroves from that area was completed in December 2016.

No migratory shorebird species were recorded in Fish Fry Flat during baseline studies in 2015 (Rainsford, 2016) when much of Fish Fry Flat was covered with mangroves. Some waterbirds such as Teal, Cormorants and Egrets were present. Surveys during and after clearing of mangroves from Fish Fry Flat in 2016 recorded a small number of migratory shorebirds (O'Brien, 2017).

Prior to the mid 1990's Fish Fry Flat supported mainly saltmarsh and mudflat areas favourable to shorebird usage (NCIG, 2015). Restoring tidal flushing of Fish Fry Flats at that time encouraged the growth and expansion of mangroves.

Mangroves were completely cleared by NCIG from the Fish Fry Flat area (the activity area) to provide compensatory saltmarsh, mudflat and shallow water habitat for shorebirds in response to expansion by NCIG along the east edge of Area E (O'Brien, 2017).

Shorebird species richness and total abundance was recorded during each survey session over the activity area and reference sites within Area E (**Fig-1**). These are Fish Fry Flat (activity area) and adjacent reference sites including North West Pond, Swan Pond South, Swan Pond North and Wader Pond.

The Guiding document for this survey of Area E is the "Provisional MERI plan for Migratory Shorebird Habitat Establishment" (Rainsford, 2016). Part 2 of the MERI plan suggests a number of Key Evaluation Questions. These questions apply to shorebird usage of the activity area after mangrove removal plus habitat usage by threatened White-fronted Chats in area E. These are addressed in this report.

Some shorebird species affected by the project are protected under State (Biodiversity Conservation Act 2016) and Federal (Environmental Protection and Biodiversity Conservation Act 1999) legislation and various international migratory bird agreements including CAMBA, JAMBA and ROKAMBA.

Shorebirds as discussed in the MERI plan for Area E includes a variety of bird groups that may variously be described as wetland birds, waterbirds, waterfowl, shorebirds etc. A number of shorebirds recorded in Area E are "migratory" shorebirds. These are shorebird species most of which leave each year about March to breed in Northern Hemisphere locations such as Siberia and Alaska. They return about September each year to Southern Hemisphere locations such as the Hunter Estuary. These migratory shorebirds do not breed in Australia. For these species the requirements for suitable and adequate forage and refuge habitat, such as saltmarsh, mudflats, shallow water and safe high tide roosts, is extremely important. Please note that Double-banded Plovers breed in New Zealand, some migrate to south-east Australia for the winter and return to New Zealand about September. White-fronted Chats are a small day active, insectivorous passerine that inhabit low wetlands particularly salt marsh, as a local population, in the lower Hunter estuary.

Methods

Shorebird usage of Fish Fry Flats, North West Pond, Swan Pond South, Swan Pond North and Wader Pond (**Fig-1**) was monitored according to Part 6 of the MERI plan. Specifically Part 6.1 Shorebird Usage was adopted regarding timing (Table 9) and minimum data requirements (Table 10). Timing of each shorebird monitoring session was according to Table 9 of the MERI plan. This included during the on peak period between September and March survey on the high and low tide during each of two days per month plus two night surveys per month. During the off peak period between April and August survey was reduced to a single day and no nights.

Binoculars and spotting scopes were used as necessary at each location to identify and count each species of shorebird. At night a 100 Watt spotlight was used to observe the shorebirds. Enough time was allowed to carefully and thoroughly investigate the water surface, water edge, mudflats and salt marsh for bird presence and activity. Observations were recorded on field sheets. All shorebird monitoring was conducted from the existing gravel tracks.

- NW Pond - shorebird monitoring from an access track off Southbank Road.
- Fish Fry Flats - shorebird monitoring from along Southbank Road and along a gravel service track on the east and north edges of Fish Fry Flats.
- Swan Pond South - shorebird monitoring from along Wagtail Way.
- Swan Pond North - shorebird monitoring from along Wagtail Way.
- Wader Pond - shorebird monitoring from along Wagtail Way.

Night survey provided difficulties with identification and observation of activity. When the spotlight was shone over the ponds invariably many birds immediately flushed those remaining were very alert and moved about.

Figure – 1 Survey sites within Area E. Fish Fry Flat is the activity area from which mangroves were removed. The North West Pond, Wader Pond, Swan Pond North and Swan Pond South are reference sites.

Results

Raw Excel spreadsheet data derived from this 2017 shorebird survey is supplied to, and available from, NCIG. A large amount of data was collected, therefore, for the purposes of this report the results are here presented as summaries, tables and graphs.

All Shorebirds

39 shorebird species were recorded from all sites in Area E, as presented in **Appendix-A**. **Figs-2 & 3** below are taken from **Graphs 1 & 3** in **Appendix C**.

Results of this survey suggest that all shorebird species richness declined slightly for the reference sites (**App-C**). This may be due to the slow drying out of the reference ponds through the year. At Fish Fry Flat the "all shorebird" species richness can be seen to increase through 2017 for Day High Tide surveys (**Fig-2**). While the reference sites were drying out during 2017 Fish Fry Flat retained regular tidal flows. This may have influenced the increase in species richness for Fish Fry Flat. Similar species richness results are observed (**App-C**) for the Day Low Tide.

Total abundance of all shorebird species at Fish Fry Flat appeared to remain level through 2017 except for a spike in the May survey (**Fig-3**) caused by a high number of Teal at that time. Similar abundance results are observed (**App-C**) for the Day Low Tide. Total abundance of all shorebirds appeared to be declining at the reference sites except at Swan Pond North where the total abundance increased through the year (**App-C**). By the end of December the abundance of all shorebirds declined dramatically, even at Swan Pond North, probably because the ponds had almost completely dried out.

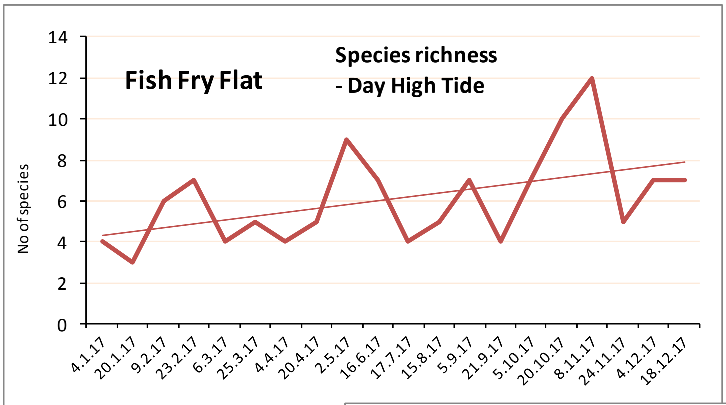


Figure – 2
Fish Fry Flat had a trend of increasing species richness of all shorebird species through the year.

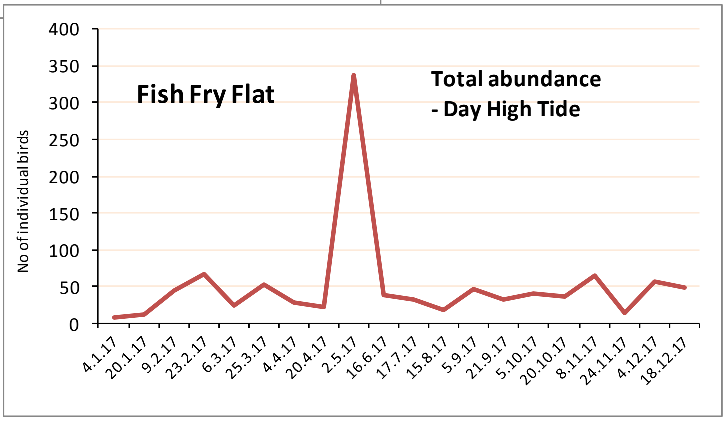


Figure – 3
Total abundance of all shorebird species remained stable through the year, except for the spike (of Teal) in May.

Migratory Shorebirds

Nine (9) migratory shorebird species were recorded at all sites in Area E during the 2017 survey. **Table-1** below presents a summary of counts and locations of migratory shorebird species. Unfortunately the results for migratory shorebirds were too few for useful graphical presentation. Of note, Fish Fry Flat did record several (6) species of migratory shorebirds, an equivalent number to Swan Pond North (6).

Table - 1 Migratory shorebird species recorded at each survey location

table shows - No of survey visits that a species was present (Ave abundance)

	North West Pond	Fish Fry Flat	Swan Pond South	Swan Pond North	Wader Pond
Eastern Curlew		7 (1.7)			1 (1)
Bar-tailed Godwit	1 (45)			1 (6)	
Common Greenshank		1 (4)	1 (1)	2 (2.5)	1 (1)
Red Knot				2 (3)	
Double-banded Plover		1 (3)			
Pacific Golden Plover		4 (2)			1 (5)
Curlew Sandpiper				2 (2.5)	1 (1)
Sharp-tailed Sandpiper		5 (12)	3 (6.3)	10 (15.6)	7 (3.3)
Red-necked Stint		1 (4)		1 (3)	

While six (6) migratory shorebird species were recorded using Fish Fry Flat at various times during 2017 they were not all recorded at the same time. However, it is apparent that clearing of the heavy cover of mangroves from Fish Fry Flat has provided habitat for these migratory shorebirds.

The following observations are made of records of migratory shorebirds at Fish Fry Flat.

- Small numbers of Eastern Curlews were recorded from January to April only during day surveys, on both high and low tides.
- A small number of Common Greenshanks were recorded once on the low tide at night in April.
- Three Double-banded Plovers were recorded during the day low tide in May. The only migratory shorebirds recorded at Fish Fry Flat during the winter months (May, June, July and August) were Double-banded Plovers that migrate from New Zealand to south-east Australia during winter.
- Small numbers of Pacific Golden Plovers were recorded only at night on both the low and high tide.
- Sharp-tailed Sandpipers were recorded, up to 15 birds, only at night on both the high and low tides, either early in the year (Feb & Mar) or later in the year (Dec). Sharp-tailed Sandpipers were more often recorded during night survey in the latter part of the year at Fish Fry Flat than at Swan Pond North. This may be because Swan Pond North was drying out through the late 2017 summer period and Fish Fry Flat retains a tidal affected creek.
- A small number of Red-necked Stints were recorded apparently roosting during the day high tide.

White-fronted Chats

White-fronted Chats were recorded only at Swan Pond North and the Wader Pond during this 2017 Area E survey. They were recorded, in pairs or small groups, flying over or foraging in and around the Saltmarsh vegetation.

Interestingly, the White-fronted Chats were recorded at these Area E sites only between March and September. These records are outside of the general breeding season for this species.

Table - 2 White-fronted Chat sightings, showing date, location and number of individuals.

	Jan	Feb	6.3.17	25.3.17	4.4.17	May	16.6.17	17.7.17	Aug	21.9.17	Oct	Nov	Dec
Swan Pond North					2		4						
Wader Pond			2	2			8	3		2			

Discussion

For migratory shorebirds, from either the Northern Hemisphere or New Zealand, the Hunter Estuary, including Area E and Fish Fry Flat, is used only as forage and refuge habitat. Each species will disperse themselves on low tide into their various favoured foraging habitats including exposed mudflats, shallow water etc. However, all these migratory shorebird species require safe high tide roosts, during day or night. High tide roosts often support an aggregation of mixed species of migratory and other shorebirds. No aggregation of shorebirds were observed using Fish Fry Flat as a high tide roost. There was observed in the shallow waters of Swan Pond North, during both day and night surveys, dense single species congregations of obviously roosting shorebirds such as Red-necked Avocets and Black-winged Stilts.

Part 2 of the MERI plan recommends a number of Key Evaluation Questions which are further subdivided into “specific questions” in Table-1 of Part 3 of the MERI plan. The first of these questions applies specifically to shorebird usage of Area E after mangrove removal from the activity area (Fish Fry Flat). The second question applies to habitat usage by White-fronted Chats. These are addressed below.

Key Evaluation Questions

1. To what extent did mangrove removal affect shorebird usage of the Activity Area, reference sites and Hunter Estuary?

Specific questions

Did shorebird abundance change?
Through the year all shorebird abundance was apparently stable at Fish Fry Flat (the Activity Area) and increased at Swan Pond North. However, all shorebird abundance declined dramatically at the reference sites by December 2017 because of drying conditions, the ponds had almost completely dried out.

Did shorebird species diversity change?
Species diversity/richness of all shorebirds increased through the year at Fish Fry Flat. Mangrove removal from Fish Fry Flat appears to have allowed use of this area by an increased diversity of all shorebird species. All shorebird species diversity appears to have declined through the year at the reference sites, probably due again to drying out of reference site ponds. Compared to data from 2015 surveys there was an increase in migratory species diversity at Fish Fry Flat. During the 2015 survey no migratory shorebirds were recorded at Fish Fry Flat whereas during this 2017 survey six (6) migratory shorebird species were recorded in this area.

Did shorebird behavior change?
Most observations of shorebirds at Fish Fry Flat were of birds foraging. Occasionally some birds such as Cormorants or Ibis were obviously resting or roosting. However, there was no obvious large, mixed species, roosting aggregation of migratory shorebirds. Fish Fry Flat does not appear to support high tide roost habitat for migratory shorebirds. During 2017 migratory shorebirds were observed to continue normal use of high tide roosts elsewhere in the Hunter Estuary.

2. Was the extent of any existing habitat used by threatened species/EEC's affected by the activity?

Specific questions

Was there any change to habitat used by the White-fronted Chat?
Small numbers of White-fronted Chats were recorded at Swan Pond North and the Wader Pond in Area E during this 2017 survey. The habitat in these areas and elsewhere in Area E does not appear to have changed as a consequence of mangrove removal from the activity area (Fish Fry Flat).

Conclusion

During 2015 most of Fish Fry Flat supported a dense cover of mangroves. Surveys of this area at that time recorded relatively small numbers of waterbirds such as Teals, Cormorants and Egrets (Rainsford, 2016). No migratory shorebird species were recorded in Fish Fry Flat during these baseline studies in 2015.

Thirty nine (39) shorebird species including nine (9) migratory shorebird species were recorded from all sites in Area E during this 2017 survey. Total abundance of all shorebirds was stable at Fish Fry Flat during 2017 and declined at reference sites by the end of the year probably due to drying out of these ponds. Six (6) migratory shorebird species were recorded at Fish Fry Flat at various times during 2017. No mixed species aggregation of roosting migratory shorebirds was recorded at Fish Fry Flat during the survey period.

The action of mangrove removal from Fish Fry Flat (the activity area) appears to have provided additional forage habitat for shorebirds. It is apparent that clearing of mangroves from Fish Fry Flat has provided forage habitat for some migratory shorebird species known to visit the Hunter Estuary but has not provided high tide roost habitat for migratory shorebirds.

Much of Fish Fry Flat is daily affected by tides. Fish Fry Creek from the south and Wader Creek from the west enter the Fish Fry Flat. During high tide much of the area is inundated with salt water and during low tide fresh mud flats are exposed. During very high tides salt water extends further out into the mud flats currently supporting stumps and old pneumatophores of the cleared mangroves. In contrast the reference site ponds have a different flooding regime, being less affected by regular tidal inundation and apparently more dependent on rainfall to maintain constant water levels. Fish Fry Flat may not in the future provide a high tide roost habitat for migratory shorebirds but with continued appropriate management will provide forage habitat with a different tidal regime in Area E for shorebirds including migratory shorebirds.

Clearing of mangroves from Fish Fry Flat does not appear to have affected the presence of White-fronted Chats in Area E. Additional habitat for this species may develop as Saltmarsh returns to the Fish Fry Flat area.

References

F. Rainsford, (2016), Provisional Monitoring, Evaluation, Reporting and Improvement (MERI) Plan for the Migratory Shorebird Habitat Establishment; Migratory Shorebird Habitat Establishment, Ash Island, NSW, by Kleinfelder, unpublished document prepared for Newcastle Coal Infrastructure Group.

D. O’Brien, (2017), Shorebird Monitoring: Final Report, Migratory Shorebird Habitat Establishment, Ash Island, NSW, by Kleinfelder, unpublished document prepared for Newcastle Coal Infrastructure Group.

NCIG, (2015), Compensatory Habitat and Ecological Monitoring Program, Newcastle Coal Infrastructure Group (NCIG) Coal Export Terminal.

APPENDIX - A

All species recorded during 2017 Area E survey

Common Name	Scientific Name	NSW BC Act Status	Comm EPBC Act Status	North West Pond	Fish Fry Flat	Swan Pond South	Swan Pond North	Wader Pond
Red-necked Avocet	*Recurvirostra novaehollandiae*		Mar	Y	Y	Y	Y	Y
Great Cormorant	*Phalacrocorax carbo*				Y			
Little Black Cormorant	*Phalacrocorax sulcirostris*				Y			
Little Pied Cormorant	*Microcarbo melanoleucos*				Y	Y	Y	Y
Eastern Curlew	*Numenius madagascariensis*		CE,C,J,K		Y			Y
Black-fronted Dotterel	*Elseyornis melanops*				Y	Y	Y	Y
Red-kneed Dotterel	*Erythrogonys cinctus*				Y	Y		Y
Pacific Black Duck	*Anas superciliosa*			Y			Y	
Eastern Great Egret	*Ardea modesta*		Mar,C,J,	Y	Y	Y	Y	Y
Intermediate Egret	*Ardea intermedia*				Y			
Little Egret	*Egretta garzetta*				Y	Y	Y	Y
Bar-tailed Godwit	*Limosa lapponica*		V,C,J,K	Y			Y	
Common Greenshank	*Tringa nebularia*		Mig,C,J,K		Y	Y	Y	Y
Silver Gull	*Chroicocephalus novaehollandiae*				Y	Y	Y	Y
Striated Heron	*Butorides striatus*				Y			
White-faced Heron	*Egretta novaehollandiae*			Y	Y	Y	Y	Y
Australian White Ibis	*Threskiornis molucca*			Y	Y	Y	Y	Y
Straw-necked Ibis	*Threskiornis spinicollis*							Y
Red Knot	*Calidris canutus*		E,C,J,K				Y	
Masked Lapwing	*Vanellus miles*			Y	Y	Y	Y	Y
Nankeen Night Heron	*Nycticorax caledonicus*				Y	Y		
Australian Pelican	*Pelecanus conspicillatus*				Y	Y	Y	Y
Double-banded Plover	*Charadrius bicinctus*		Mig		Y			
Pacific Golden Plover	*Pluvialis fulva*		Mig,K		Y			Y
Red-capped Plover	*Charadrius ruficapillus*		Mar	Y	Y	Y	Y	Y
Buff-banded Rail	*Gallirallus philippensis*							Y
Curlew Sandpiper	*Calidris ferruginea*	E1	CE,C,J,K				Y	Y

Common Name	**Scientific Name**	**NSW BC Act Status**	**Comm EPBC Act Status**	**North West Pond**	**Fish Fry Flat**	**Swan Pond South**	**Swan Pond North**	**Wader Pond**
Sharp-tailed Sandpiper	*Calidris acuminata*		Mig,C,J,K		Y	Y	Y	Y
Australasian Shoveler	*Anas rhynchotis*						Y	Y
Royal Spoonbill	*Platalea regia*			Y	Y	Y	Y	Y
Black-winged Stilt	*Himantopus himantopus*		Mar	Y	Y	Y	Y	Y
Red-necked Stint	*Calidris ruficollis*		Mig,C,J,K		Y		Y	
Black-necked Stork	*Ephippiorhynchus asiaticus*	E1		Y				
Black Swan	*Cygnus atratus*				Y	Y	Y	Y
Chestnut Teal	*Anas castanea*			Y	Y	Y	Y	Y
Grey Teal	*Anas gracilis*			Y	Y	Y	Y	Y
Caspian Tern	*Hydroprogne caspia*		C		Y		Y	
Gull-billed Tern	*Gelochelidon nilotica*				Y	Y	Y	Y
Whiskered Tern	*Chlidonias hybrida*						Y	
White-fronted Chat	*Epthianura albifrons*	V					Y	Y
Totals -	40			13	30	21	28	27

Y = Yes, recorded at that location
V = Vulnerable under the BC Act
E1 = Endangered under the BC Act
Mig = listed only as a Migratory species under EPBC Act
Mar = listed only as a Marine species under the EPBC Act
C = CAMBA
J = JAMBA
K = ROKAMBA

Migratory shorebirds, species and abundance

	4.1.17	14.1.17	20.1.17	6.2.17	9.2.17	9.2.17	23.2.17	23.2.17	5.3.17	6.3.17	25.3.17	25.3.17	25.3.17	4.4.17	4.4.17	6.4.17	12.4.17	2.5.17	June	July	August	14.9.17	21.9.17	21.9.17	5.10.17	5.10.17	5.10.17	20.10.17	8.11.17	8.11.17	9.12.17	17.12.17	18.12.17
	Day	Night	Day	Night	Day	Day	Day	Day	Night	Day	Day	Day	Night	Day	Day	Night	Night	Day				Night	Day	Day	Day	Day	Night	Day	Day	Day	Night	Night	Day
	Low	High	High	Low	High	Low	High	Low	Low	High	High	Low	High	Low	High	Low	High	Low				Low	High	Low	High	Low	High	High	Low	High	Low	High	High
North West Pond																																	
Bar-tailed Godwit				45																													
Fish Fry Flat																																	
Eastern Curlew					2		2	3		2	1	1		1																			
Common Greenshank																4																	
Double-banded Plover																		3															
Pacific Golden Plover		1							4				2									1											
Sharp-tailed Sandpiper									8							13	9														15	15	
Stint, Red-necked																																	4
Swan Pond South																																	
Common Greenshank														1																			
Sharp-tailed Sandpiper																6						1		12									
Swan Pond North																																	
Bar-tailed Godwit																								6									
Common Greenshank						4				1																							
Red Knot																													3	3			
Curlew Sandpiper																													1	4			
Sharp-tailed Sandpiper			20												5								8	60	3	25	12	7	1	15			
Stint, Red-necked																														3			
Wader Pond																																	
Eastern Curlew						1																											
Common Greenshank	1																																
Pacific Golden Plover																													5				
Curlew Sandpiper																													1				
Sharp-tailed Sandpiper											6				2		1	1				4							6	3			

APPENDIX - C

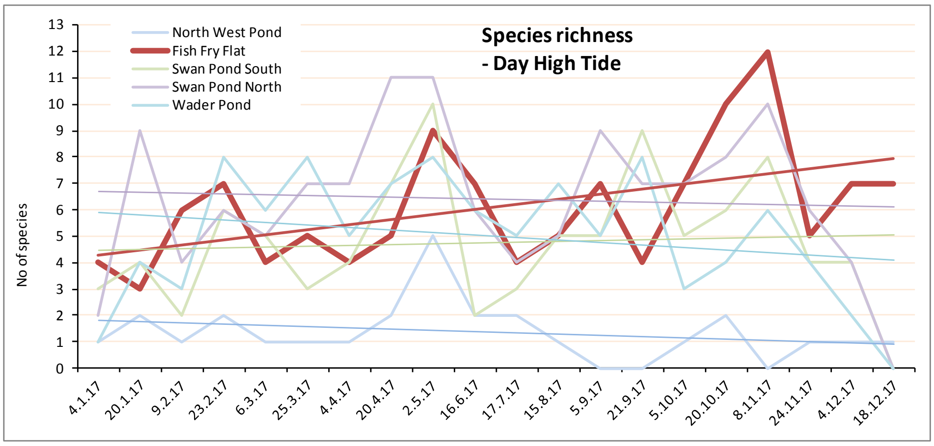
Migratory shorebirds, species and abundance - arranged by Day, Night & Tide

Date	20.1.17	9.2.17	23.2.17	6.3.17	25.3.17	4.4.17	21.9.17	5.10.17	20.10.17	8.11.17	18.12.17	4.1.17	9.2.17	23.2.17	25.3.17	4.4.17	2.5.17	21.9.17	5.10.17	8.11.17	14.1.17	25.3.17	12.4.17	5.10.17	17.12.17	6.2.17	5.3.17	6.4.17	14.9.17	9.12.17
Day/night	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day	Night	Night	Night	Night	Night	Night	Night	Night	Night	Night
Tide	High	High	High	High	High	High	High	High	High	High	High	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	High	High	High	High	Low	Low	Low	Low	Low
North West Pond																														
Bar-tailed Godwit																										45				
Fish Fry Flat																														
Eastern Curlew		2	2	2	1									3	1	1														
Common Greenshank																												4		
Double-banded Plover																	3													
Pacific Golden Plover																					1	2					4		1	
Sharp-tailed Sandpiper																							9		15		8	13		15
Stint, Red-necked											4																			
Swan Pond South																														
Common Greenshank																1														
Sharp-tailed Sandpiper																		12										6	1	
Swan Pond North																														
Bar-tailed Godwit																		6												
Common Greenshank				1									4																	
Red Knot										3										3										
Curlew Sandpiper										4										1										
Sharp-tailed Sandpiper	20					5	8	3	7	15								60	25	1				12						
Stint, Red-necked										3																				
Wader Pond																														
Eastern Curlew													1																	
Common Greenshank												1																		
Pacific Golden Plover																				5										
Curlew Sandpiper																				1										
Sharp-tailed Sandpiper					6	2				3							1			6			1						4	

APPENDIX – D Graphs

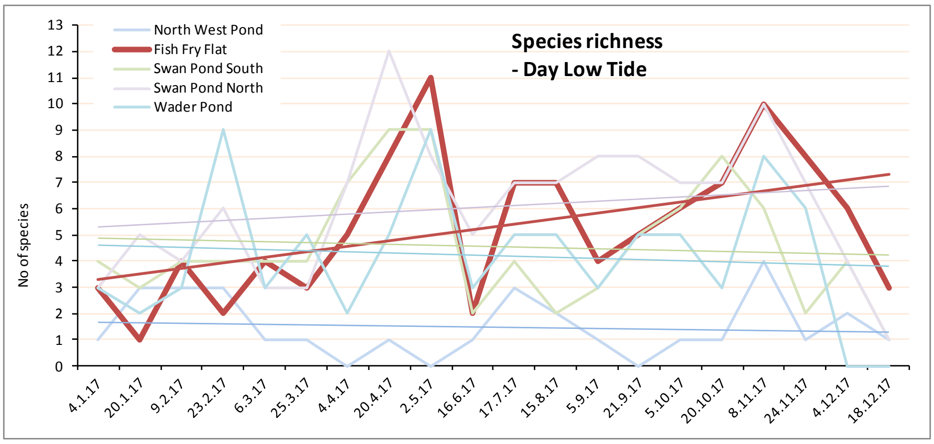
Graph – 1

All shorebird species richness at all sites in Area E during day high tide. Note the trend at Fish Fry Flat compared to other sites.



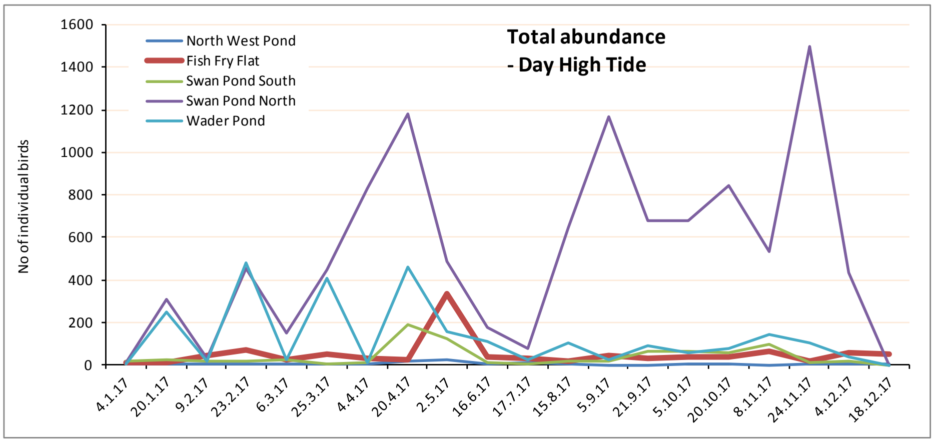
Graph – 2

All shorebird species richness at all sites in Area E during day low tide. Note the trend at Fish Fry Flat compared to other sites.



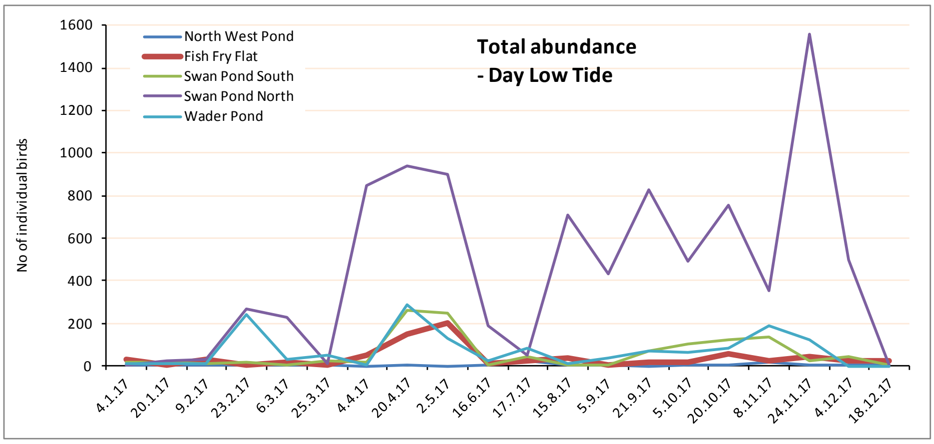
Graph – 3

All shorebird total abundance at all sites in Area E during day high tide.



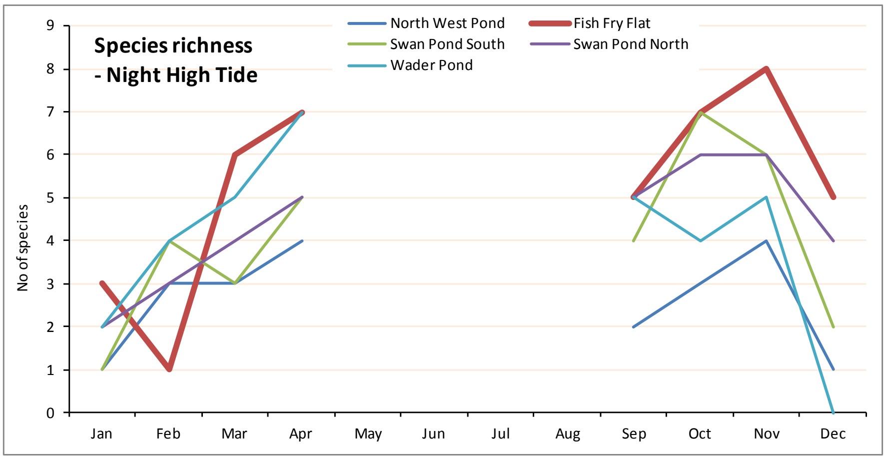
Graph – 4

All shorebird total abundance at all sites in Area E during day low tide.



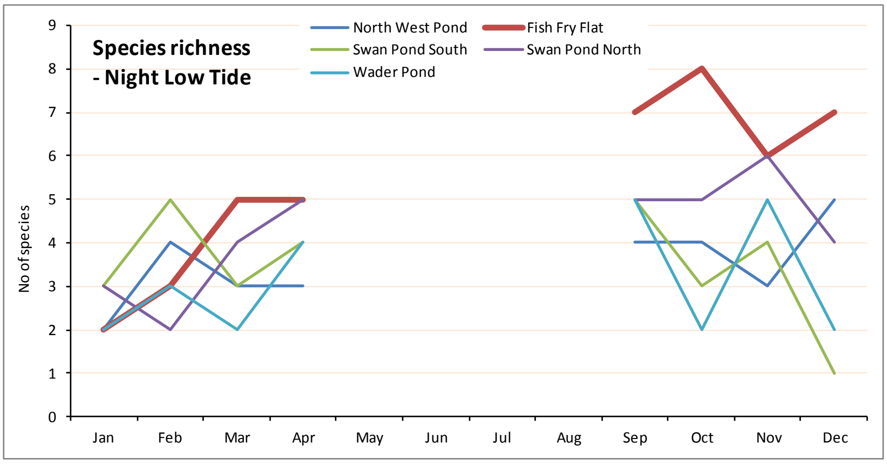
Graph – 5

All shorebird species richness at all sites in Area E during night high tide.



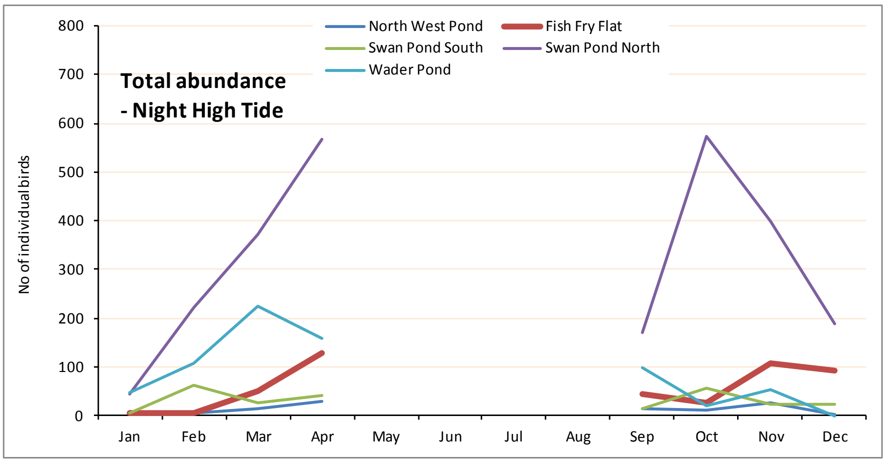
Graph – 6

All shorebird species richness at all sites in Area E during night low tide.



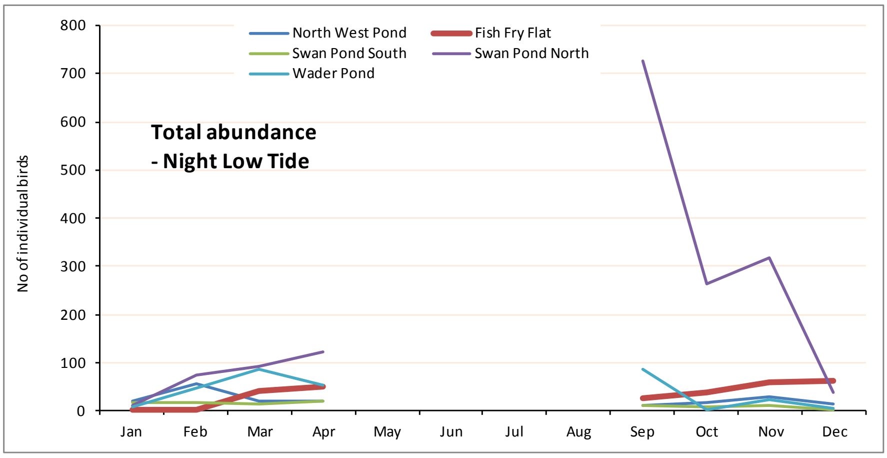
Graph – 7

All shorebird total abundance at all sites in Area E during night high tide.



Graph – 8

All shorebird total abundance at all sites in Area E during night low tide.



Appendix D – NCIG Compensatory Habitat Management Six Monthly Works Overview (Conservation Volunteers Australia)

NCIG Compensatory Habitat Management

6 Monthly Works Overview – June - December 2017

Weed Control

- Spraying of Alligator Weed and others (Lantana, Blackberry), was undertaken in the north-western portion of Licence Area 10 (as indicated in Appendix A). The majority of spraying was undertaken with backpacks, and the 250L Rapid Spray was used to treat Alligator Weed in the Macrophyte Trench, using Metsulfuron Methyl mix under off-label permit PER14734.
- After 3 seasons of treatment (2015-2017), Alligator Weed infestations remain an issue throughout Licence Area 10 and will require ongoing work to keep under control. Alligator Weed infestations within the Macrophyte Trench and KWRP are no longer expanding and the current spray regime is keeping these under control. A new infestation was observed in the far eastern end of LA 10 adjacent to Pond 5, which will require spraying in early 2018.
- Slashing the interior and exterior of the frog fence in Stage 1 was undertaken to ensure vegetation growth did not exceed 300 mm 1m from the fence line.
- CVA Community Engagement teams also undertook manual weed removal within pond buffers, targeting annual weeds and invasive grasses.
- Site reports detailing works conducted are contained in Appendix C.

Trial Pond Planting

- A planting project was undertaken within the NCIG GGBF Trial Pond site in late November 2017, to create native vegetation linkages between the ponds, and improve habitat value for GGBF.
- In preparation for planting dense grasses were slashed to ground level using a brush cutter. A GGBF pre-clearing survey was undertaken by the CVA Senior Ecologist prior to any slashing commencing. No GGBF were observed or heard during the survey.
- Planting was undertaken over 7 days by CVA Community Engagement teams, consisting of local and international volunteers.
- 1,680 native shrubs and groundcovers were installed, including Terracottem (water crystals/fertiliser), tree guards and watering in.
- Follow up watering was undertaken throughout December by Paul Davidson Landcare and Pest Control.

Mangrove Removal

- Mangrove removal was undertaken within NCIG Shorebird Compensatory Habitat (Area E) throughout October to December.
- Prior to removal mangrove distribution and density was mapped throughout the site, to inform the level of effort required for removal. Density mapping can be seen in Appendix B.
- Works were undertaken by CVA Community Engagement Teams over 8 days, removing and collecting over 15,000 mangrove seedlings, reshoots, and progagules.
- In addition to removal, all mangrove biomass was collected, sorted and counted, this information can be seen in the table below.

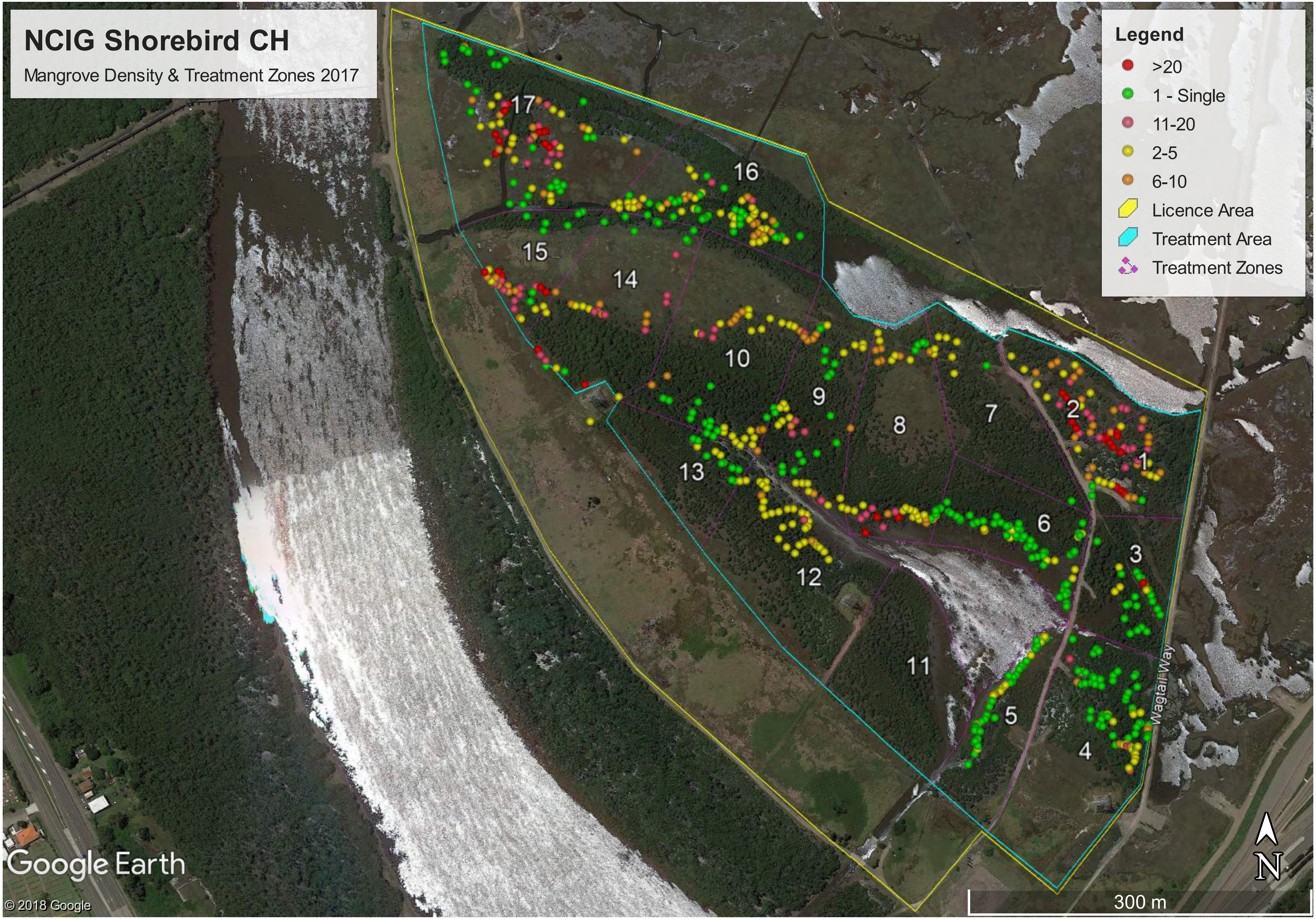
NCIG Mangrove Removal Data 2017

Zone	Seedlings	Propagules	Regrowth	Total
1	3238		122	3360
2	1468		199	1667
3	119		5	124
4	985		10	995
5	46	290	1	337
6	114			114
7	136		20	156
8	802		35	837
9	501		111	612
10	910		89	999
11	236			236
12	1397		25	1422
13	476		24	500
14	499		13	512
15	988	134	125	1247
16	341		9	350
17	1497	2	276	1775
Total	**13753**	**426**	**1064**	**15243**

Photos

Trial Pond Native Corridors Planting

APPENDIX A - WEED CONTROL AREAS


NCIG Shorebird CH
Mangrove Density & Treatment Zones 2017
Legend
● >20
● 1 - Single
● 11-20
● 2-5
● 6-10
Licence Area
Treatment Area
Treatment Zones
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Wagtail Way
N
300 m
Google Earth
© 2018 Google

Compensatory Habitat and Ecological Monitoring Program – Half-yearly Report (January-June 2018)

AUTHOR		AUTHORISED BY	
Name	Hayley Ardagh, Phil Reid (NCIG), Dean Lenga, John Cluelow, Caleb Rankin (UoN), Mahmood Sadat-Noori, Will Glamore (UNSW), Conservation Volunteers Australia (CVA).	**Name**	**Nathan Juchau**

INTRODUCTION

This report provides an update of activities relating to the NCIG Compensatory Habitat and Ecological Monitoring Program since the previous Report from December 2017. The report aims to provide information on key components of the program and how these are being implemented. Update reports will be provided to the Consultative Board every 6 month, which will coincide with Consultative Board meetings. This report provides information for the first half of 2018 (January-June 2018)

1. Kooragang Island Green and Golden Bell Frog Population Monitoring

1.1. Research Program on the Green and Golden Bell Frog (*Litoria aurea*) on Kooragang Island (Amphibian Research Group, UoN)

Once again, work recommenced by the University of Newcastle over the summer period to monitor and characterise the Green and Golden Bell Frog population on Kooragang Island, in and around the industrial areas of the island. This work is being co-funded by NCIG, Port Waratah Coal Service (PWCS) and Hunter Development Corporation (HDC). The draft report is expected to be released in the coming months and will be included in the next reporting period.

2. NCIG Green and Golden Bell Frog Compensatory Habitat

2.1. Compensatory Habitat Monitoring

The Green and Golden Bell Frog Research and Monitoring Program on Ash Island was again undertaken by the University of Newcastle (Conservation Biology Group), during January and March 2018. During this period, GGBF were found in 27 of the 42 ponds in the constructed habitats.

A total of 91 GGBF were recorded in the constructed wetlands between the months of January and March 2018. Age and sex classes of GGBF recorded were:

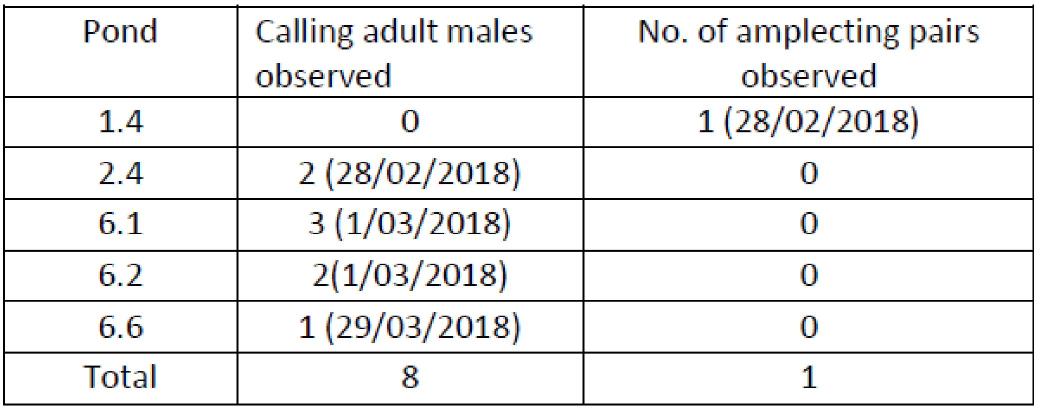
- 55 adult male
- 29 adult female
- 5 juvenile females
- 2 unsexed juveniles

Ponds 1.3, 4.9, 7.2, and 7.3, recorded the largest numbers of GGBF sightings, each with 7 or more observations. These four ponds were all ephemeral and Gambusia free at the time of surveys due to complete drying prior to the rain.

Eight instances of breeding behaviour were noted, including 7 recordings of males calling and 1 observation of amplexus. There was no confirmed evidence of breeding during the survey period, based on the absence of

GGBF tadpoles or metamorphs in the constructed habitats during the survey period.

Table 1. Records of male GGBF calling and observations of GGBF in amplexus in the NCIG compensatory (January - March 2018).

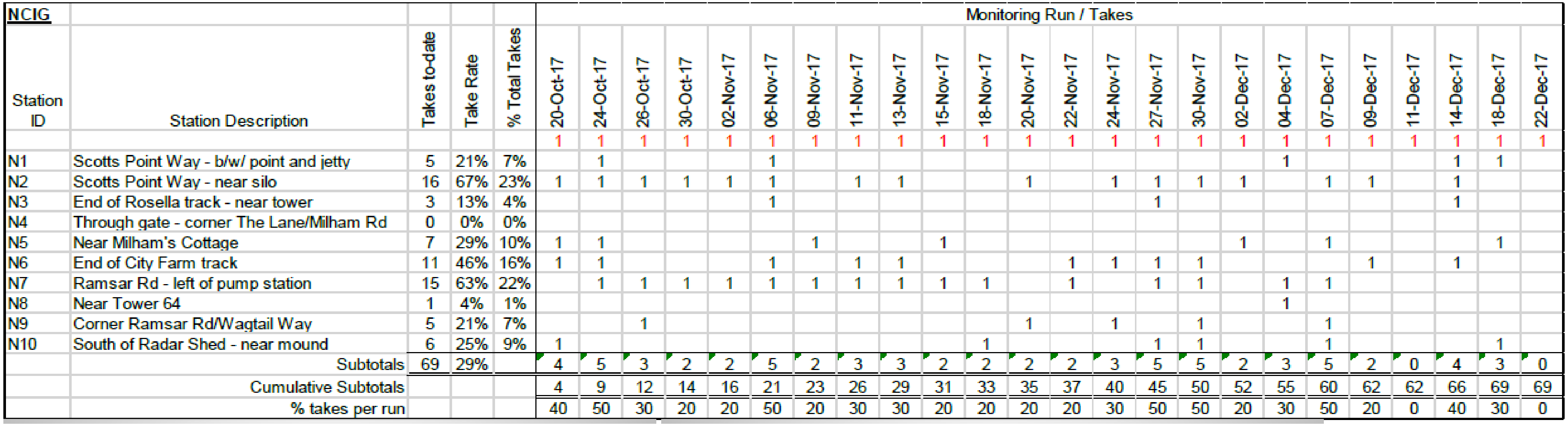


Pond	Calling adult males observed	No. of amplecting pairs observed
1.4	0	1 (28/02/2018)
2.4	2 (28/02/2018)	0
6.1	3 (1/03/2018)	0
6.2	2(1/03/2018)	0
6.6	1 (29/03/2018)	0
Total	8	1

2.2. Compensatory Habitat Management

2.2.1. Fox Control

The Fox Baiting program was undertaken between October and December 2017, across 10 sand pad stations using 1080 ground baits. The program has been very successful to date, with baits taken consistently each run. During the baiting period, a total of 69 baits were taken at a strike rate of 63% per bait laid, and an average take rate per run of 29% across all stations.



NCIG					Monitoring Run / Takes																						
Station ID	Station Description	Takes to-date	Take Rate	% Total Takes	20-Oct-17	24-Oct-17	26-Oct-17	30-Oct-17	02-Nov-17	06-Nov-17	09-Nov-17	11-Nov-17	13-Nov-17	15-Nov-17	18-Nov-17	20-Nov-17	22-Nov-17	24-Nov-17	27-Nov-17	30-Nov-17	02-Dec-17	04-Dec-17	07-Dec-17	09-Dec-17	11-Dec-17	14-Dec-17	18-Dec-17	22-Dec-17
					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
N1	Scotts Point Way - b/w/ point and jetty	5	21%	7%		1				1												1				1	1	
N2	Scotts Point Way - near silo	16	67%	23%	1	1	1	1	1	1		1	1			1		1	1	1	1		1	1		1		
N3	End of Rosella track - near tower	3	13%	4%						1									1							1		
N4	Through gate - corner The Lane/Milham Rd	0	0%	0%																								
N5	Near Milham's Cottage	7	29%	10%	1	1					1			1							1		1				1	
N6	End of City Farm track	11	46%	16%	1	1				1		1	1				1	1	1	1				1		1		
N7	Ramsar Rd - left of pump station	15	63%	22%		1	1	1	1	1	1	1	1	1	1		1		1	1		1	1					
N8	Near Tower 64	1	4%	1%																		1						
N9	Corner Ramsar Rd/Wagtail Way	5	21%	7%			1									1		1		1			1					
N10	South of Radar Shed - near mound	6	25%	9%	1										1				1	1			1				1	
	Subtotals	69	29%		4	5	3	2	2	5	2	3	3	2	2	2	2	3	5	5	2	3	5	2	0	4	3	0
	Cumulative Subtotals				4	9	12	14	16	21	23	26	29	31	33	35	37	40	45	50	52	55	60	62	62	66	69	69
	% takes per run				40	50	30	20	20	50	20	30	30	20	20	20	20	30	50	50	20	30	50	20	0	40	30	0

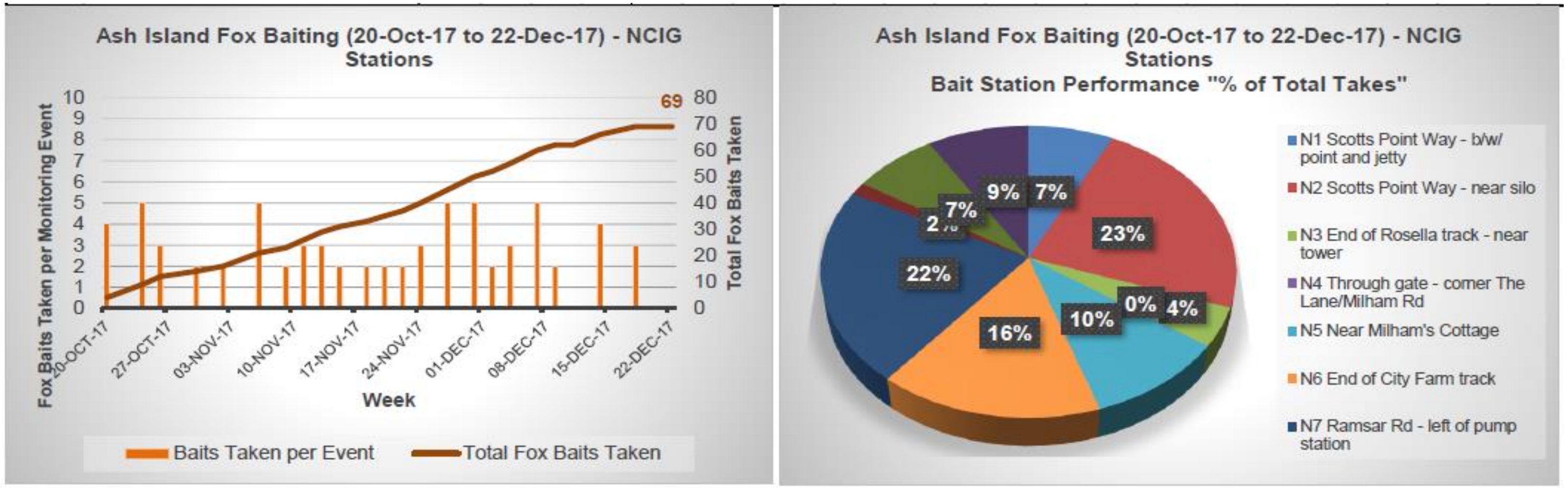


Figure 1 and 2: Ash Island Fox Baiting Performance (20 Oct- 22 Dec 17)

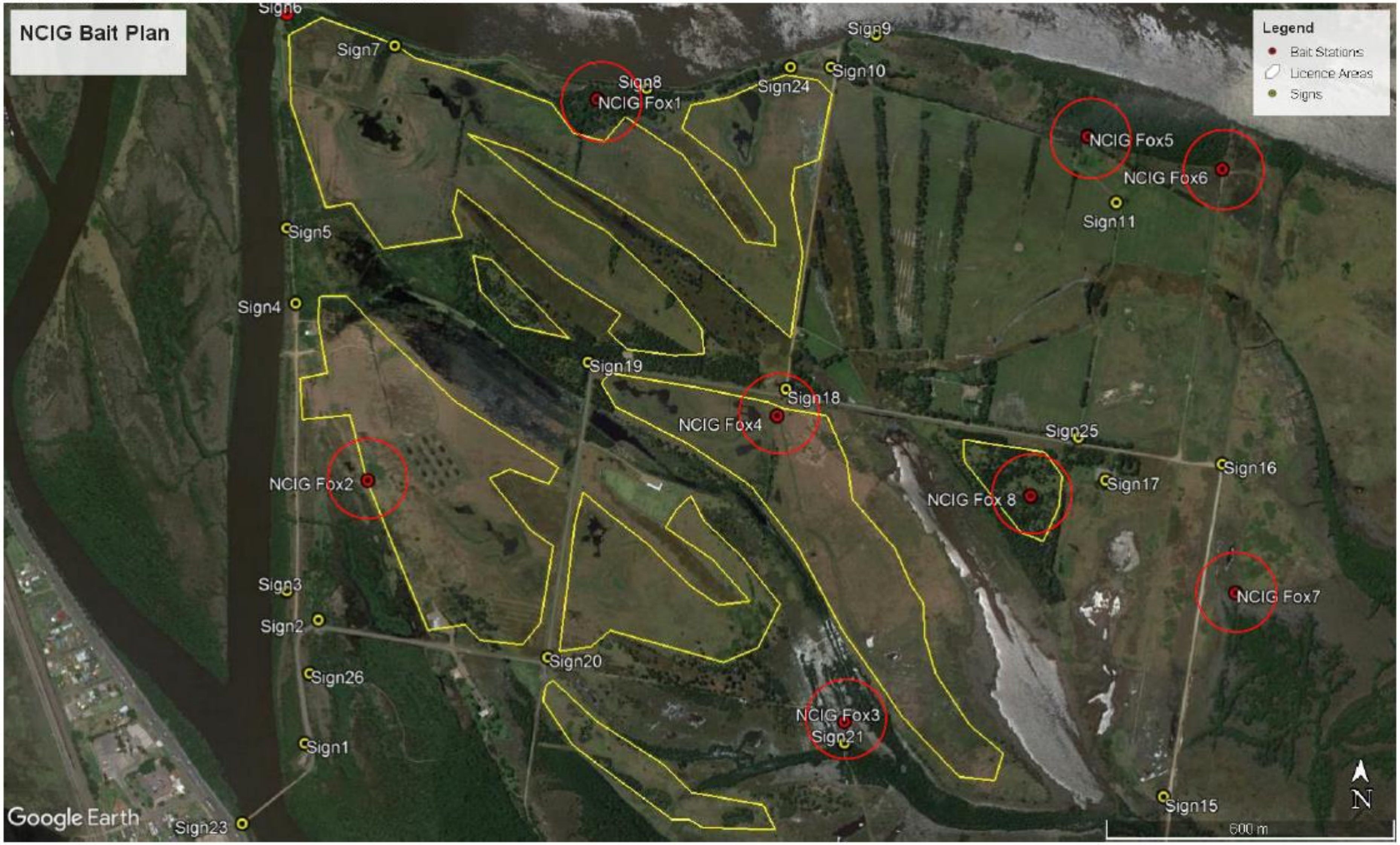


Figure 3: GGBF Compensatory Habitat Fox Baiting Locations

Figure 4: Shorebird Compensatory Habitat Fox Baiting Locations

2.2.2. Fence Repairs and Bunding - Stage 1

The deliberately lit fire in February burnt the vegetation in Stage 1, 2 and 3, and destroyed the Frog Fence in Stage 1. In consultation with UoN, it was decided that the Frog Fence would be repaired as it is likely to be used in the future for release of excess GGBF spawn and further monitoring of population dynamics. The fence repair works began in June and are almost complete.

Prior to the Frog Fence repairs, bunding was able to be undertaken in Stage 1. The bunding works were completed in June, however, a couple of areas have slumped during heavy rain. This will be rectified once the ponds in Stage 1 dry and water levels drop. This bunding will help prevent water bodies connecting during periods of high rainfall, reducing the spread of *Gambusia.*

Figure 5: Damage to Frog Fence at Stage 1 After the Fire

Figure 6: Stage 2 After the Fire

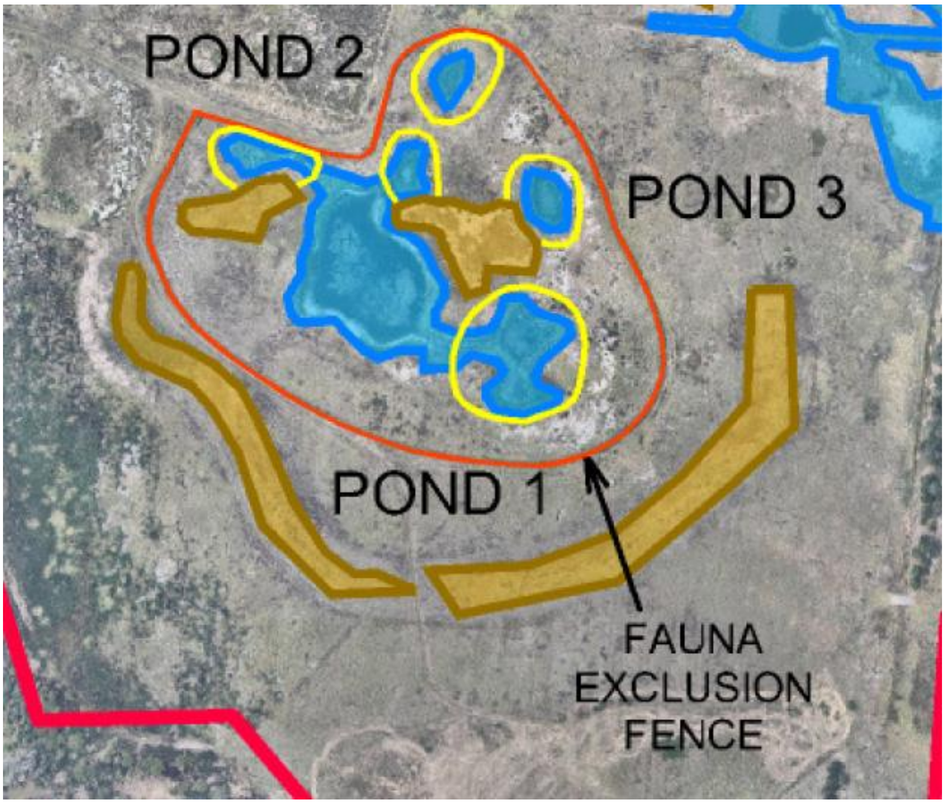


Figure 7: New Bunding Locations in Stage 1

Figure 8: New Bunding in Stage 1

2.2.3. Trial Ponds

As mentioned in the previous CHEMP Half-yearly Report, CVA planted approximately 1900 plants around the NCIG Trial Ponds in December 2017. With the help of Paul Davidson and Bernie Rafferty regularly watering the plants over summer, majority of the plants have made it through the hot and dry summer period.

2.2.4. Weed Control

Weed control spraying was undertaken by CVA throughout the GGBF Compensatory Habitat during this reporting period. Priority weeds were targeted including Blackberry, *Juncus acutus*, Bitou Bush and Lantana. The majority of dense infestations of these weeds are now under control and maintenance will be required to control regrowth. Targeted spraying of Alligator Weed was also undertaken, predominantly throughout the eastern extent of the Licence Area. The infestation of Alligator Weed has increased since the recent fire as the ground vegetation was burnt off. CVA has recommended that Alligator Weed control is undertaken at a greater frequency to ensure the extent of infestation is reduced. Slashing of the vegetation on the interior and exterior of the Frog Fence in stage 1 was also undertaken to ensure vegetation growth does not exceed 300mm, 1m from the fence line.

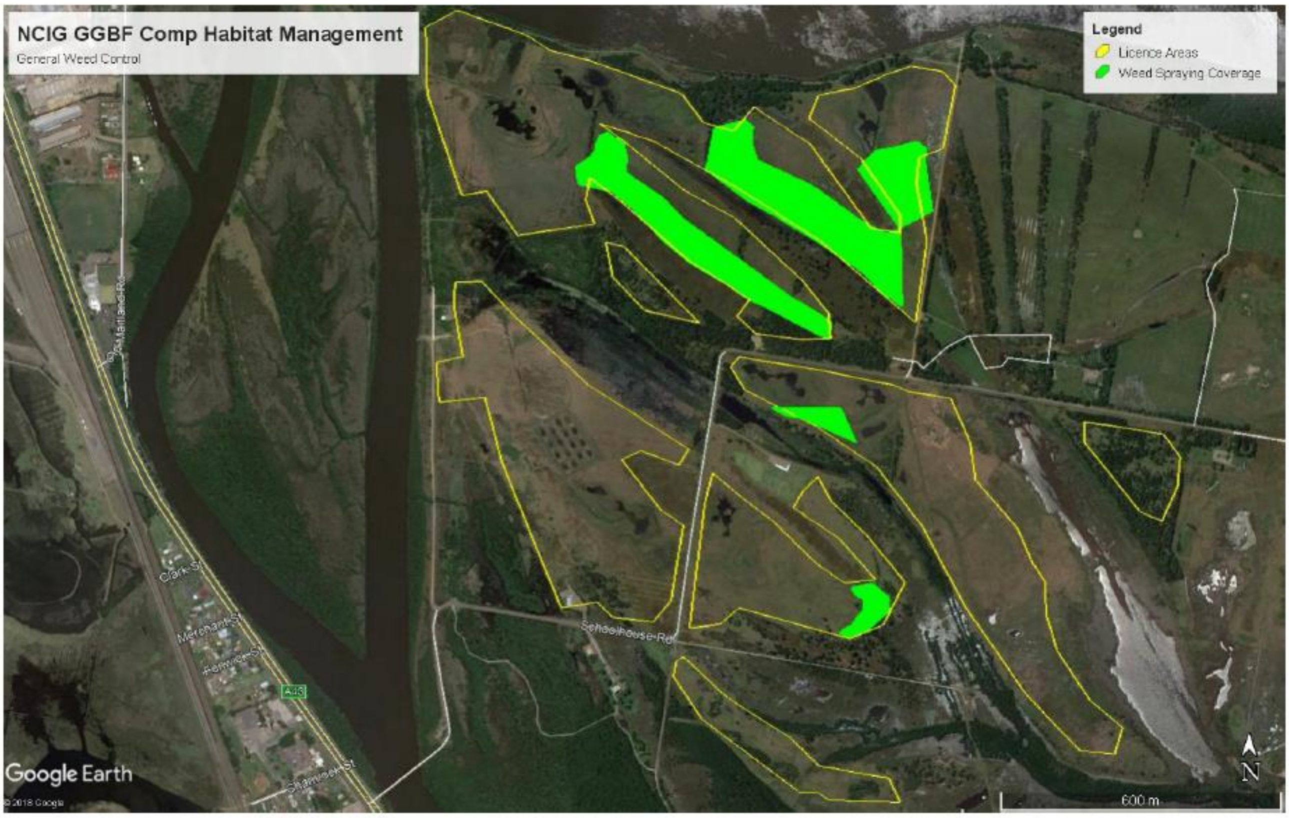


Figure 9: Weed Spraying Undertaken by CVA in GGBF Compensatory Habitat

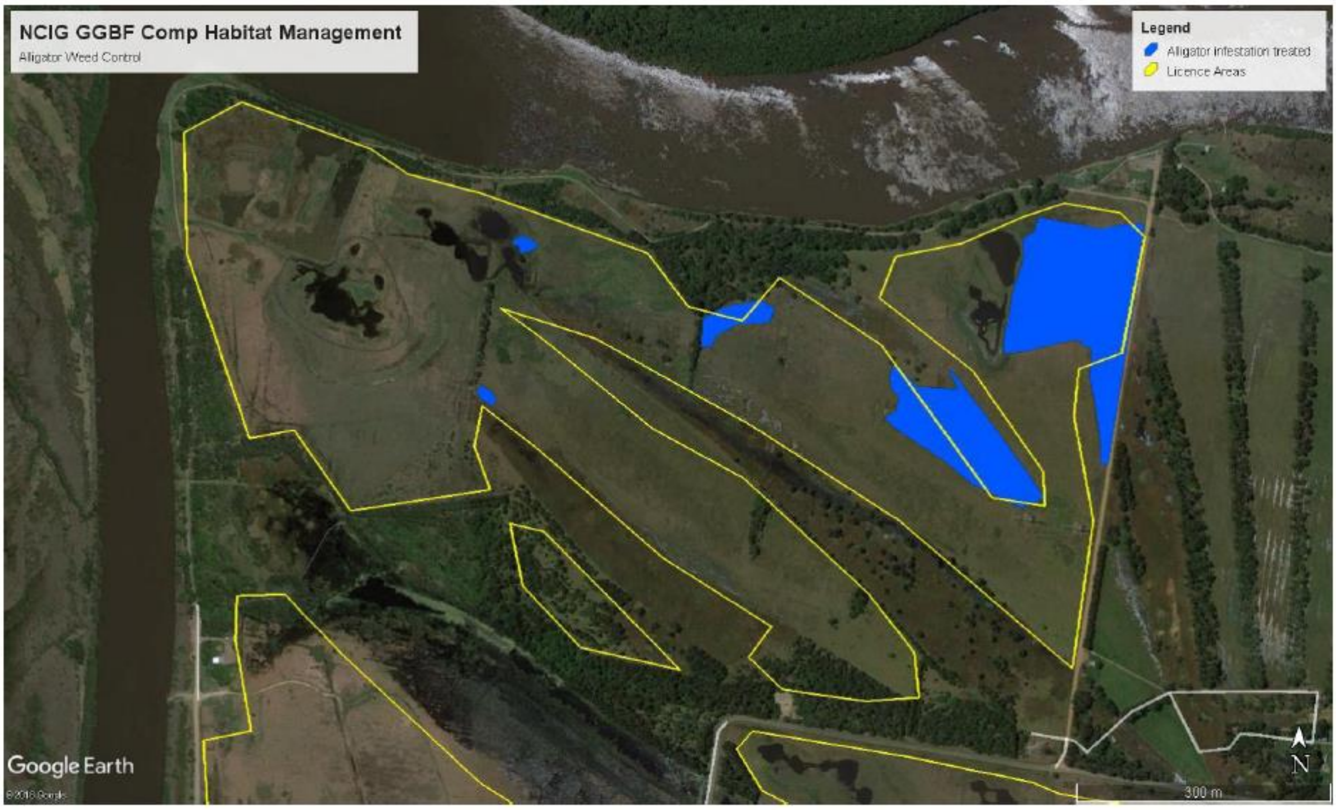


Figure 10: Alligator Weed Control in GGBF Compensatory Habitat

3. NCIG Shorebird Compensatory Habitat

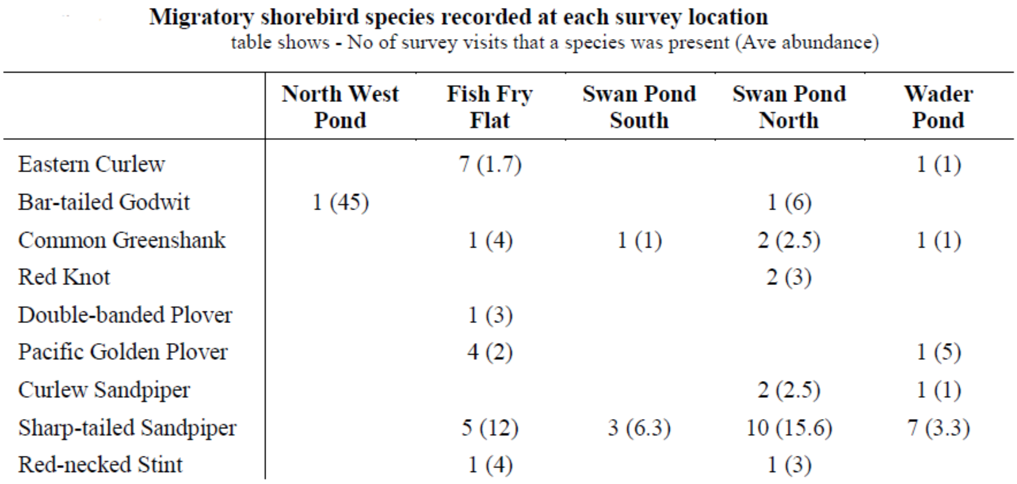
3.1. Shorebird Compensatory Habitat Monitoring

3.1.1. Area E Shorebird Monitoring

In accordance with the Shorebird Monitoring Evaluation Reporting and Improvement (MERI) Plan, General Flora and Fauna have undertaken regular surveying. Surveys are undertaken fortnightly in September-April (high tide, low tide and nocturnal roosting), and monthly in April-September (high tide and low tide).

The final report for 2017 Area E Shorebird Monitoring was provided to NCIG during this reporting period. During the 2017 surveys, 39 shorebird species were recorded in Area E, including 9 migratory shorebird species (Including 6 at Fish Fry Flats).

Table 2. Migratory Shorebird Species Recorded in Area E in 2017



Migratory shorebird species recorded at each survey location

table shows - No of survey visits that a species was present (Ave abundance)

	North West Pond	Fish Fry Flat	Swan Pond South	Swan Pond North	Wader Pond
Eastern Curlew		7 (1.7)			1 (1)
Bar-tailed Godwit	1 (45)			1 (6)	
Common Greenshank		1 (4)	1 (1)	2 (2.5)	1 (1)
Red Knot				2 (3)	
Double-banded Plover		1 (3)			
Pacific Golden Plover		4 (2)			1 (5)
Curlew Sandpiper				2 (2.5)	1 (1)
Sharp-tailed Sandpiper		5 (12)	3 (6.3)	10 (15.6)	7 (3.3)
Red-necked Stint		1 (4)		1 (3)	

An update of the 2018 surveys has been provided to NCIG by General Flora and Fauna. After a very dry summer period, regular water levels appear to have now returned to all ponds in Area E. Three new waterbird and shorebird species have been added to the list in 2018, including Australasian Grebe, Wood Duck and Latham's Snipe, a threatened migratory shorebird. One Latham's Snipe was recorded on two nights in February, foraging on mud at Fish Fry Flats. Four White-fronted Chats were also recorded at Fish Fry Flats in June, previously they had only been recorded at Swan Pond North and Wader Pond.

Discussions have been held with migratory shorebird expert, Danny Rogers. Danny is based at the Arthur Rylah Institute for Environmental Research in Victoria and is a shorebird expert for Birdlife Australia. We hope that Danny will assist in reviewing the existing monitoring data and making management recommendations in the coming months.

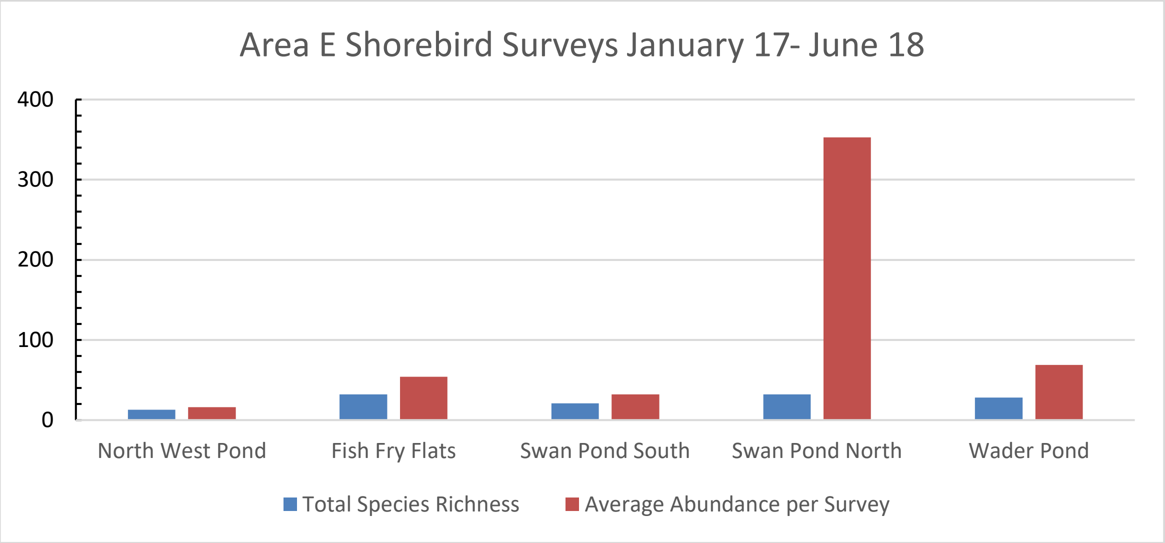


Figure 11: Total Species Richness and Average Abundance Per Survey Jan 17 - June 18

3.1.2 Area E Wetland Hydrology Monitoring (Water Research Laboratories UNSW)

The UNSW Water Research Laboratory (WRL) have continued with the ongoing hydrological monitoring program in 2018, in particular, investigating the relationship between the surface water and groundwater at Area E. Monitoring was undertaken in April and May to investigate groundwater movement and its interaction with surface water. Radon, a naturally occurring groundwater tracer, was used to detect the extent of groundwater seepage info Fish Fry Creek. A continuous 6-hour time series dataset of radon and water levels collected during monitoring at Fish Fry Creek clearly shows that groundwater discharges into the creek during periods of low tide. This can be seen in Figure 12, specifically from the data collected on 1st May, where a 1m decline in Fish Fry Creek water levels caused a radon concentration increase of approximately 45-fold, indicating large amounts of groundwater entering Fish Fry Creek.

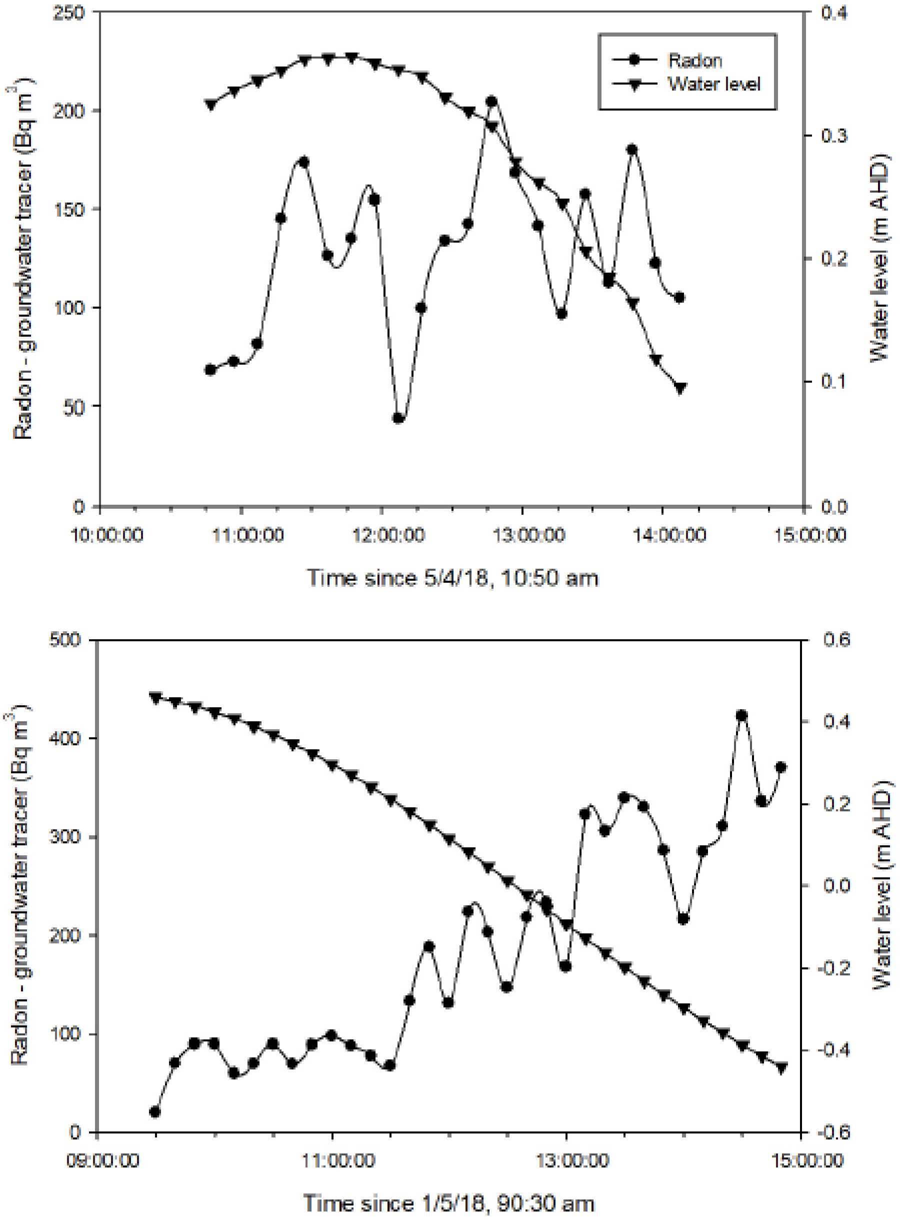


Figure 12: Radon Concentration in Fish Fry Creek

A dataset covering a full diel cycle of water quality parameters in Fish Fry Creek was required to better understand the role groundwater discharge has on the water quality of Area E. For this, WRL undertook monitoring for one week during July 2018, including the collection of continuous water quality data in Fish Fry Creek over a 24-hour period. A report including the results of this analysis will be provided to NCIG upon completion of data analysis.

Groundwater levels at Area E are continuously recorded using solinst pressure transducer loggers placed in piezometers. Additionally, 6 of the 15 piezometers also log the electrical conductivity (EC) of the groundwater. WRL extracted data from the piezometers to create groundwater levels and conductivity time-series plots for the period of 1st January to 1st May 2018 (Figure 13). The extracted data shows the average depth to the groundwater table at Area E is approximately 1.0 m, with a maximum depth of 1.4 m. In general, depth to the groundwater table at Area E was stable during this time period, with no obvious decline or incline trends observed. The groundwater EC levels indicate the groundwater at Area E is hypersaline, with all piezometers, except 1, showing a higher EC value than that of seawater (52,000 uS cm-1), ranging from 48,500 uS cm-1 to 64,000 uS cm-1. The high levels indicate large amounts of inorganic matter present in the subsurface, or/and high evapotranspiration rates. As there is no baseline data, it is unclear whether these hypersaline conditions are specific to Area E, or natural conditions in the area. Higher detailed sampling, including shallow groundwater aquifer at Area E is required to identify the constituents in the groundwater.

WRL conducted another drone survey in April to create a digital elevation model for the site. Previously, three surveys have been conducted (13th February, 5th July and 19th October in 2017). The elevation models are used to investigate the changes in land elevation after the removal of the mangroves in the compensatory habitat. Although minor variations in elevation have occurred in Fish Fry Flats, the variations are less than 0.1 meters. These variations area within the uncertainty of the measurement techniques used. Therefore, changes at this time are considered to be not significant. It is recommended that drone surveys continue every six months to capture potential land elevation changes.

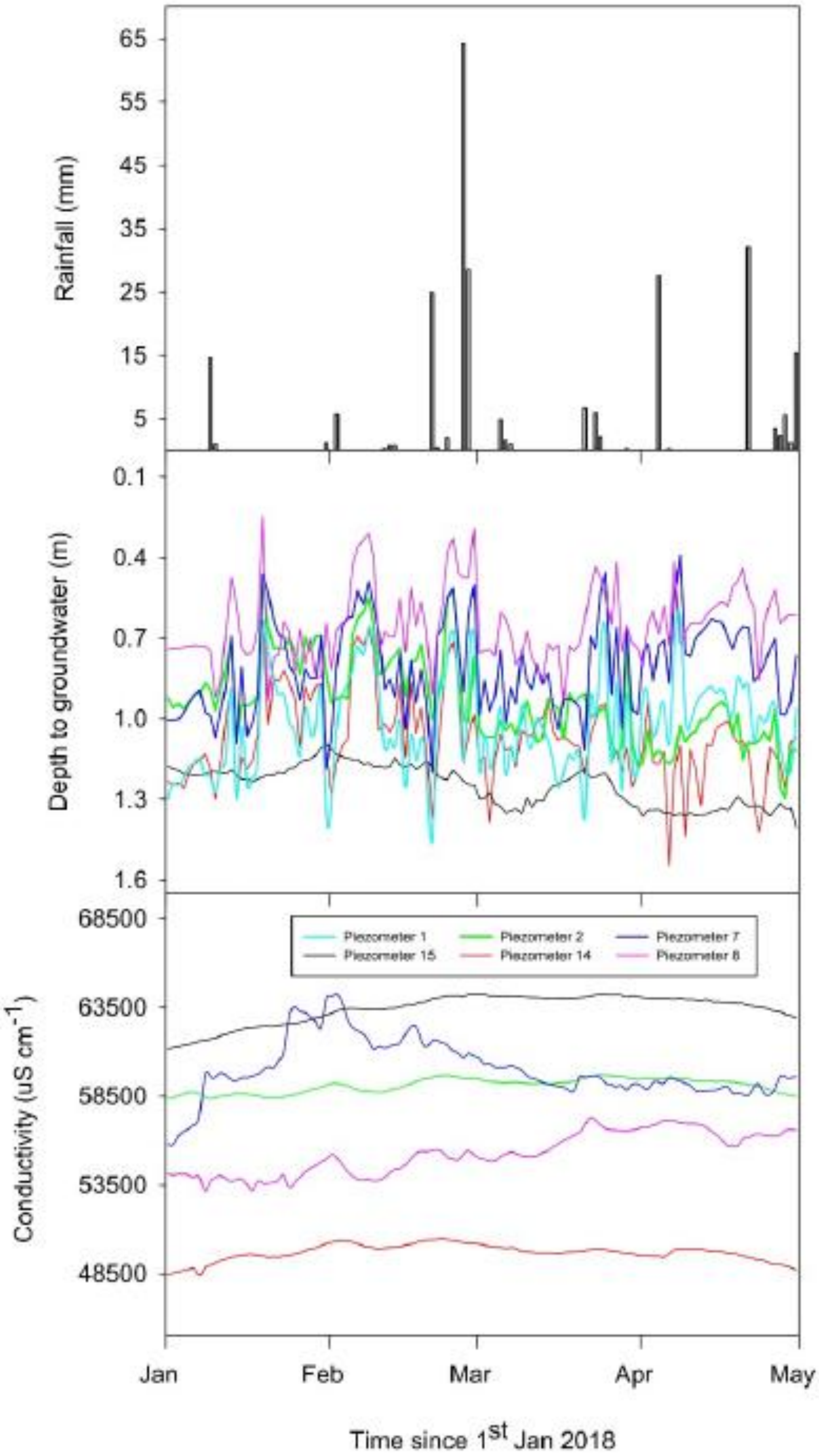


Figure 13: Rainfall, depth to groundwater and groundwater conductivity time series data from 1st January 2018

3.1.3 Fish Fry Flats Vegetation and Benthos Survey- Preliminary Report (Caleb Rankin - UoN)

The University of Newcastle has provided NCIG with a preliminary report of the benthos and vegetation monitoring they have undertaken at the Shorebird Compensatory Habitat. UoN are monitoring various ecological indicators to reliably measure and identify restoration success with regards to habitat functioning. Specifically, UoN have been monitoring various indicators of saltmarsh functioning that affect its value as shorebird habitat, including plant diversity and cover, organic litter, crab holes, and macro and meio infauna.

1m^2 quadrats have been placed randomly in each of the five strata present at Area E (based on Digital Elevation Model). to measure vegetation cover and diversity, organic litter cover and active crab holes. Random sampling using 6cm deep cores extracted by PVC pipes has been used for sampling macro and meio infauna at each site. In addition to Area E, control and reference sites will be monitored in future to compare and interpret the data collected from Area E. The two control sites include Crabhole Flats and Cobbans Creek, and the two reference sites include Wagtail Way east and Twelve-Mile Creek.

Although few results are yet available, a summary of preliminary results has been provided by UoN. These results give an indication of the current health of the system and potential trajectories.

Vegetation, Litter and Crabholes

Though not significant, vegetation cover and species richness has slightly decreased overall since November 2017, largely due to losses of saltmarsh above the new tidal regime over summer. However, saltmarsh has increased in the mid and low marsh, which are inundated more frequently (Figure 14). There has also been an increase in litter throughout the site, contributing organic matter and potentially aiding seedling growth.

Since the February 2018 sampling event, increased numbers of saltmarsh seedlings have been observed (Figure 15 and 16). *S. australis* and *S. quinifora* are recruiting more rapidly than *S. virginicus*. This may affect crabs, infauna and fish assemblages, and may have a flow on impact on shorebird communities.

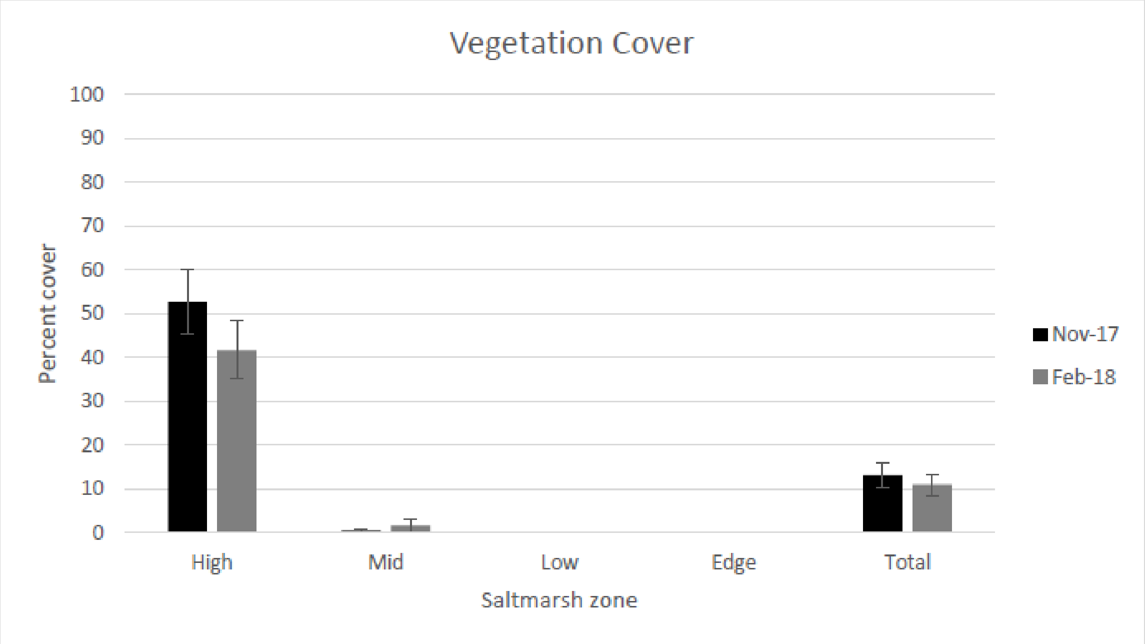


Figure 14: Saltmarsh vegetation cover in each strata sampled in Area E in November 2017 and February 2018.

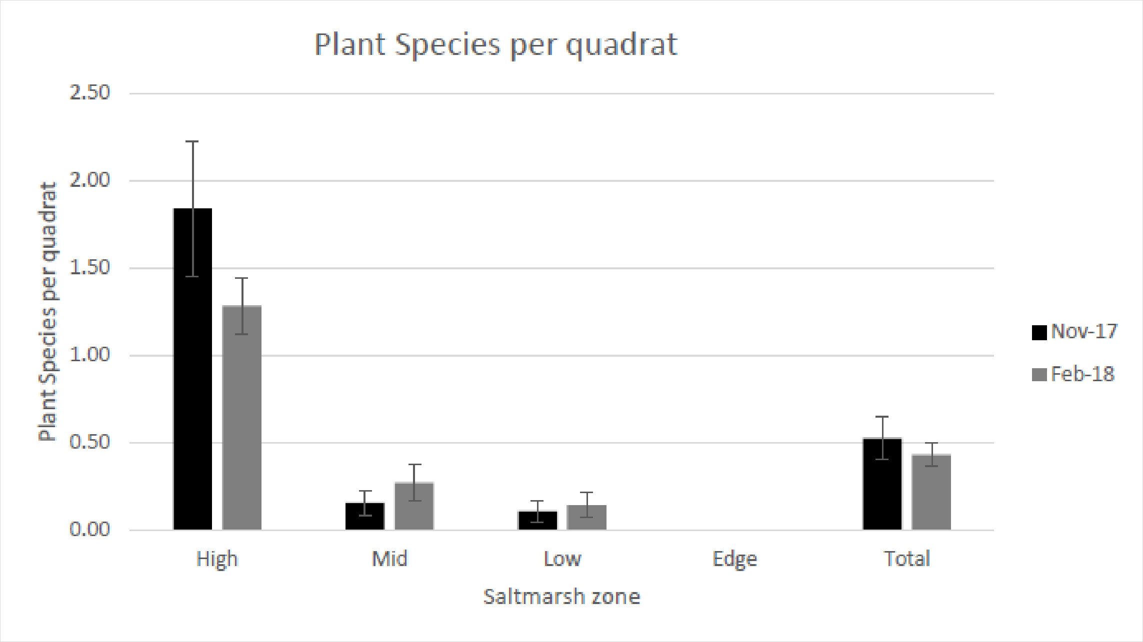


Figure 15: Number of saltmarsh species in each strata sampled in Area E in November 2017 and February 2018.

Figure 16: New saltmarsh seedling growth at Fish Fry Flats in May 2018

Infauna

A large variety of infauna has been observed in the samples to date (Figure 17), including various crustaceans such as copepods, isopods, amphipods, and clam shrimp, insect larvae, small bivalves, gastropods and bristle worms. Infauna provide a valuable food source for crabs, fish, and birds. However, nematodes (roundworms) were found in significantly higher numbers than other infauna types. The preliminary data indicates a disturbed system and an increase in the abundance of other types infauna will be required if the system is to support a robust and healthy saltmarsh community. Although it is important to note that very little sampling has been completed to date. Further sampling is expected to be completed by UoN in late July.

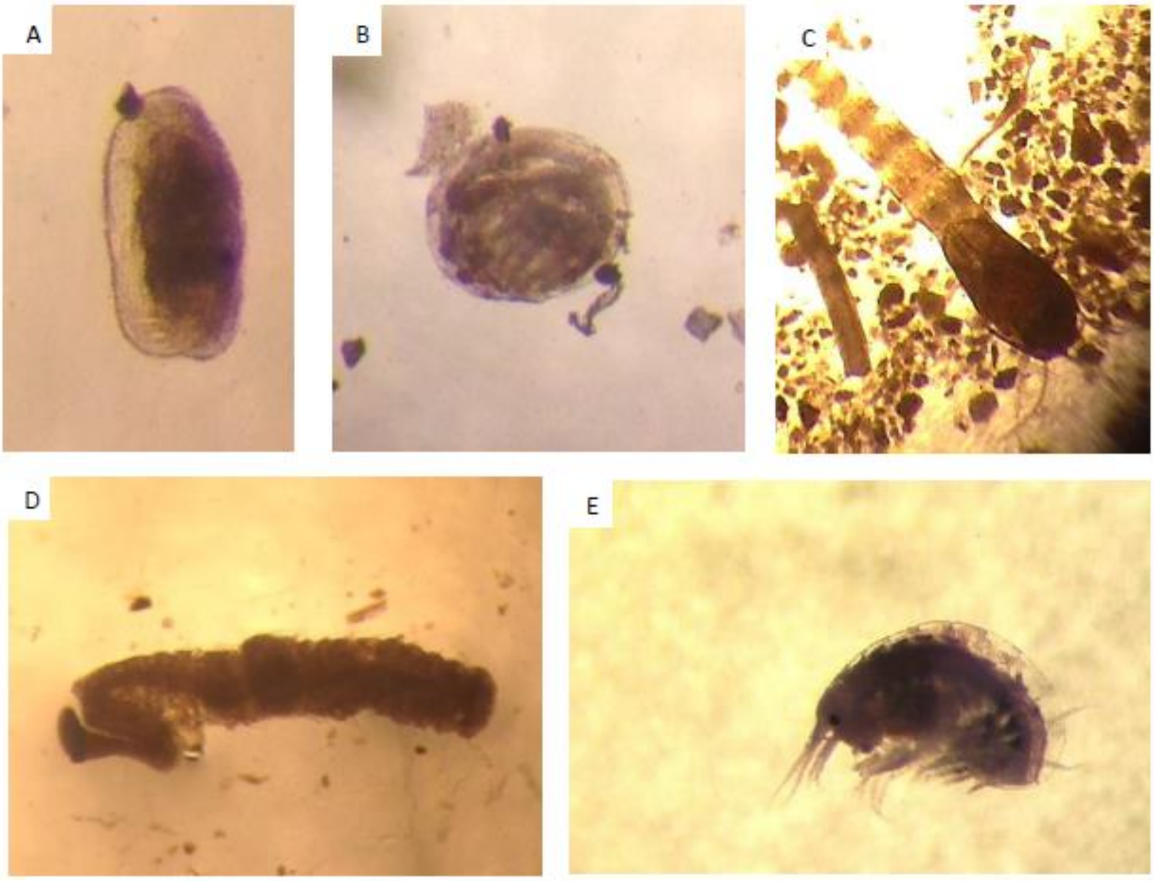


Figure 17: Some of the infauna found at Area E including crab shrimp (A), bivalve (B), insect larvae (C), bristle worm (D) and amphipod (E).

3.2 Compensatory Habitat Management

Weed control spraying was undertaken throughout the Shorebird Compensatory Habitat during this reporting period. Scattered occurrences of *Juncus acutus*, Bitou Bush and Groundsel Bush were targeted (Figure 18).

Figure 18: Weed Spraying Coverage in Shorebird Compensatory Habitat

Appendix A – Green and Golden Bell Frog Research and Monitoring Program on Ash Island 2017/18 Season (UoN)

Green and Golden Bell Frog Research and Monitoring Program on Ash Island

Report for 2017/2018 Season

Prepared for Newcastle Coal Infrastructure Group

Prepared: Dean Lenga & John Clulow

Reviewed: Michael Mahony, Simon Clulow

July, 2018

Executive Summary

Introduction

This report constitutes a summary of data and results of surveys for the presence, abundance and breeding of green and golden bell frogs (*Litoria aurea*) (GGBF) within the NCIG Compensatory Habitat Wetlands (Stages 1-7), Ash Island, undertaken between January and March, 2018. The surveys were undertaken by the University of Newcastle (Conservation Biology Group) as a part of the Compensatory Habitat and Ecological Management Program (CHEMP) of NCIG on Ash Island.

Survey Techniques

Ponds were surveyed using established methods used to investigating the Green and Golden Bell frog on Ash/Kooragang Islands over multiple seasons. Techniques include:

- Visual Encounter Surveys: visually evaluating the presence of GGBF at ponds to generate estimates of relative population densities in habitats.
- Capture Mark Release Surveys in GGBF occupied waterbodies:
    - Recording gender, reproductive status, weight, snout-vent length, marking individual animals with microchips.
    - Estimating population sizes at individual ponds using mark-release-recapture data, monitoring development and growth of individuals, and the migration of individuals between wetlands.
    - Genetic samples of captured frogs will be taken to allow the analysis of the population genetics of the population, including parameters such as heterozygosity, effective population size and overall population genetic structure.
- Fyke netting of waterbodies
    - This allows monitoring of the presence of tadpoles, fish and invertebrates in each wetland.
    - GGBF tadpole presence will be used as evidence of breeding events, and as an indicator of habitat suitability.
    - Determination of the occurrence and population density of *Gambusia* as an indicator of predatory pressure and impacts on GGBF in the studies wetlands.
- Habitat data collection: regular surveys of the state of habitat in each of the monitored wetlands including: vegetation composition and percentage cover, water quality, water body size and water depth.

Weather data were accessed from Bureau of Meteorology, Williamstown Weather Station, for period January to March, 2018.

Results

Rainfall

Average maximum temperatures were above average, and rainfall below average, for what was a hot, dry month in January, 2018 (Figure 1). This was associated with declining ground water and above ground water levels in ephemeral and permanent water bodies, and with complete drying in various ephemeral ponds. The first substantial rainfall for the period occurred on 20th February followed by heavier rain (54 mm) on 26th February; this resulted in partial to complete filling of a number of ephemeral ponds in the system. This was followed up in the following month with two consecutive days of heavy rain on the 21st and 22nd of March in which a total of 144 mm was recorded. This second large rainfall event of the summer season further filled most ephemeral ponds to 100% capacity as well as filling a number of permanent ponds, resulting in some ponds overtopping within the system. The rainfall event also resulted in local flooding of some ponds within Stages 1-7 and the connection (joining) of ponds not separated by bunding from other ponds within stages.

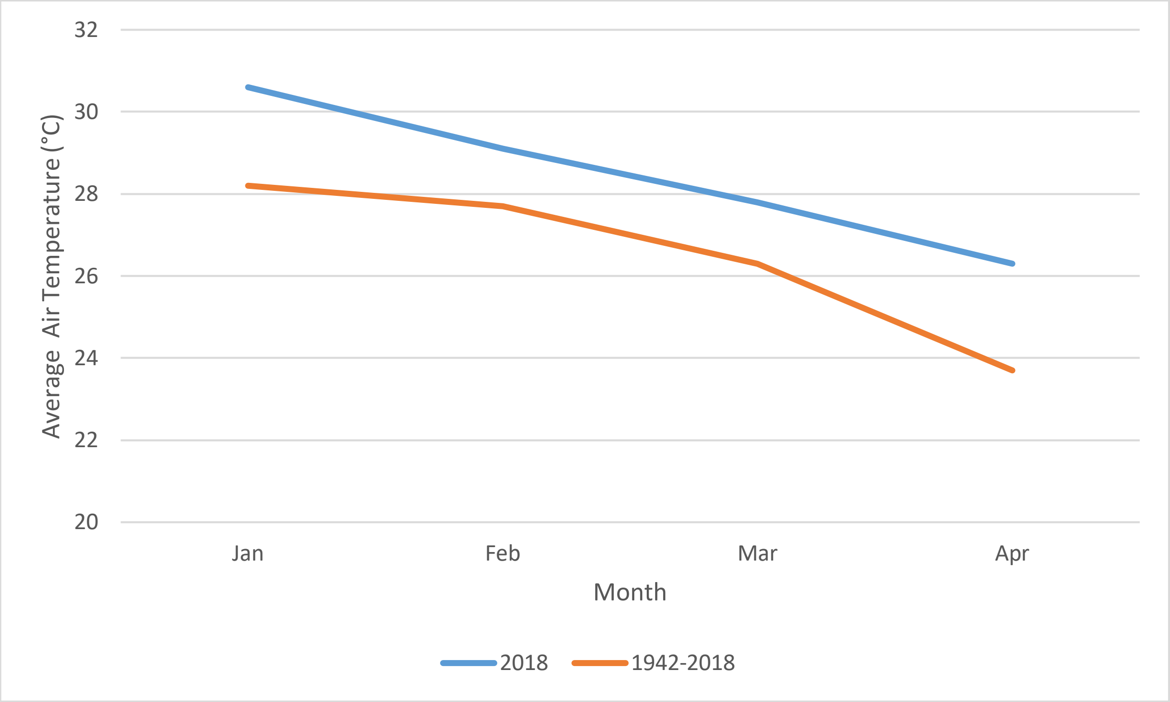


Figure 1. Average air temperatures for the months January to April in 2018 and average air temperatures from 1942-2018, recorded from the Williamstown weather station (061078)

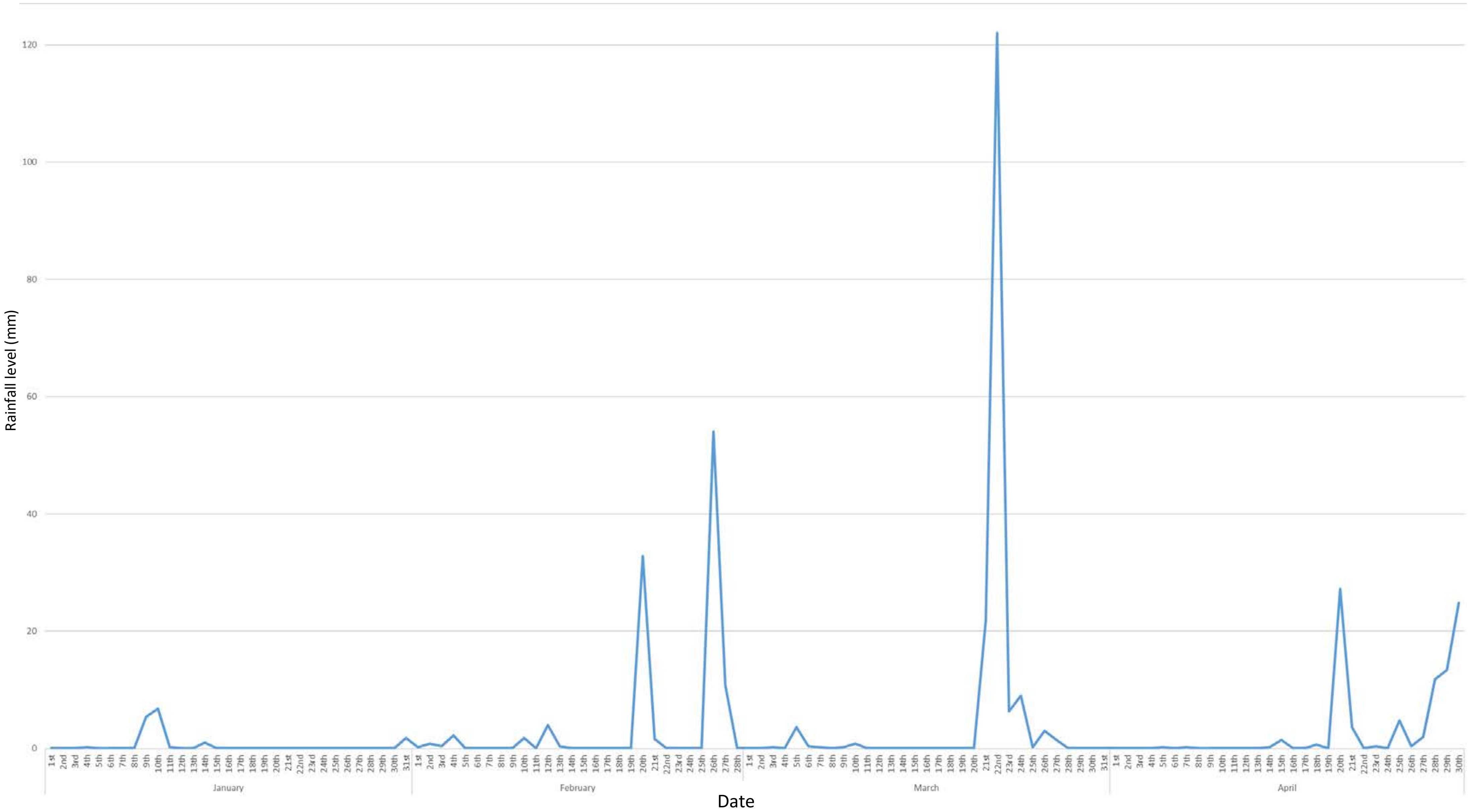


Figure 2. The total amount of rainfall (mm) for each day of the months of January to April 2018 recorded from the Williamstown weather station (061078)

Table 1. The total amount of rainfall (mm) for months January to April 2018 compared to the average amount of rainfall (mm) for the month January to April for the years 1942 to 2018. Recorded from the Williamstown weather station (061078)

	Jan	**Feb**	**Mar**	**Apr**
Total Rainfall in 2018 (mm)	15.4	109	169.2	91
Average Rainfall 1942-2018 (mm)	99.9	118.2	120.5	111.6

GGBF numbers recorded within survey period Jan to March, 2018.

GGBF were found in 27 of the 42 ponds in constructed habitats. Ponds 1.3, 4.9, 7.2, and 7.3, recorded the largest numbers of GGBF sightings, each with 7 or more observations. These four ponds were all ephemeral and were *Gambusia* free at the time of surveys (Appendix 1, Table 1) due to complete drying prior to the rain.

At total of 91 GGBF were recorded in the constructed wetlands between the months of January and March, 2018. Age and sex classes of GGBF recorded were:

- 55 adult male
- 29 adult female
- 5 juvenile females
- 2 unsexed juveniles

Breeding behaviours in response to rainfall, but no confirmed breeding during survey period.

Eight instances of breeding behaviour (males calling or frogs in amplexus) were noted with 7 recordings of calling and 1 observation of amplexus. There was no confirmed evidence of breeding during the survey period based on the absence of recording any GGBF tadpoles or metamorphs at any water bodies in the constructed habitats during the survey period (Jan – March, 2018).

Table 2. Records of male Green and Golden Bell frogs calling and observations of GGBF in amplexus in the NCIG compensatory habitats between the months of January and March 2018. Dates of observation shown.

Pond	Calling adult males observed	No. of amplecting pairs observed
1.4	0	1 (28/02/2018)
2.4	2 (28/02/2018)	0
6.1	3 (1/03/2018)	0
6.2	2(1/03/2018)	0
6.6	1 (29/03/2018)	0
Total	8	1

Other frog species observed within the NCIG habitats

Along with the GGBF, various other species of frogs were observed in the NCIG Compensatory Habitat wetlands. These included: the Dwarf Green Tree Frog (*Litoria fallax*), Bleating Tree Frog (Litoria dentata), Emerald Spotted Tree Frog (*Litoria peronii)*, Striped Marsh Frog (*Limnodynastes peronii*), Spotted Marsh Frog (*Limnodynastes tasmaniensis*) and the Common Eastern Froglet (*Crinia signifera*).

Presence of *Gambusia* and other fish in constructed NCIG wetlands.

Twenty of the 41 NCIG compensatory habitat ponds on Kooragang Island (not including K58B) were found to have *Gambusia holbrooki* present during the survey period ranging in abundance levels (low, medium, high), and 20 were found to be *Gambusia* free. The presence/absence of *Gambusia* in Pond 5.8 was not confirmed. Nineteen of the 20 ponds that were free of *Gambusia* were ephemeral. In comparison, 15 of the 20 ponds that were found to have *Gambusia* were classified as permanent ponds (see Appendix 1, Table 1), indicating the strong trend towards occurrence of *Gambusia* in permanent ponds.

Other fish species caught in fyke nets in NCIG wetlands were recorded and counted (see Appendix 1, Table 1). These included the Short-finned Eel (*Anguilla australis*), Long-finned Eel (*Anguilla reinhardti*), Striped Gudgeon (*Gobiomorphus australis*) and the Empire Gudgeon (*Hypseleotris compressa).* All of these fish are native to Australia and to the Hunter region.

Discussion

The January to March summer survey period was characterised by below average summer rainfall early in the summer (and prior to surveys commencing), followed by heavy rainfall that resulted in ephemeral and permanent ponds filled to capacity. Post the rainfall events, breeding activity was detected (male calling and amplexus), but there was no evidence of successful breeding occurring during the survey period.

Prior to the first large rain event in mid-February, the 2017/2018 breeding season was relatively dry compared to previous recent seasons. The below average rainfall resulted in low water levels (below 30%) or complete drying in the majority of the ephemeral ponds across the 7 NCIG wetland stages. The dry period across the landscape was associated with low numbers or absence of GGBF records during surveys. GGBF activity (animals detected, calling males and amplexus) was primarily restricted to the periods after heavy rainfall resulted in the filling of ephemeral and permanent water bodies from the second half of February.

There was evidence that rainfall linked flooding of the landscape was associated with increased dispersal of frogs associated with the rainfall event. One example was a frog first caught in pond 7.1 (permanent pond) on the 21/02/2018 and later recaptured in stage 6.2 (ephemeral pond) on the 1/03/2018, a minimum dispersal distance of 250 m.

Inspection of the data in Table 1 suggests an association between GGBF records and levels of *Gambusia* infestation at waterbodies (not tested statistically, or related to other prior data), potentially indicating an association between *Gambusia* and GGBF activity within the landscape. Taken together, the data also suggests a positive association for the survey period between ephemerality, the absence of *Gambusia* in waterbodies and the occurrence of GGBF.

Associated with the intense dry period in the first part of the summer season, there was also a large fire event at the northern end of Ash Island, burning the majority of the vegetation in and around the ponds of stage 1, 2 & 3. The loss of vegetation post fire had a major effect on the number of frogs observed in these ponds since the rain event (data not shown). It is not known how many GGBF were lost as a result of this event (no bodies were located). Nevertheless, GGBF persisted within the post-fire landscape, and were recorded at a number of ponds.

Appendix 1.

Table 1. Abundance of fish captured in fyke nets in NCIG constructed wetlands during January to March, 2018. Relative *Gambusia* abundance was scored as low, medium, high for all ponds in which they were detected, and numbers are provided where fyke netting was used; numbers of other fish species caught in fyke nets are supplied. The total number of GGBF represent total recorded during surveys at each pond for the 3 months of survey data collection. Fish species netted included *Gambusia holbrooki,* Short-finned Eel (*Anguilla australis*), Long-finned Eel (*Anguilla reinhardti*), Striped Gudgeon (*Gobiomorphus australis*) and the Empire Gudgeon (*Hypseleotris compressa).* Ponds that were not surveyed using fyke nets are indicated; these were swept with a dip net to determine relative abundance levels of *Gambusia holbrooki.*

Pond	**Type**	**Number of GGBF**	***Gambusia* Relative abundance**	***Gambusia* caught (total)**	**Short-finned Eel (total)**	**Long-finned Eel (total)**	**Empire Gudeon (total)**	**Striped Gudgeon (total)**
1.1	permanent	1	High	1412	0	0	296	0
1.2	ephemeral	6	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
1.3	ephemeral	11	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
1.4	ephemeral	3	High	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
2.1	permanent	0	High	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
2.2	ephemeral	0	Low	38	17	2	1	0
2.3	permanent	1	Low	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
2.4	ephemeral	1	High	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
3.1	ephemeral	0	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
3.2	ephemeral	0	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
3.3	permanent	1	Medium	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
3.4	ephemeral	0	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
3.5	ephemeral	1	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
4.1	permanent	5	Medium	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
4.2	permanent	2	High	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
4.3	permanent	0	High	188	11	0	0	0
4.4	permanent	1	High	47	2	0	0	0
4.5	ephemeral	1	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net

4.6	ephemeral	0	Medium	0	1	0	1	0
4.7	permanent	0	Medium	80	30	0	18	23
4.8	permanent	5	Medium	117	3	0	0	0
4.9	ephemeral	11	Absent	0	1	0	0	0
4.10	permanent	0	High	497	4	0	0	0
4.11	permanent	0	Low	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
5.1	ephemeral	0	Absent	0	0	0	0	0
5.2	ephemeral	2	Absent	0	0	0	0	0
5.3	ephemeral	0	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
5.4	ephemeral	2	Absent	2	0	0	0	0
5.5	ephemeral	2	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
5.6	ephemeral	1	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
5.7	permanent	0	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
5.8	permanent	2	Unknown	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
6.1	ephemeral	0	Absent	0	0	0	0	0
6.2	ephemeral	3	High	270	2	0	0	8
6.3	permanent	2	High	5	3	0	2	11
6.4	ephemeral	0	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
6.5	ephemeral	2	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
6.6	permanent	2	High	2348	12	0	0	8
7.1	permanent	5	High	403	3	0	0	2
7.2	ephemeral	7	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
7.3	ephemeral	9	Absent	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net
K58B	ephemeral	2	NA	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net	Did not Fyke net

Table 2. Pond structure and water chemistry. Summary of the data collected for all NCIG compensatory habitat ponds surveyed between the months of January to March 2018. Pond type (ephemeral or permanent) and presence/absence and relative abundance *Gambusia* shown. The total number of GGBF recorded at each pond for the 3 month of data collection are shown. Water quality data for each pond includes mean and standard deviations, as well as the minimum and maximum water depth recorded for the season at each pond. Missing values for standard deviations indicate insufficient data to calculate. Abbreviations: Temp = Temperature; Sal = Salinity; DO = Dissolved Oxygen.

Pond	Type	Number of GGBF	Gambusia abundance	Average of pH	Standard Dev (+/-)	Average of Temp °C	Standard Dev (+/-)	Average of Sal (ppt)	Standard Dev (+/-)	Average of DO (mg/L)	Standard Dev (+/-)	Maximum of Depth recorded (cm)	Minimum of Depth recorded (cm)
1.1	permanent	1	High	9.43	0.15	25.00	1.42	1.11	0.02	31.75	52.19	126.00	66.00
1.2	ephemeral	6	None	7.45	0.54	25.55	2.33	32.19	43.79	4.64	0.34	10.00	0.00
1.3	ephemeral	11	None	5.45	1.49	23.17	2.59	1.41	0.67	3.10	3.03	52.00	23.00
1.4	ephemeral	3	High	8.44	0.18	24.27	2.92	1.67	0.42	5.66	3.42	106.00	81.00
2.1	permanent	0	High	7.41		27.30		19.76		4.85		27.00	5.00
2.2	ephemeral	0	Low	6.69	0.01	23.85	1.91	2.46	0.16	5.25	4.09	140.00	115.00
2.3	permanent	1	Low	5.86	0.99	27.80	2.40	5.08	2.96	4.62	4.19	58.00	38.00
2.4	ephemeral	1	High	4.84	0.38	26.55	0.21	5.97	3.89	4.05	2.70	28.00	11.00
3.1	ephemeral	0	None	7.31	0.71	23.65	3.18	0.44	0.05	4.03	1.65	10.00	0.00
3.2	ephemeral	0	None	6.78		25.70		0.40		5.15		6.00	0.00
3.3	permanent	1	Medium	8.17	0.73	26.37	0.06	1.59	0.44	5.03	3.85	150.00	127.00
3.4	ephemeral	0	None	7.39		26.00		0.85		5.79		30.00	0.00
3.5	ephemeral	1	None	7.06		26.00		0.71		5.91		40.00	0.00
4.1	permanent	5	Medium	8.07	0.35	26.23	2.47	0.48	11.03	2.35	1.85	82.50	25.00
4.2	permanent	2	High	6.85	0.14	25.93	1.80	0.78	11.24	2.79	1.99	128.00	127.00
4.3	permanent	0	High	7.43	0.09	25.70	1.95	0.34	0.37	5.42	2.10	135.00	25.00
4.4	permanent	1	High	7.23	0.30	26.27	1.10	0.54	0.05	2.74	2.61	95.00	125.00
4.5	ephemeral	1	None	6.35	0.08	24.43	3.06	0.57	0.09	2.68	1.51	100.00	75.00
4.6	ephemeral	0	Medium	6.63	0.17	25.00	1.96	0.50	0.52	2.71	1.49	128.00	10.00
4.7	permanent	0	Medium	7.33	0.51	27.10	1.77	0.26	0.38	5.34	1.67	75.00	10.00

4.8	permanent	5	Medium	8.68	0.55	26.47	3.68	0.47	0.04	3.65	4.85	120.00	50.00
4.9	ephemeral	11	None	7.45	0.60	26.63	1.70	2.99	0.06	3.42	2.13	115.00	120.00
4.10	permanent	0	High	7.54	0.49	26.43	2.24	19.39	1.35	3.74	2.05	57.33	29.00
4.11	permanent	0	Low	7.86		25.77		35.04		2.95		147.00	0.00
5.1	ephemeral	0	None	6.79		29.30		0.06		3.92		40.00	0.00
5.2	ephemeral	2	None	6.82		29.30		0.13		5.07		60.00	0.00
5.3	ephemeral	0	None	6.60	0.57	27.70	5.51	0.13	0.87	4.69	0.78	100.00	0.00
5.4	ephemeral	2	None	6.13	0.15	28.30	0.71	0.92	0.11	3.00	0.14	118.00	0.00
5.5	ephemeral	2	None	5.91	0.40	21.20	0.42	0.22	0.17	1.65	1.66	90.00	0.00
5.6	ephemeral	1	None	7.02	0.18	19.40	1.08	0.30	0.15	2.22	2.49	120.00	0.00
5.7	permanent	0	None	6.52	0.56	23.43	3.00	0.32	0.23	2.27	5.01	120.00	0.00
5.8	permanent	2	Unknown	9.01	0.52	25.83	5.30	0.34		5.46	1.74	NA	NA
6.1	ephemeral	0	None	6.40	1.00	22.65	3.93	0.16	1.09	3.13	0.64	120.00	10.00
6.2	ephemeral	3	High	6.06	0.60	27.30	1.75	1.20	0.12	2.04	0.69	130.00	0.00
6.3	permanent	2	High	7.46		22.40		0.46		2.91		137.00	0.00
6.4	ephemeral	0	None	NA		NA		NA		NA		NA	NA
6.5	ephemeral	2	None	6.20	0.36	20.20	7.23	0.52	0.55	1.17	1.27	10.00	4.00
6.6	permanent	2	High	6.83	0.31	26.13	1.08	0.84	0.98	1.62	1.32	30.00	60.00
7.1	permanent	5	High	8.71	0.31	22.87	0.92	5.77	2.16	2.28	0.30	100.00	15.00
7.2	ephemeral	7	None	7.81	0.07	22.15	1.37	3.13	0.93	2.04	1.26	40.00	40.00
7.3	ephemeral	9	None	7.44	0.13	20.93	3.21	5.15	19.70	1.68	53.71	47.00	0.00
K58B	ephemeral	2	NA	6.72		24.57		52.74		32.99		NA	NA

Appendix B – NCIG Compensatory Habitat Management 6 Monthly Overview, January – June 2018 (CVA)

NCIG Compensatory Habitat Management

6 Monthly Works Overview – January - June 2018

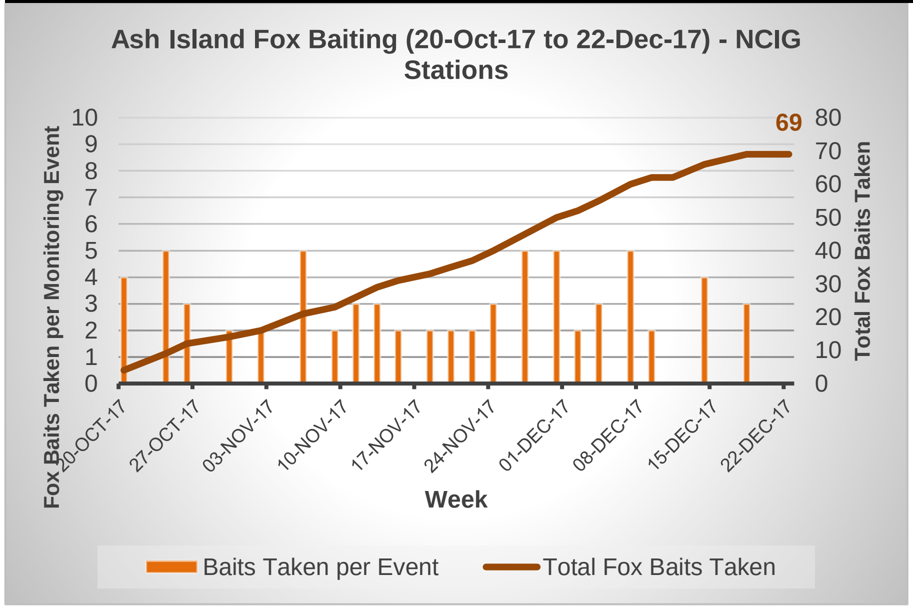
Weed Control

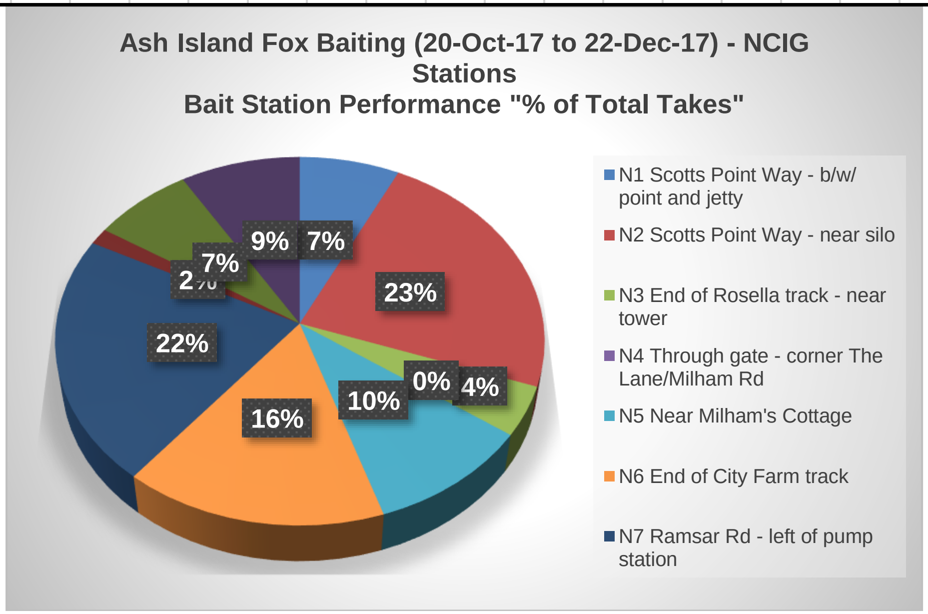
- Weed control spraying was undertaken throughout the broader GGBF licence areas this period, targeting priority weeds including Blackberry, Juncus acutus, Bitou Bush and Lantana, as indicated in Appendix A. The majority of dense infestations of these weeds are now under control and now are in maintenance phase to control regrowth.
- Targeted spraying for Alligator Weed was undertaken, predominantly throughout the eastern extent of Licence Area 10. Monitoring this period indicated that the extent of this infestation was greater than previously known. This infestation became more prominent after wild fire burnt off the majority of overlying vegetation (Kikuyu grass), and Alligator Weed regenerated and expanded rapidly from sub-surface stolons not affected by fire. It is recommended that control in this area and Macrophyte Trench / KWRP Ponds is undertaken at a greater frequency next annual period, to ensure the extent of infestation is reduced.
- Weed control spraying was undertaken throughout the Shorebird licence area (Area E) this period, targeting scattered occurrences of Juncus acutus, Bitou Bush, and Groundsel Bush.
- The majority of spraying was undertaken with backpacks, and the 250L Rapid Spray unit. Spraying of Alligator Weed in wet areas using Metsulfuron Methyl mix was undertaken using off-label permit PER14734.
- Slashing the interior and exterior of the frog fence in Stage 1 was undertaken to ensure vegetation growth did not exceed 300 mm 1m from the fence line.
- Site reports detailing works conducted are contained in Appendix C.

Fox Control

- The Fox Baiting program was undertaken between October and December 2017, across 10 sand pad stations using 1080 ground baits. The program has been very successful to date, with baits taken consistently each run. A total of 69 baits were taken at a strike rate of 63% strike rate per bait laid, and an average take rate per monitoring run of 29% across all stations. The table below and figures show a detailed summary of the results to date. Appendix B shows the bait station locations.

NCIG					Monitoring Run / Takes																							
Station ID	Station Description	Takes to-date	Take Rate	% Total Takes	20-Oct-17	24-Oct-17	26-Oct-17	30-Oct-17	02-Nov-17	06-Nov-17	09-Nov-17	11-Nov-17	13-Nov-17	15-Nov-17	18-Nov-17	20-Nov-17	22-Nov-17	24-Nov-17	27-Nov-17	30-Nov-17	02-Dec-17	04-Dec-17	07-Dec-17	09-Dec-17	11-Dec-17	14-Dec-17	18-Dec-17	22-Dec-17
					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
N1	Scotts Point Way - b/w/ point and jetty	5	21%	7%		1				1												1				1	1	
N2	Scotts Point Way - near silo	16	67%	23%	1	1	1	1	1	1		1	1			1		1	1	1	1		1	1		1		
N3	End of Rosella track - near tower	3	13%	4%						1									1							1		
N4	Through gate - corner The Lane/Milham Rd	0	0%	0%																								
N5	Near Milham's Cottage	7	29%	10%	1	1					1			1							1		1				1	
N6	End of City Farm track	11	46%	16%	1	1				1		1	1				1	1	1	1				1		1		
N7	Ramsar Rd - left of pump station	15	63%	22%		1	1	1	1	1	1	1	1	1	1		1		1	1		1	1					
N8	Near Tower 64	1	4%	1%																		1						
N9	Corner Ramsar Rd/Wagtail Way	5	21%	7%			1									1		1		1			1					
N10	South of Radar Shed - near mound	6	25%	9%	1										1				1	1			1				1	
	Subtotals	69	29%		4	5	3	2	2	5	2	3	3	2	2	2	2	3	5	5	2	3	5	2	0	4	3	0
	Cumulative Subtotals				4	9	12	14	16	21	23	26	29	31	33	35	37	40	45	50	52	55	60	62	62	66	69	69
	% takes per run				40	50	30	20	20	50	20	30	30	20	20	20	20	30	50	50	20	30	50	20	0	40	30	0





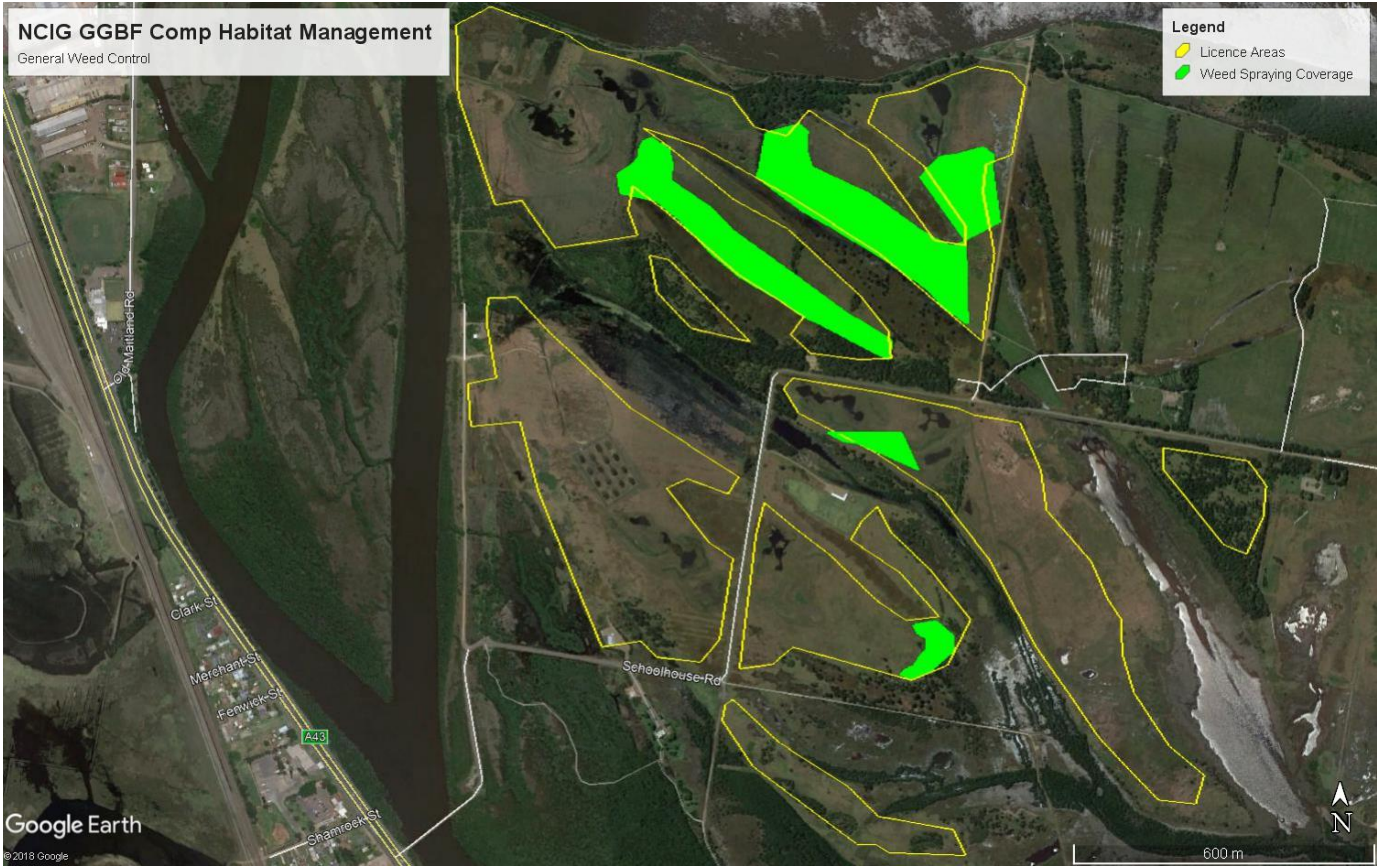
Frog Fence Repair and Bunding Installation

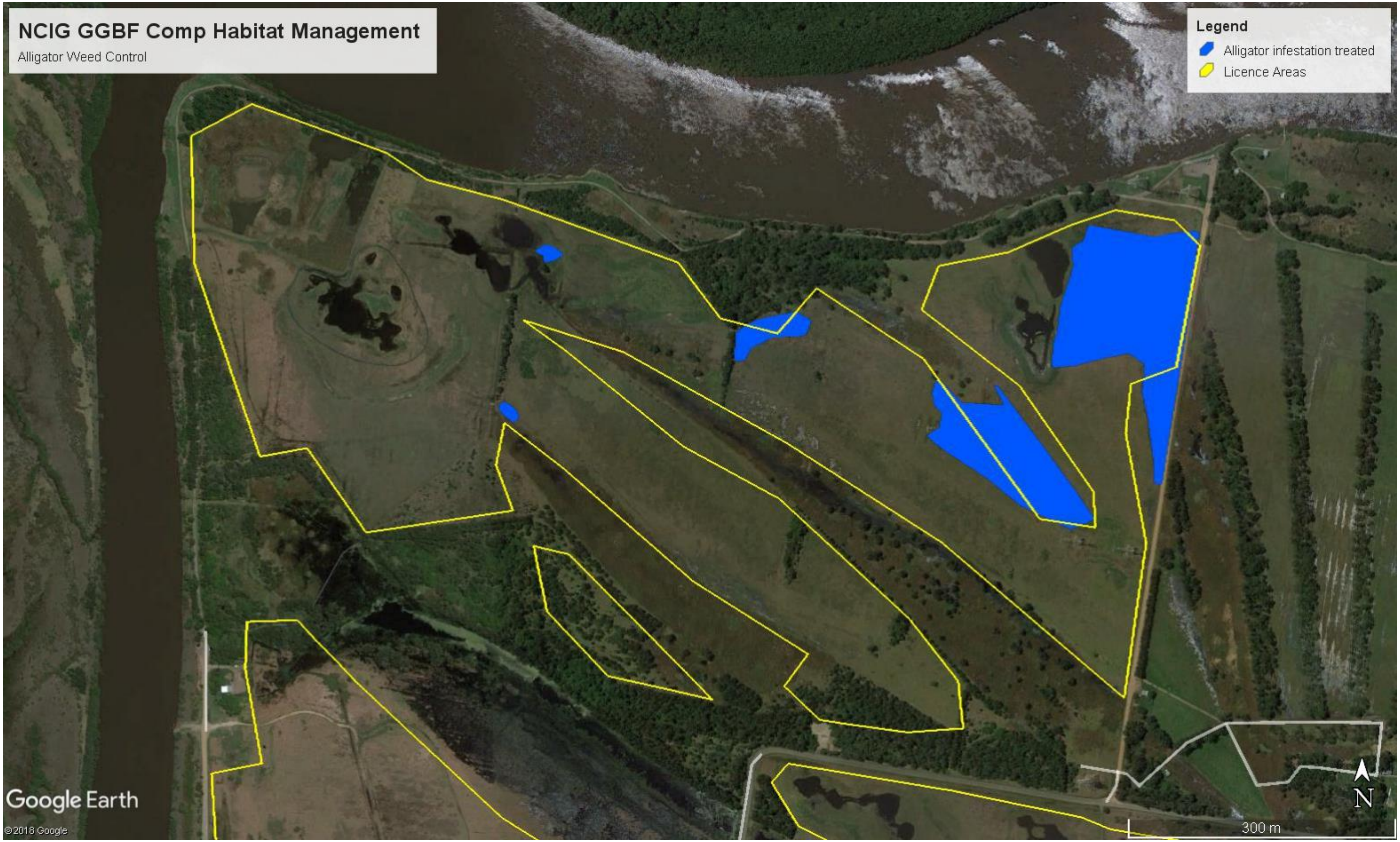
- Wildfire destroyed the frog fence surrounding Stage 1 ponds during February 2018. Repair works are underway to reinstate this fence, and pond bunding has now been installed to fully contain this area.

Photos

Alligator Weed infestation east of Stage 3 (Area 10)

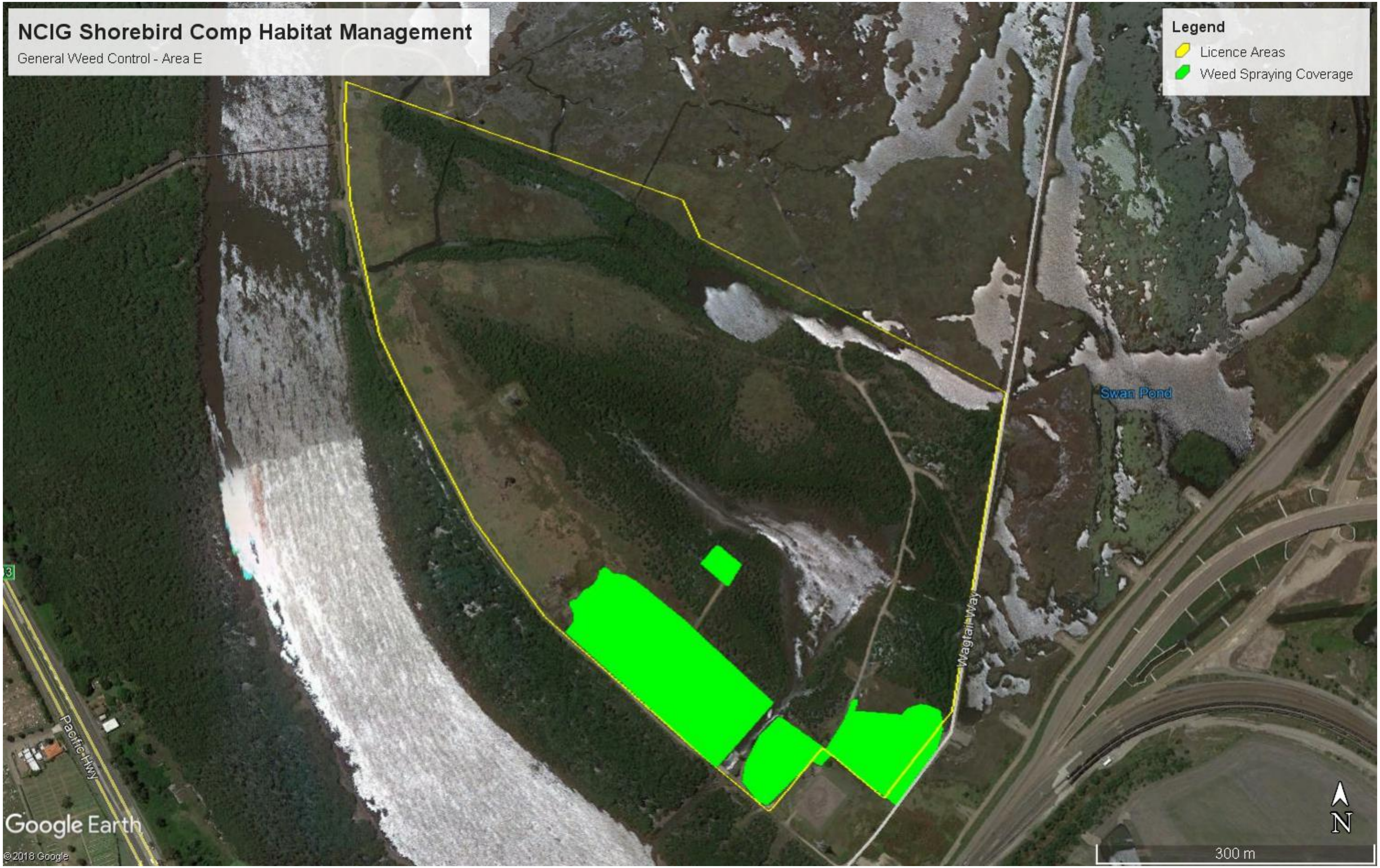
APPENDIX A - WEED CONTROL AREAS





NCIG GGBF Comp Habitat Management

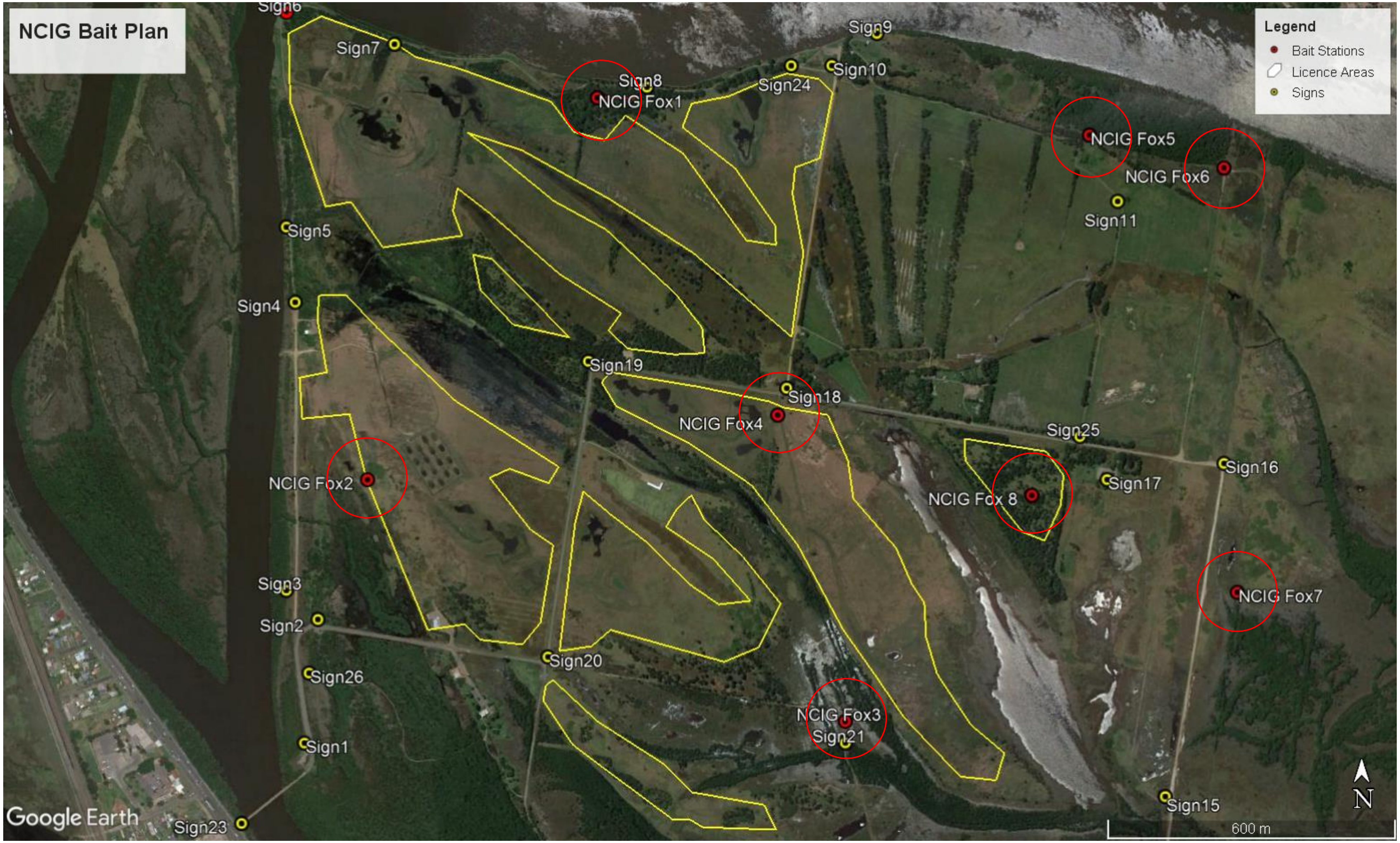
Alligator Weed Control

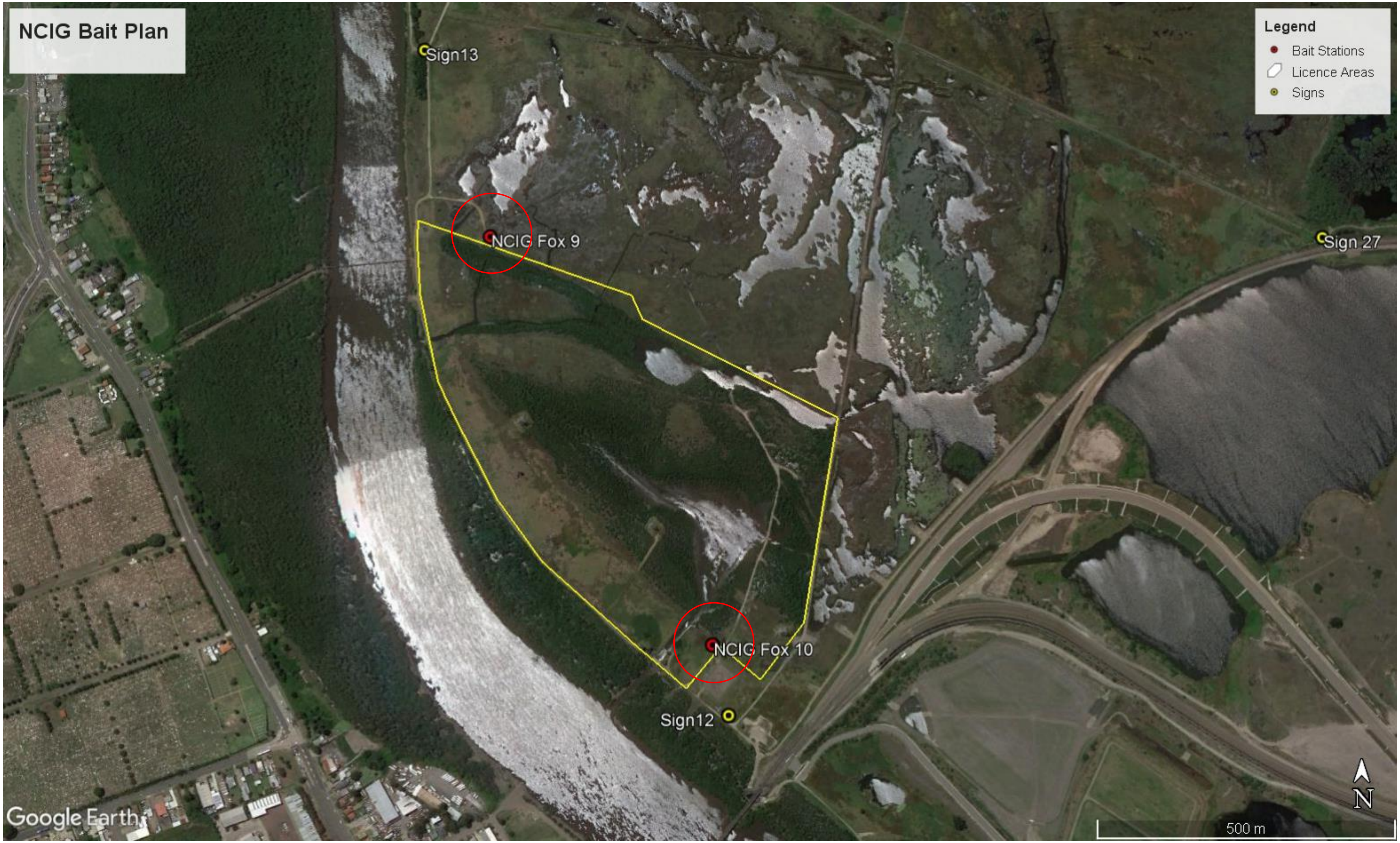


NCIG Shorebird Comp Habitat Management

General Weed Control - Area E

APPENDIX B – FOX BAITING STATION LOCATIONS




NCIG Bait Plan
Legend
Bait Stations
Licence Areas
Signs
Sign13
NCIG Fox 9
Sign 27
NCIG Fox 10
Sign12
Google Earth
N
500 m

APPENDIX C – PWIS SITE REPORTS

NPWS Lower Hunter Area
Weed Treatment Recording Sheet

AMS - Data

AMS Equipment ID No:	AMS Work Order No:	AMS Site Name: Ash Island NC14	Reserve Name:

Activities Undertaken/ Situation

Spray Alligator weed on NC1a Site adjacent to The Lane / Riverside Park.
Approx 5000 m²

NPWS Staff and Equipment (Operations)

Date:	Work centre:	Description:	Duration:	Number:

External Contractors and Equipment (Components)

Contractor Company Name: CVA	Contact Number:	Purchase Order:

Date	Contractor or equipment	Duration	Number
7/3/18	CVA Staff	6 hrs	2
	Elise Budden Zachariah Cotter		

Pest and Weed Information System (PWIS) – Data

Operator data

Operator name/s: Elise Budden Zacharia Cotter	Date/s: 7/3/18	Time/s 8.30 - 14.30

Spatial Data – Arc Map

Specific Location (in order of treatment):	Easting or Latitude	Northing or Longitude

Spatial Data Capture Method: GPS [✓ Map / eye ball] Other________	Datum (circle): GDA94 AGD66 Map supplied	Spatial Data Captured By:

Weed Information

Weeds Targeted (common name)	Weed Density	Additional info
Alligator weed	Medium	

Weed Density: Sparse >1%: Light 1 – 10% Medium 10-50% : Heavy 51-70%; Very Heavy 70%<

Situation (circle): bushland grassland [✓ wetland] rainforest trail/road along river/creek

Spray Data

Full product name/s of chemical/s used:	Rate /100L water:	Total Used (ml or L):
Metsulfuron Methyl	1 g	7 g
Additive/Wetters Used (specify):		
Dye Used (specify):		

Spray Equipment Used (circle):

Spray gun Quik Spray [✓ Backpack] Splatter gun Spray bottle

Other:______________

Total Spray Mix Applied: 7 g

Method (circle):

Foliar (spot) spray Boom spray Basal bark Stem injection Cut & paint Splatter gun

Other:________________

Weather Conditions

☐ Showers ☐ Light Cloud

☐ Overcast ☒ Clear Sky

Time	Temperature (°C)	Relative Humidity (%)	Wind Speed (km/h)	Direction (from)	Variability (e.g. gusting)
Start: 08.30	22		10	N	Gusting
Finish: 14.30	26		20	NE	Strong

Comments (e.g. any problems with the application)

General Information

Observations General / Interesting Sightings

Wind picked up so finished spraying 14.30

Accident/ Incident/ Near Miss Report

N/A

Requirements for follow work

Continue spray work in area

Entered in **AMS ☐** **PWIS ☐** ☺

NPWS Lower Hunter Area
Weed Treatment Recording Sheet

AMS - Data

AMS Equipment ID No:	AMS Work Order No:	AMS Site Name:	Reserve Name:
		Ash Island NCIG	

Activities Undertaken/ Situation

12/3 → Spray Alligator weed priority Areas

13/3 Spray Alligator weed priority Areas and spot Spray Juncus Accutus

15/3 Spray groundsal bush, Juncus acutus, B.tou, Lantana

NPWS Staff and Equipment (Operations)

Date:	Work centre:	Description:	Duration:	Number:

External Contractors and Equipment (Components)

Contractor Company Name:	Contact Number:	Purchase Order:
CVA		

Date	Contractor or equipment	Duration	Number
12/3/18	CVA Staff	7.5hrs	2
13/3/18	CVA Staff	7.5hrs	2
15/3/18	CVA Staff	7.5hrs	2
		22.5	6

Pest and Weed Information System (PWIS) – Data

Operator data

Operator name/s:	Date/s:	Time/s
Elise Budden Zach Cotter		

Spatial Data – Arc Map

Specific Location (in order of treatment):	Easting or Latitude	Northing or Longitude

Spatial Data Capture Method:	Datum (circle):	Spatial Data Captured By:
GPS [✓ Map] / eye ball Other___________	GDA94 AGD66 Map supplied	

Weed Information

Weeds Targeted (common name)	Weed Density	Additional info
Alligator Weed	40%	
Juncas acutas	10%	
Lantana	10%	
Biton bush	5%	

Weed Density: Sparse >1%: Light [✓ 1 – 10%] Medium 10-50% : Heavy 51-70%; Very Heavy 70%<

Situation (circle): bushland grassland [✓ wetland] rainforest trail/road along river/creek

Spray Data

Full product name/s of chemical/s used:	Rate /100L water:	Total Used (ml or L):
Glyphosate 360g/L	2L or 10L	2.6L
Metsulphuron	10g	19g
Additive/Wetters Used (specify): Spred wet	~~Spred~~ ~~[illegible]~~ 10ml	
Dye Used (specify):		

Spray Equipment Used (circle):

Spray gun [✓ Quik Spray] Backpack [✓ Splatter gun] Spray bottle

Other:______________

Total Spray Mix Applied: 190L

Method (circle):

[✓ Foliar (spot) spray] Boom spray Basal bark Stem injection Cut & paint [✓ Splatter gun]

Other:______________

Weather Conditions

☐	Showers	/	Light Cloud
☐	Overcast	/	Clear Sky

Time	Temperature (°C)	Relative Humidity (%)	Wind Speed (km/h)	Direction (from)	Variability (e.g. gusting)
Start:			light but		
			gusty in afternoons		
			on all days		
Finish:					

Comments (e.g. any problems with the application)

General Information

Observations General / Interesting Sightings

near the road in ~~there~~ ~~tooks~~ site E to the south there appears to be a patch of Juncas Kraussii thats been sprayed, this was not CVA. Possibly flooded with sea water in King tide

Accident/ Incident/ Near Miss Report

No

Requirements for follow work

Yes, Alligator will need extensive follow up for a few years

Entered in **AMS ☐** **PWIS ☐** ☺

NPWS Lower Hunter Area
Weed Treatment Recording Sheet

AMS - Data

AMS Equipment ID No:	AMS Work Order No:	AMS Site Name:	Reserve Name:
		Ash Island NCIG	

Activities Undertaken/ Situation

Spray Blackberry stage 5, Area 8

NPWS Staff and Equipment (Operations)

Date:	Work centre:	Description:	Duration:	Number:

External Contractors and Equipment (Components)

Contractor Company Name:	Contact Number:	Purchase Order:
CVA		

Date	Contractor or equipment	Duration	Number
28/3/18	CVA Staff	7.5 hrs	2

Pest and Weed Information System (PWIS) – Data

Operator data

Operator name/s:	Date/s:	Time/s
Elise Budden Zach Cotter	28/3/18	

Spatial Data – Arc Map

Specific Location (in order of treatment):	Easting or Latitude	Northing or Longitude

Spatial Data Capture Method:	Datum (circle):	Spatial Data Captured By:
GPS [✓ Map / eye ball] Other__________	GDA94 AGD66 Map supplied	

Weed Information

Weeds Targeted (common name)	Weed Density	Additional info
Blackberry	Heavy	

Weed Density: Sparse >1%: Light 1 – 10% Medium 10-50% : Heavy 51-70%; Very Heavy 70%<

Situation (circle): bushland [✓ grassland] wetland rainforest trail/road along river/creek

Spray Data

Full product name/s of chemical/s used:	Rate /100L water:	Total Used (ml or L):
Glyphosate	2L	6L
Metsulfuron Methyl	15g	4.5g
Additive/Wetters Used (specify):		
Dye Used (specify):		

Spray Equipment Used (circle):

Spray gun Quik Spray [✓ Backpack] Splatter gun Spray bottle

Other:______________

Total Spray Mix Applied:

Method (circle):

[✓ Foliar (spot) spray] Boom spray Basal bark Stem injection Cut & paint Splatter gun

Other:________________

Weather Conditions

	Showers		Light Cloud
	Overcast	✓	Clear Sky

Time	Temperature (°C)	Relative Humidity (%)	Wind Speed (km/h)	Direction (from)	Variability (e.g. gusting)
Start:					
Finish:					

Comments (e.g. any problems with the application)

General Information

Observations General / Interesting Sightings

Accident/ Incident/ Near Miss Report

Requirements for follow work

Entered in **AMS ☐** **PWIS ☐** ☺

NPWS Lower Hunter Area
Weed Treatment Recording Sheet

AMS - Data

AMS Equipment ID No:	AMS Work Order No:	AMS Site Name:	Reserve Name:
		Ash Island NCIG	

Activities Undertaken/ Situation

Spray Juncus acutus + Blackberry

NPWS Staff and Equipment (Operations)

Date:	Work centre:	Description:	Duration:	Number:

External Contractors and Equipment (Components)

Contractor Company Name:	Contact Number:	Purchase Order:
CVA		

Date	Contractor or equipment	Duration	Number
6/4/18	CVA Staff	7.5 hrs	2

Pest and Weed Information System (PWIS) – Data

Operator data

Operator name/s:	Date/s:	Time/s
Elise Budden Zachariah Cotter	6/4/18	

Spatial Data – Arc Map

Specific Location (in order of treatment):	Easting or Latitude	Northing or Longitude

Spatial Data Capture Method:	Datum (circle):	Spatial Data Captured By:
GPS [✓ Map / eye ball] Other_____________	GDA94 AGD66 Map supplied	

Weed Information

Weeds Targeted (common name)	Weed Density	Additional info
Juncus acutus	Light	
Blackberry	Light	

Weed Density: Sparse >1%: [✓ Light 1 – 10%] Medium 10-50% : Heavy 51-70%; Very Heavy 70%<

Situation (circle): bushland grassland [✓ wetland] rainforest trail/road along river/creek

Spray Data

Full product name/s of chemical/s used:	Rate /100L water:	Total Used (ml or L):
Glyphosate 360	2 : 100	750 mL
Meltsulfuron Methyl	1.5g : 10L	6.5g
Additive/Wetters Used (specify): Brush Wet		
Dye Used (specify): EnviroDye	10 : 100	30 mL

Spray Equipment Used (circle):

Spray gun Quik Spray [✓ Backpack] Splatter gun Spray bottle

Other:______________

Total Spray Mix Applied:

Method (circle):

Foliar (spot) spray Boom spray Basal bark Stem injection Cut & paint Splatter gun

Other:________________

Weather Conditions

	Showers		Light Cloud
	Overcast	X	Clear Sky

Time	Temperature (∘C)	Relative Humidity (%)	Wind Speed (km/h)	Direction (from)	Variability (e.g. gusting)
Start:					
Finish:					

Comments (e.g. any problems with the application)

General Information

Observations General / Interesting Sightings

Accident/ Incident/ Near Miss Report

N/A

Requirements for follow work

Entered in **AMS** ☐ **PWIS** ☐ ☺

Appendix C – Shorebird Monitoring tabulated results (General Flora and Fauna)

Date/Times																												
Date	8.1.18	9.1.18	9.1.18	23.1.18	23.1.18	24.1.18	8.2.18	8.2.18	8.2.18	15.2.18	22.2.18	22.2.18	8.3.18	8.3.18	9.3.18	15.3.18	20.3.18	20.3.18	6.4.18	6.4.18	14.4.18	22.4.18	22.4.18	24.4.18	15.5.18	15.5.18	13.6.18	13.6.18
Day	Mon	Tue	Tue	Tue	Tue	Wed	Thu	Thu	Thu	Thu	Thu	Thu	Thu	Thu	Fri	Thu	Tue	Tue	Fri	Fri	Sat	Sun	Sun	Tue	Tue	Tue	Wed	Wed
Time start	8.45pm	9.10am	3.05pm	6.55am	1.00pm	8.37pm	9.50am	3.30pm	9.48pm	9.14pm	7.42am	1.31pm	8.00am	1.56pm	8.55pm	8.50pm	11.24am	5.17pm	6.25am	12.15pm	7.36pm	8.45am	3.27pm	9.47pm	7.57am	1.40pm	7.45am	1.42pm
Time end	9.40pm	10.04am	3.37pm	7.45am	1.45pm	9.12pm	10.35am	4.12pm	10.32pm	9.50pm	8.37am	2.20pm	8.53am	2.40pm	9.40pm	9.43pm	12.08pm	6.07pm	7.30am	1.08pm	8.26pm	9.40am	4.10pm	10.30pm	8.55am	2.36pm	8.38am	2.20pm
Weather																												
Temp (°C)	25	25	32	18	32	26	25	31	24	23	17	27	21	24	20	25	26	26	17	27	20	17	23	18	12	20	9	17
Wind speed (km/h)	19	13	9	4	20	28	11	24	24	28	0	28	20	28	26	20	24	33	11	13	30	11	15	24	17	17	19	31
Wind Direction	E	SSW	N	NNE	ESE	ENE	NNE	ENE	ENE	ESE		ESE	SE	SE	SE	NNW	SW	S	NW	SE	NW	W	E	S	WNW	S	NW	WNW
Precipitation (mm)	0	5.4	5.4	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0.2	0	0	0	0	0	0	0
Tide																												
Day/Night	Night	Day	Day	Day	Day	Night	Day	Day	Night	Night	Day	Day	Day	Day	Night	Night	Day	Day	Day	Day	Night	Day	Day	Night	Day	Day	Day	Day
High/Low	Low	Low	High	Low	High	Low	Low	High	Low	High	Low	High	Low	High	Low	High	High	Low	Low	High	High	Low	High	Low	High	Low	High	Low
Time	9.09pm	9.34pm	3.31pm	7.19am	1.30pm	8.50pm	10.06am	3.50pm	9.53pm	9.56pm	8.00am	2.02pm	8.25am	2.15pm	8.57pm	8.53pm	11.31am	5.36pm	6.52am	12.48pm	7.54pm	9.09am	3.28pm	10.18pm	8.20am	2.13pm	7.59am	1.43pm
Height	0.47m	0.73m	1.42m	0.66m	1.58m	0.49m	0.75m	1.24m	0.67m	1.44m	0.61m	1.45m	0.68m	1.31m	0.76m	1.48m	1.69m	0.41m	0.64m	1.31m	1.68m	0.52m	1.39m	0.74m	1.65m	0.45m	1.58m	0.46m
Other																												
Observers	GL, JL	GL	GL	GL	GL	GL, JL	GL	GL	GL, JL	GL, JL	GL	GL	GL	GL	GL, JL	GL. JL	GL	GL	GL	GL	GL, JL	GL	GL	GL, JL	GL	GL	GL	GL

Area E sub sites listed below

North West Pond	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
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White-fronted Chat																																																																																							
Avocet, Red-necked			70	F	W																							5	F	W	30	F	W																200	F	W	90	F	W														90	F	W							50	F	W				6	F	W	12	F	W	10	F	W
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Ibis, Australian White						4	F	SM													1	F	SM																																														4	F	W																		
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Stilt, Black-winged			10	F	W													2	F	W							12	F	W	20	F	W																				5	F	W																																			
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Teal, Grey			20	F	W													50	F	W							20	F	W	15	F	W																60	F	W																25	F	W																					
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Species richness -			4			1			0			1			0			2			1			0			4			4			2			1			0			0			3			3			1			0			1			2			3			2			1			2			2			3			3			2		
Total abundance -			101			4			0			3			0			52			1			0			40			67			3			2			0			0			262			97			1			0			2			3			125			6			1			55			6			11			16			12		

Fish Fry Flat	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
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Avocet, Red-necked			5	F	W													26	F	W							10	F	W	20	F	W																30	F	W	10	F	W																									11	F	W										14	F	W
Cormorant, Great																																																																																					
Cormorant, Little Black																																								5	F	W																										1	F	W							1	R	A									
Cormorant, Little Pied																																																																					1	R	A	1	R	A				1	R	A				1	R	M			
Cormorant, Pied																																																																																					
Curlew, Eastern						1	F	M				1	F	M																1	F	M																																																							
Darter																																																																																						
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Egret, Cattle																																																																																						
Egret, Eastern Great						1	F	W																										1	F	W	1	F	W	1	F	W	1	F	W							1	F	W				2	F	W										1	R	A															
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Egret, Little									1	F	W																										1	F	W																																				1	F	W									
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Heron, Striated																																																																																							
Heron, White-faced	F	M				8	F	M	7	F	M	7	F	M	4	F	M				4	F	M	2	F	W							1	F	W	2	F	M				1	F	W							2	F	M	1	F	M	8	F	M							2	F	W	2	F	M				2	F	M	1	F	M	2	F	M	2	F	M
Ibis, Australian White	F	M				17	F	M				31	F	M	10	F	M				4	F	M	19	F	M							10	F	M				11	F	M										9	R	M	4	F	M	7	F	M							25	F	M	21	F	M				19	R	M	4	F	M						
Ibis, Straw-necked																																																																																						
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Night Heron, Nankeen																												2	F	W	1	F	W																1	F	W																																						
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North West Pond		Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
Plover, Double-banded																																																																																					
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Plover, Pacific Golden																												3	F	M																1	F	M	2	F	W																																				
Plover, Red-capped		F	M	2	F	M	12	F	M	6	F	M	15	R	M	8	F	M	13	F	M	16	R	M	11	R	M	8	F	M	15	F	M				13	F	M	22	F	M	9	R	M	20	F	M	10	F	W	3	R	M	21	R	M	13	R	M	9	R	M				14	F	M							8	R	M	16	R	M						
Rail, Buff-banded																																																																																				
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Stilt, Black-winged				30	F	W													7	F	W							40	F	W	31	F	W													50	F	W	40	F	W													7	F	W																					
Stint, Red-necked													3	R	M							1	F	M				1	F	M							17	F	M										10	F	W																																				
Stork, Black-necked																																																																																						
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Teal, Chestnut													9	F	W				30	F	W							10	F	W	21	F	W													20	F	W	30	F	W													20	F	W										36	F	W	32	R	M	24	F	W	5	F	W			
Teal, Grey				75	F	W													70	F	W							60	F	W	80	F	W													90	F	W	200	F	W													60	F	W										90	F	W	3	R	M									
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Species richness -				5			5			3			6			4			5			4			3			11			9			3			5			6			3			9			9			6			4			6			2			4			8			6			4			8			6			5			2		
Total abundance -				118			39			14			66			23			146			25			32			139			172			12			34			42			11			218			316			17			27			34			11			89			50			27			141			67			51			13			16		
Swan Pond South		Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
0 = nothing							0			0			0			0			0			0			0			0			0			0			0									0						0			0																														
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Avocet, Red-necked																																																																1	F	W										24	F	W	9	F	W	10	F	W	1	F	W	5	F	W
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Dotterel, Black-fronted																																																										2	F	M	2	F	M				3	F	M				2	F	M	2	F	M									
Dotterel, Red-kneed																																																																												3	F	M	3	F	M	2	F	M	9	F	M
Duck, Mallard/hybrid																																																																																							
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Lapwing, Masked		F	M																																					4	F	SM																			2	F	SM	2	F	SM				2	F	SM	2	F	SM				2	R	SM				4	F	M	4	F	SM
Night Heron, Nankeen																																																																																							
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Swan, Black																																																																																2	F	W	8	F	W
Tattler, Grey-tailed																																																																																							
Teal, Chestnut																																																		6	F	W							56	F	W													5	F	W	32	R	W	26	F	W				8	F	W
Teal, Grey																																																										20	F	W				3	F	W							20	F	W	30	R	W	34	F	W						
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Turnstone, Ruddy																																																																																							
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Species richness -				1			0			0			0			0			0			0			0			0			0			0			0			2			2			0			1			0			0			5			3			2			2			1			4			7			4			4			5		
Total abundance -				6			0			0			0			0			0			0			0			0			0			0			0			5			4			0			6			0			0			81			5			4			5			2			51			79			73			9			34		
Swan Pond North		Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
0 = nothing							0			0			0			0			0						0																																																																
White-fronted Chat																																																																																								
Avocet, Red-necked				120	R	W																															1	F	M	4	F	W				10	F	W	6	F	W										11	F	W	120	F	W				22	F	W	300	F	W	510	R	W	380	F	W	85	R	W	75	F	W
Cormorant, Great																																																																																							
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Dotterel, Red-kneed																																														4	F	M	1	F	M																																				
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North West Pond		Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha	No	Ac	Ha
Grebe, Australasian																																																													4	F	W																								
Greenshank, Common																																																																																										
Gull, Silver																																								10	F	W													1	F	W				3	R	W	6	F	W	54	F	W	6	R	W	1500	R	W							9	R	W			
Heron, Striated																																																																																							
Heron, White-faced																																								17	F	M	21	R	SM										2	F	W				1	F	W				1	F	W	2	F	W				1	F	SM	1	F	SM						
Ibis, Australian White																																																																																							
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Lapwing, Masked		F	M																			6	F	M																4	F	SM	7	F	SM							6	F	M				2	F	SM	2	R	SM	2	F	SM	8	F	SM	8	F	SM				4	F	SM	4	F	SM	2	R	SM	2	F	SM
Night Heron, Nankeen																																																																																							
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Appendix D – Shorebird Compensatory Habitat- Ongoing Hydrological Monitoring (Mahmood Sadat-Noori and William Glamore)

UNSW AUSTRALIA

Water Research Laboratory

Memorandum

Never Stand Still Faculty of Engineering School of Civil and Environmental Engineering

To: Philip Reid **Date:** 26/07/2018
From: Mahmood Sadat-Noori, Will Glamore
Subject: Shorebirds Compensatory Habitat – ongoing hydrological monitoring

1. Introduction

The Newcastle Coal Infrastructure Group (NCIG) shorebirds project focuses on the creation of habitat suitable for migratory wader birds in the lower Hunter River estuary. This primarily relates to the removal of mangroves and expansion of existing saltmarsh communities at the NCIG shorebirds site, referred to as Area E (Figure 1). The Water Research Laboratory (WRL), School of Civil & Environmental Engineering at UNSW Sydney, has previously provided advice and recommendations on this project in the report "Shorebirds Compensatory Habitat Area – Hydrological Controls for Ongoing Management". This report provides an update on the desktop and on-ground work accomplished till July 2018.

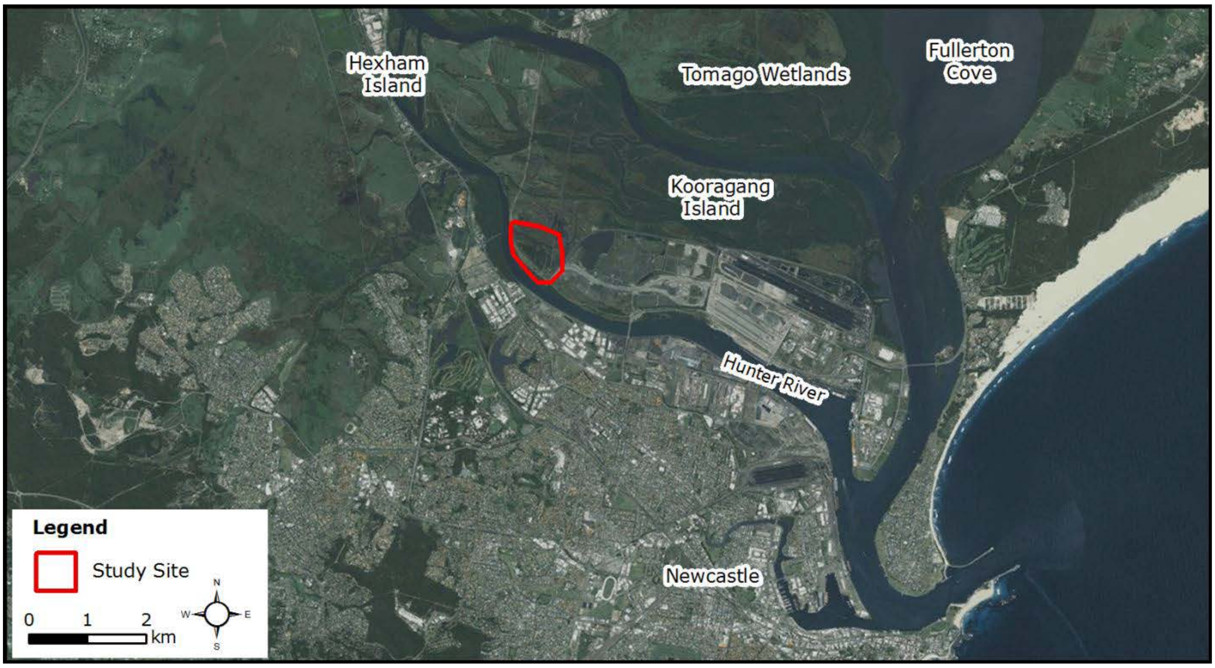


Figure1. The study site

2. Trigger Levels for 2018

UNSW's Water Research Laboratory has previously built a calibrated RMA model of the Hunter River, extending upstream of the study site from which water levels at Hexham Bridge, the Hunter River entrance and near Area E have been extracted for 2018. The modelled data indicates that water levels at Area E are more closely related, in amplitude and phasing, to levels at the river entrance than Hexham Bridge. All three water levels typically peak at similar heights, however the water level at Hexham Bridge fall less rapidly than at the entrance and near Area E.

Based on tidal water levels at the entrance to the river, trigger levels for the period February 2018 to February 2019 were calculated and provided to NCIG in April, 2018. It is recommended that the triggers remain constant between any two consecutive dates unless specified. Changes in the SmartGate trigger level have been designed to coincide with low tide to prevent rapid changes in water levels unrelated to the tidal cycle. The resulting synthetic tide, alongside the natural tide at Newcastle, is shown in Figure 2. These trigger levels are provided on a trial basis, with the recommendation that active monitoring occurs at the site, including water level monitoring and visual inspection of vegetation growth. To promote the on-going success of the project, adaptive management of the trigger levels is recommended to align with the environmental response of the site.

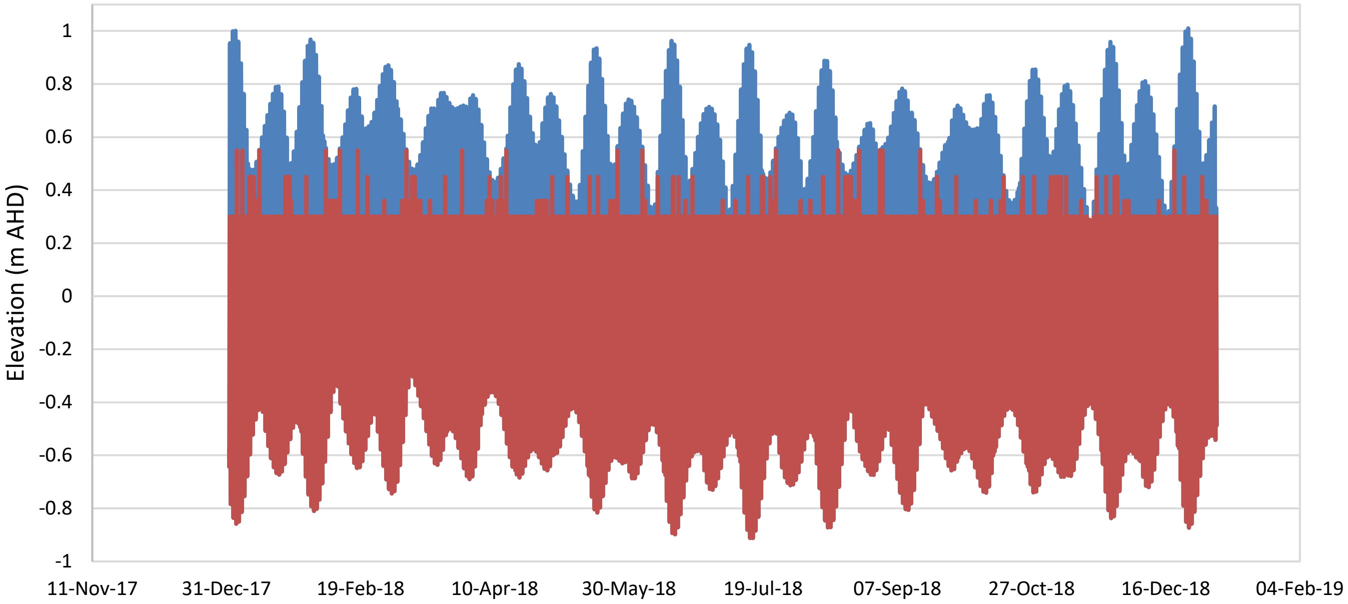


Figure 2. Newcastle tides and synthetic design tides for the 2018 period

3. Hydrology Monitoring

3.1 Groundwater dynamics

Detailed field investigations are ongoing. Specific tests were undertaken on April 4, 2018 and 1st May 2018 to investigate groundwater movement and interaction with surface waters at the site. Radon, a naturally occurring groundwater tracer was used to detect groundwater seepage into Fish Fry creek. A continues 6-hour time series dataset of radon (groundwater tracer) and water levels collected on each field campaign at the SmartGates at Fish Fry creek, clearly showed groundwater discharging into the creek during low tide periods (Figure 3).

This is specifically seen from the data collected on the 1st May (1/5/18) where a decline of about 1 meter in the Fish Fry creek water levels, caused a radon concentration increase of about 45 folds, indicating large amount of groundwater entering Fish Fry creek. Even small amounts of groundwater discharge have the potential to affect the quality of surface waters as groundwater often contains higher concentrations of organic and inorganic substances compared to surface waters. A dataset covering a full diel cycle of water quality paraments for both surface water and groundwater may be required to better evaluate the role of groundwater discharge on the water quality of Area E wetland.

For this, a week-long field campaign was conducted at Area E on the 16 July 2018. Surface water quality parameters were collected continually for 24 hrs in addition to groundwater quality data to investigate hydrological connectivity at Area E and how groundwater may effect Fish Fry creek water quality. A detailed report of the results from this on-groundwork will be provided upon analysis of the data.

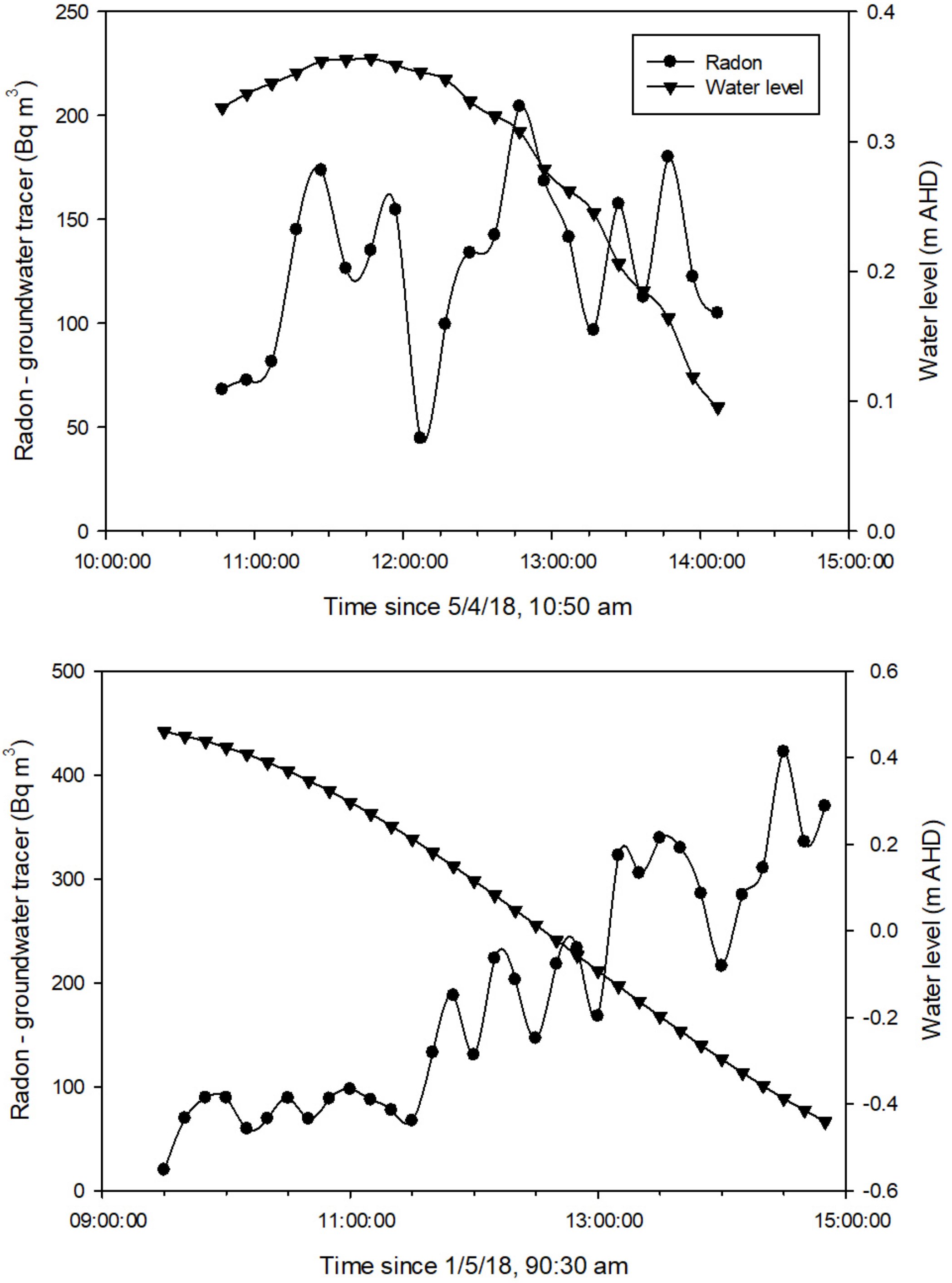
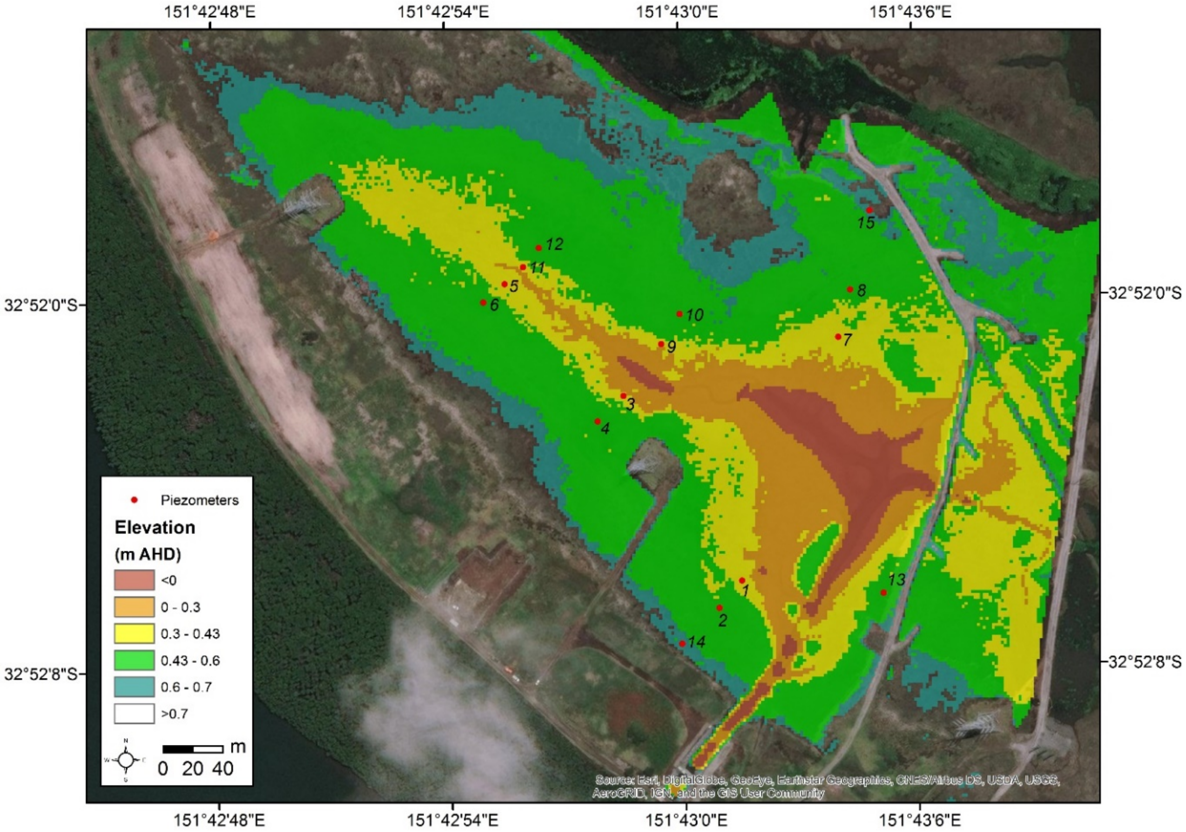


Figure 3. Newcastle and synthetic tides for 2018

3.2 Groundwater levels

Groundwater levels at Area E are continually recorded using Solinst pressure transducer loggers placed in piezometers that were installed at the end of 2017. Figure 4 shows the location of the piezometers at Area E. In additional to groundwater levels, piezometers 14, 2, 1, 7, 8, and 15 log groundwater Electrical Conductivity (EC) or salinity. These piezometer have been installed in a transect to cover groundwater dynamics on both sides of Fish Fry flats. Data from the aforementioned piezometers were extracted and groundwater level and conductivity times-series plots were created for the period 1st Jan to 1st May 2018 (Figure 5).

Data shows the average depth to groundwater at Area E is around 1.0 meter with the maximum depth of 1.4 m recorded at piezometer 15. Groundwater at this location also appears to be less affected by the diel tidal cycles and rainfall. Groundwater fluctuation showed similar patterns at piezometers 7 and 8, and also 1 and 2, which are 20 m apart. Groundwater depth at these locations shows the most variation caused by the tidal regime and flood inundation. In general, depth to the groundwater table at the Area E was stable during the first five months of 2018 with no obvious decline or incline trend observed in the graphs.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4. Location of the piezometers at Area E

3.3 Groundwater electrical conductivity (EC)

Conductivity is one way to measure of the inorganic materials including calcium, bicarbonate, nitrogen, phosphorus, iron, sulphur and other ions dissolved in a water body. Seawater EC is usually around 52,000 uS cm^{-1} (micro siemens per cm). Groundwater conductivity (EC) data indicate groundwater at Area E is hypersaline with all piezometer (except 14) showing a higher EC value than seawater (52,000 uS cm^{-1}). The highest conductivity of 64,000 uS cm^{-1} was observed at piezometer 15. This could be due to tides only reaching piezometer 15 location 0.3% of the time in a year (approximate 45 tides in a year) allowing large amounts of evaporation to take place which, in turn, can increase the concentration of salt delivered during tidal inundations to the area. This process on a smaller scale could also explain the high EC values in the remaining piezometers.

The lowest EC (48,500 uS cm^{-1}) was observed at piezometer 14 located on the opposite side of piezometer 15 towards Wader creek. Although piezometer 14 at Area E is located on an elevation similar to piezometer 15 (which had the highest EC) it shows considerably lower EC values. This lower EC is assumed to be caused by rainwater recharge as there is no other source of freshwater (i.e. no fresh surface water runoff) in the area. Due to the topography of the area in vicinity of piezometer 14, rainwater can infiltrate the banks located on the South West side of the piezometer and slightly reduces groundwater EC levels at this location compared to the rest of the piezometers in the transect. A 65mm rainfall event at the end of February 2018 shows a slight reduction in EC levels at Piezometer 14.

The data presented in Figure 5 provides an initial insight on groundwater EC at Area E. Overall, groundwater EC levels are high, indicating large amounts of inorganic mater present in the subsurface and/or high evapotranspiration rates. Due to no baseline data it is unclear whether hypersaline conditions are specific to Area E or natural condition at Kooragang Island. More detailed sampling from the area including shallow groundwater aquifer at Area E is required to identify the constituents in the groundwater.

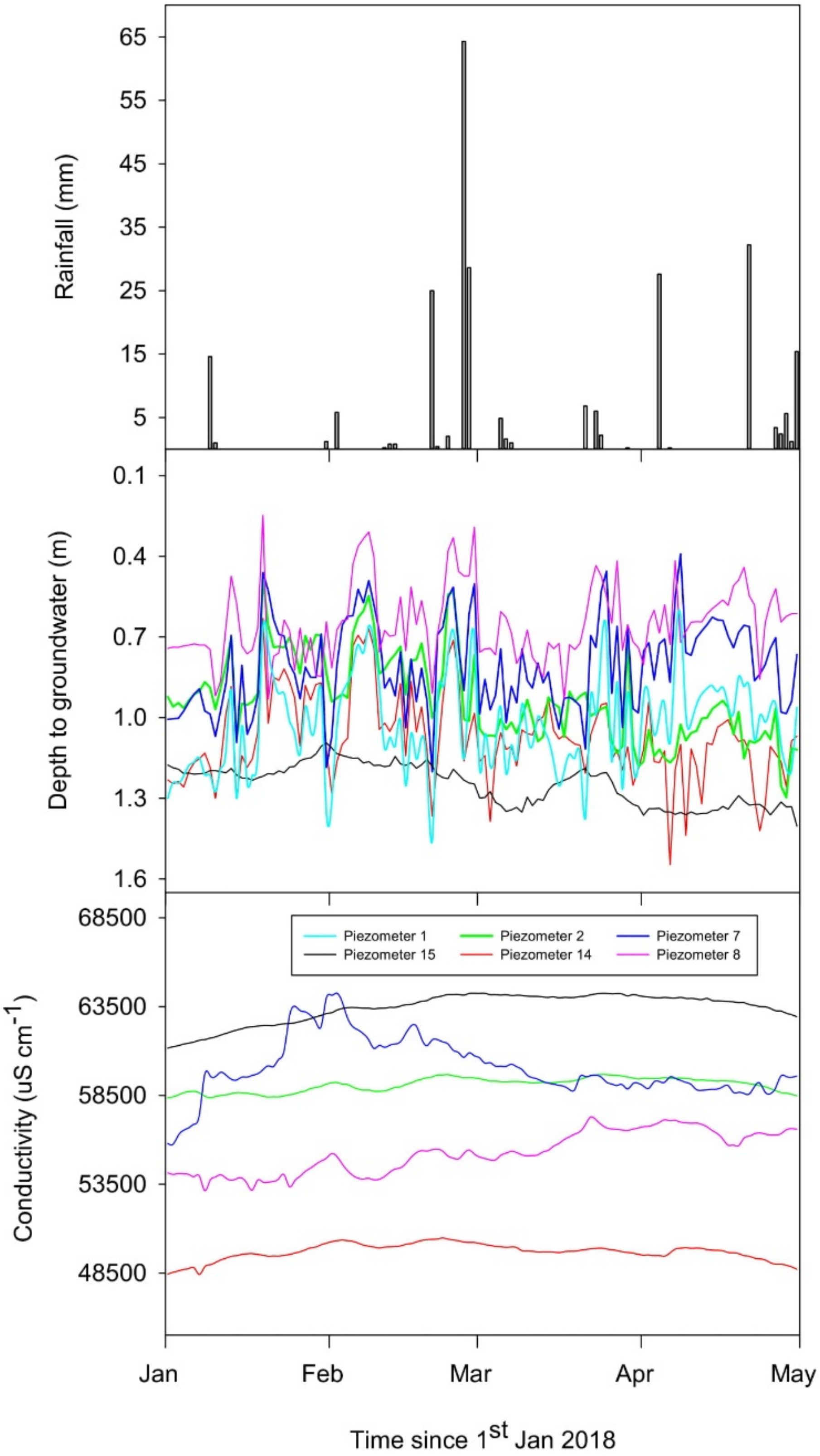


Figure 5. Rainfall, depth to groundwater and groundwater conductivity times series data from 1Jan 2018

4. Drone Survey

A total of four drone surveys have been conducted to date. Drone surveys were conducted on the 13th February, 5th July and 19th October in 2017 and 4th April 2018. An eBee RTK survey grade aerial drone was flown over the site and the data was processed using the Pix4D advanced photogrammetry software to create a digital elevation model for the study site. A total of 6 (six) ground control points were distributed around the site during each survey to increase the accuracy of the drone survey. Using the same software, a high resolution, georectified ortho-mosiac was also produced.

The created elevation model was used to investigate changes in land elevation after the removal of the mangroves from the area, specifically during the period from February 2017 to April 2018. Two cross sections (A and B) covering the width of Fish Fry mud flats with South West to North East orientation (the starting point being close to Hunter River) were chosen for this purpose. Cross section A is close to the SmartGates, while cross-section B is after the power transition pole at Area E and is 220 m in length. Figures 6 and 7, below show the location of the cross-sections.

Figure 8 shows the elevation profile for cross-section A. At the 130m distance from the starting point (red line in Figure 6) a comparison between data from 13/2/2017 (the dark blue line) and data form 5/4/2018 (the light blue line) depicts a slight increase in elevation at this location over the 1-year period. Figure 9 shows the elevation profile for cross-section B. Similar to cross-section A, comparison between elevation lines for the same dates (February 2017 and April 2018) shows a very minor variation in elevation at this location. However, during this 1-year period a slight increase in elevation is observed at the mud flats on the South West side of Fish Fry creek whilst an opposite trend or a slight decline is seen towards the North East of Fish Fry creek. This decline could possibly be the effect of inundation during flood tides causing minor erosion with the removal mangroves that would usually reduce these effects or organic subsidence. However, elevation variations at Area E are less than 0.1 meter and are within the uncertainty of the measurement techniques used. Therefore, changes at this stage are considered not significant. As land elevations and soil physical properties tend to change over a longer time period compared to vegetation, it is recommended to continue the drone surveys every 6 months to capture potential land elevation changes at the site.

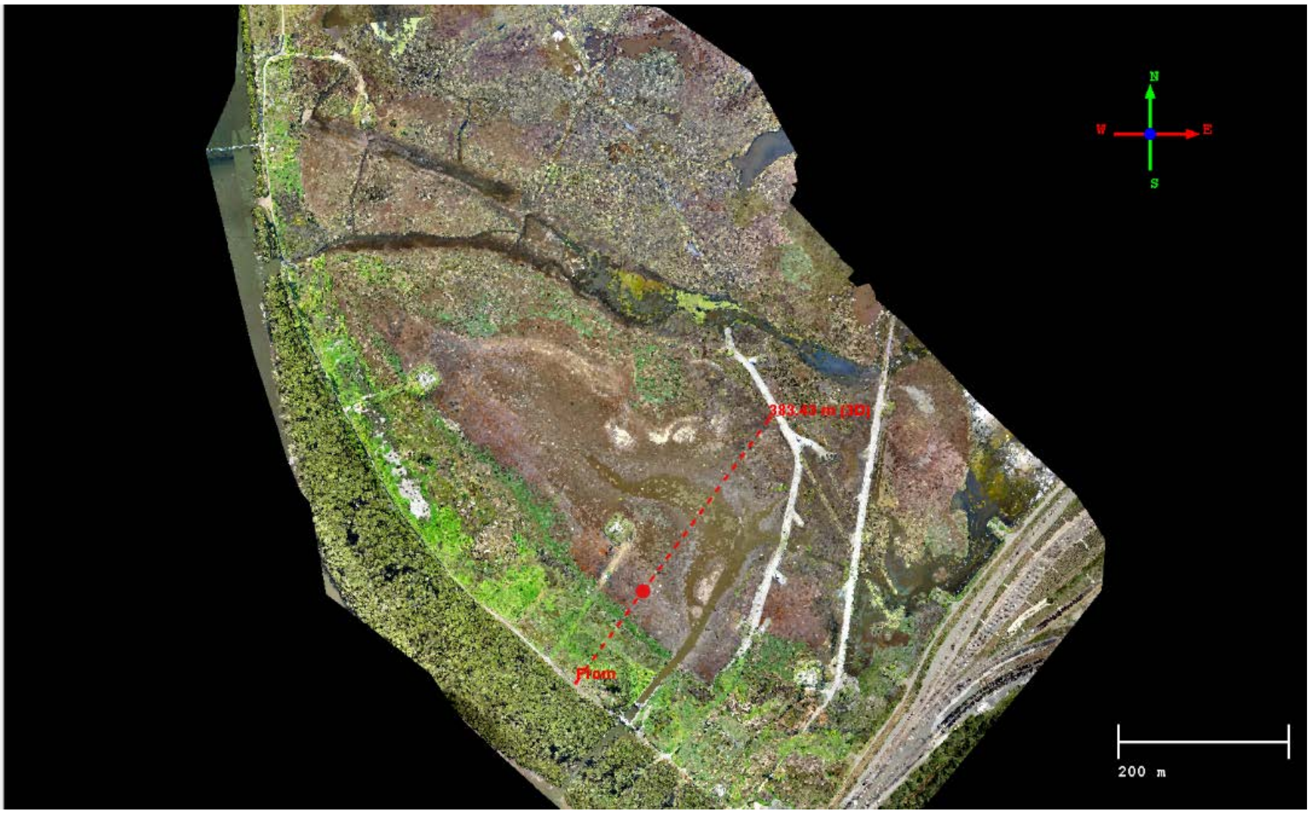


Figure 6. Location of the first cross section (A) at Area E.

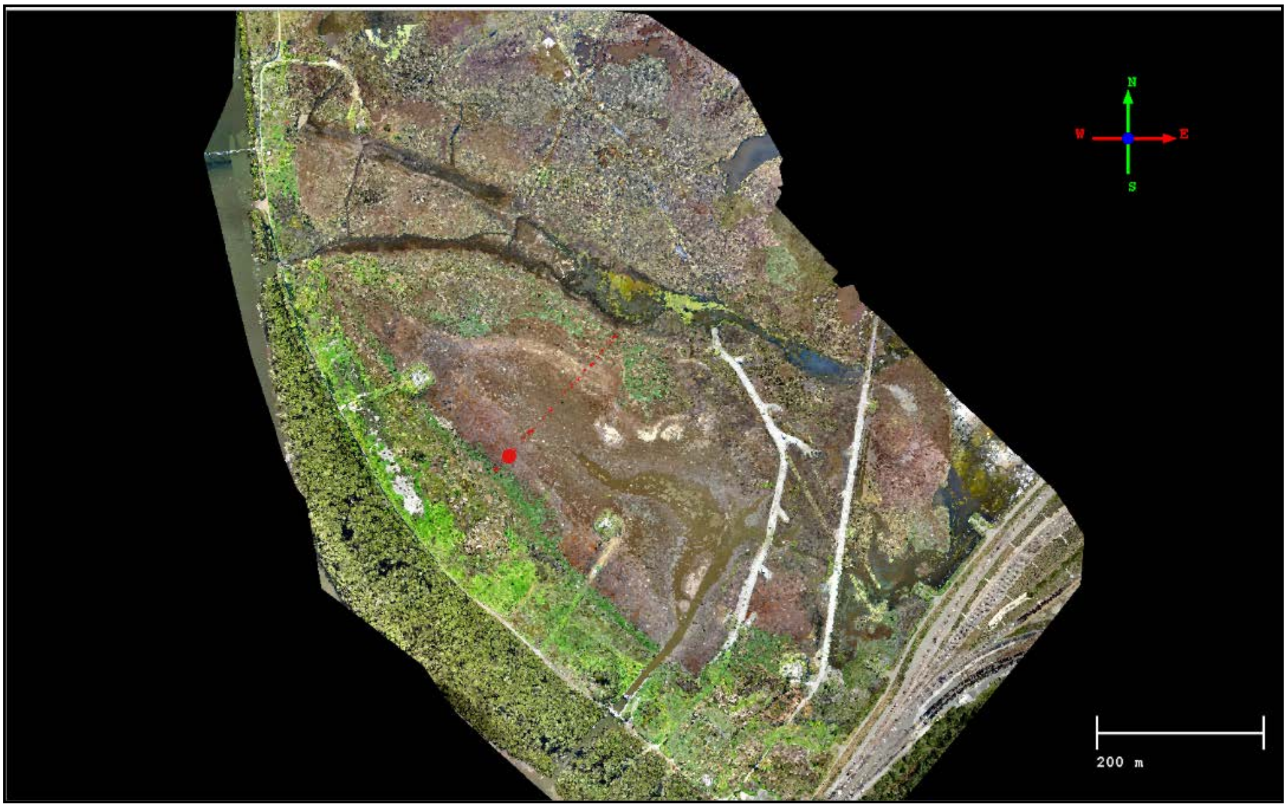
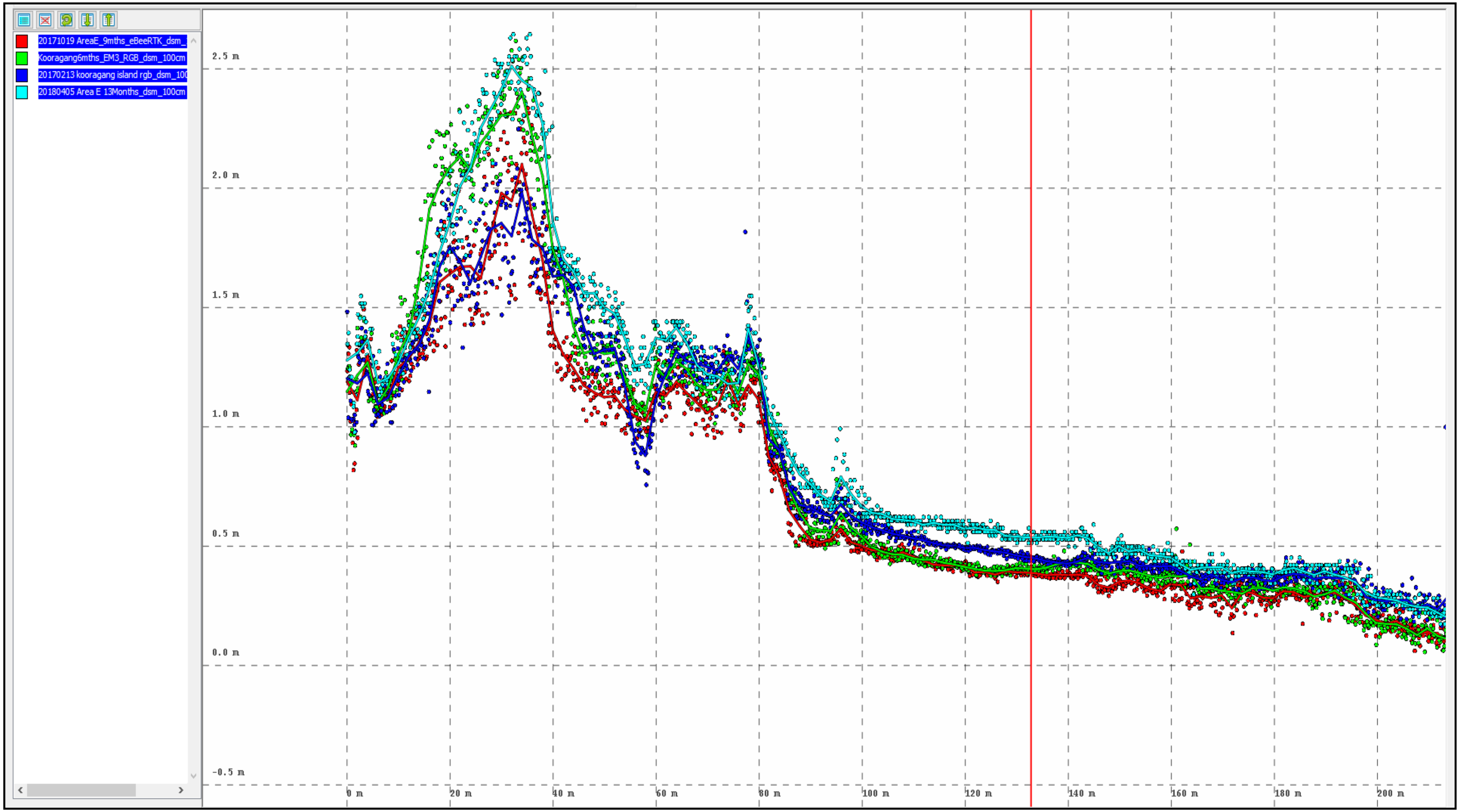


Figure 7. Location of the second cross section (B) at Area E.



Figurer 8. Elevation profile for the first cross section at Area E. Red line:19/10/2017, Green line: 8/9/2017, Dark blue line: 13/2/2017, Light blue line: 5/4/2018

Figurer 9. Elevation profile for the first cross section at Area E. Red line:19/10/2017, Green line: 8/9/2017, Dark blue line: 13/2/2017, Light blue line: 5/4/18

5. Vegetation monitoring

Multiple field campaigns have been carried out to assess vegetation distribution at Area E using 1m x 1m quadrates. Preliminary results show vegetation cover and species number has decreased slightly in the early data, though not significantly (Figure 10). However, it should be noted that in the mid and low marsh, which are inundated more frequently, these values have increased slightly. Site visits between Jan to June 2018 have seen an increase in saltmarsh seedlings. It is worth noting that *S. australis* and *S. quinifora* are recruiting more rapidly than *S. virginicus.* This may affect the infauna, crab, snail, and fish assemblages having a flow on impact on the shorebird communities. More details on vegetation monitoring are being provided by University of Newcastle staff.

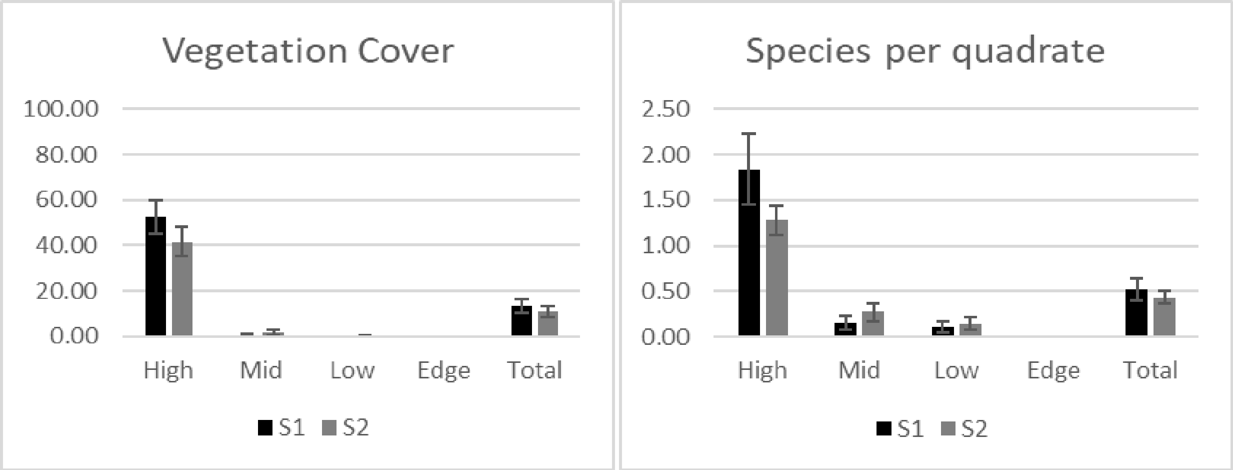


Figure 10. Preliminary saltmarsh vegetation cover and species assemblage data for November 2017 (S1) and February 2018 (S2).

6. Summary

Trigger levels for 2018 were prepared and provided to NCIG for ongoing control of SmartGates and hydrological management of Area E wetland. On-ground work during the first six months of 2018 indicate significant groundwater and surface water interaction at Area E with large amount of groundwater seepage during low tide periods. Groundwater conductivity levels are higher than se water conductivity values indicating large amount of evaporation. Vegetation surveys data from November 2017 and February 2018 show a slight decrease in vegetation cover and species number at the site but a slight increase in areas that are inundated more frequently. Drone surveys conducted till date show no significant elevation change at Area E in the period between February 2017 to April 2018. Drone surveys and surface water and groundwater quality monitoring will be continued in 2018.

Appendix E – Fish Fry Flats Vegetation and Benthos Survey Report – Methods and Preliminary Results (Caleb Rankin, UoN)

Fish Fry Flats Vegetation and Benthos Survey Report for Newcastle Coal and Infrastructure Group, Methods and Preliminary Results.

Date: 15 June 2018

Report by Caleb Rankin

All figures by Caleb Rankin unless otherwise specified.

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1 Overview

As part of their environmental offset, Newcastle Coal and Infrastructure Group (NCIG) have been leased critical shorebird habitat on Area E, Kooragang Island, to restore which they have done by means of encouraging saltmarsh growth by removing mangroves and installing floodgates (NCIG 2015). In order to determine the trajectory of the habitat restoration in with regards to overall functioning and delivery of ecosystem services, NCIG has partnered with the University of Newcastle to help identify, measure, and track these. This report gives an overview of the measures taken, the methodology, and preliminary results to date.

1.1 Measures

Ecological indicators, components of a system that are indicative on its health and functioning, can be reliably used to measure and identify restoration success with regards to habitat functioning and delivery of ecosystem services (Ruiz-Jaen and Mitchell Aide 2005, Brudvig 2017). For this study, various indicators of saltmarsh functioning that affect its value as shorebird habitat, including plant diversity and cover, organic litter, crab holes, and macro and meio infauna (organisms that live in the soil) are being measured.

2 Methods

2.1 Sites

In addition to the study site at Area E, 4 control and reference sites have been selected to compare the measures taken at Area E (Figure 1, outlined below). Control sites were selected for having a similar disturbance history both direct (e.g. grazing, invasive species, and vehicle use) and indirect (e.g. flood gates, eutrophication from farms and roads, and changes in surrounding communities) and reference sites were selected for having limited to no past disturbance as per Hobbs and Harris (2001).

2.1.1 Control and Reference sites

4 sites have been selected (Figure 1). The two control sites, Cobbans Creek and Crabhole Flats, will each be sampled 2x per year starting the end of June, (~5 sampling events by June 2020, project end. Of the two reference sites, Wagtail Way East will also be sampled twice per year with the control sites where Twelve-Mile Creek will be sampled once per year starting in November due to difficulty with access

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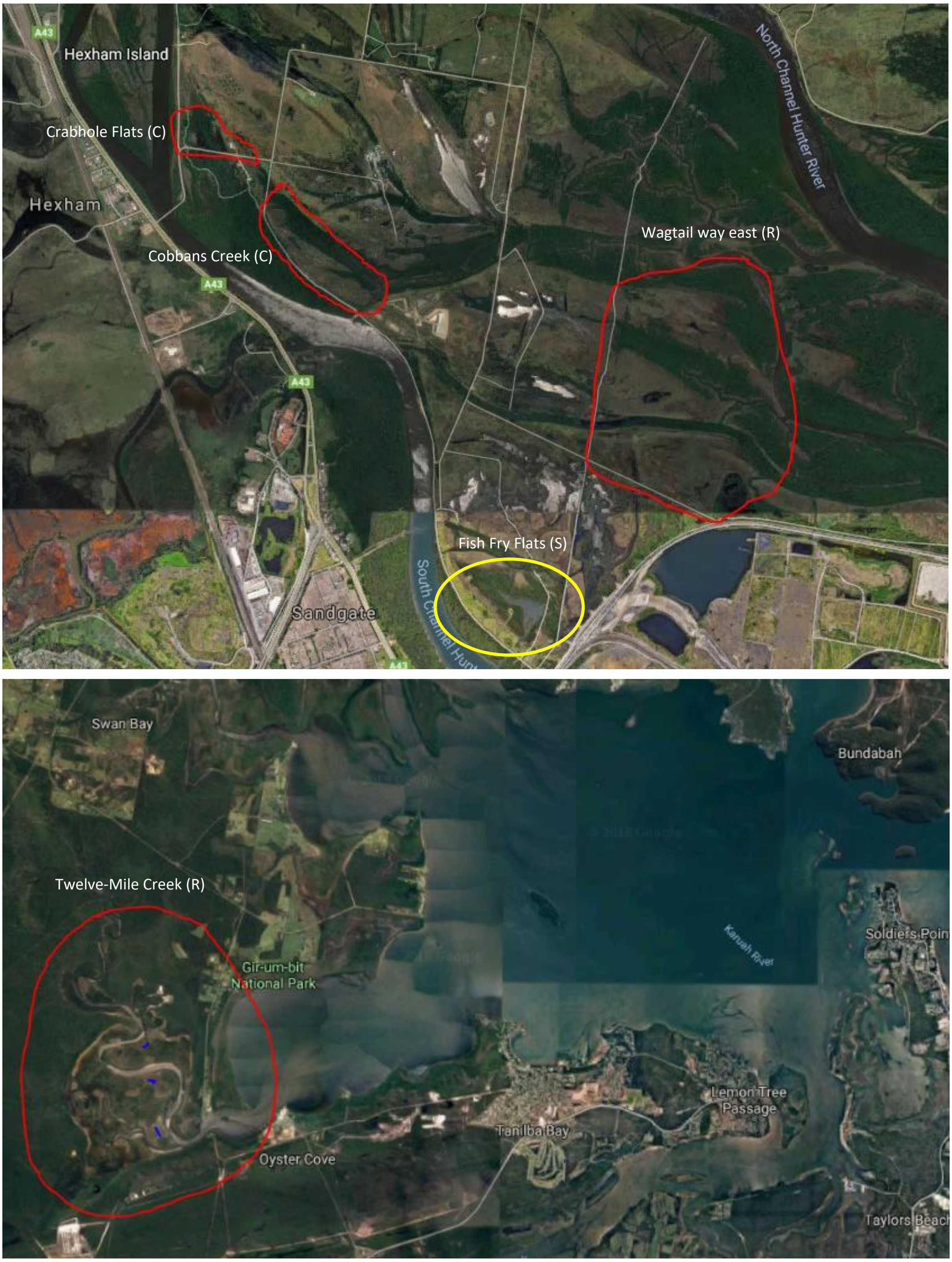


Figure 1: Locations of the control (C) and reference (R) sites in relation to the study site (S) to be used for this study. Imagery from Google Earth 2017.

2.2 Sampling strategy

Stratified random sampling is being undertaken at the sites with indicators being measured on each of five strata based on Digital Elevation Models (Figure 2).

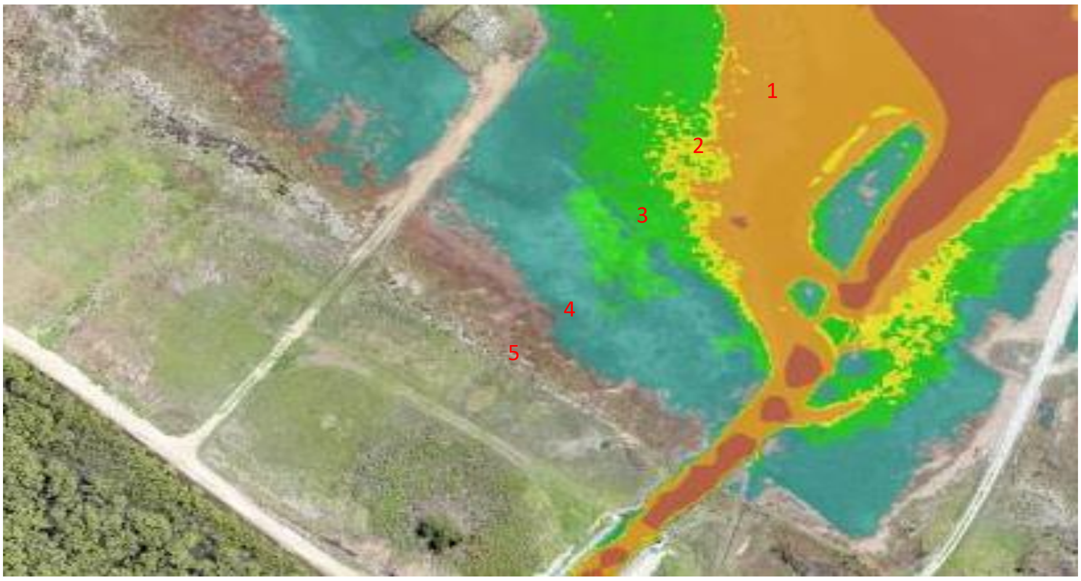


Figure 2: Digital Elevation Model detailing the strata from saltmarsh above highest tide (1) to mudflat (5) sampled in this study.

2.2.1 Vegetation, organic litter, and crabhole sampling

1m^2 Quadrats (Figure 3) placed randomly in each strata are being used to measure vegetation cover and diversity, organic litter cover, and active crab holes. In Area E, 25 quadrats have been placed in strata 5-2 with 101 quadrats sampled (including 1 reserve). In the control and reference sites, strata 5 is not present and the sampling does not need to be over as broad an area, thus 10 quadrats will be placed in strata 4-2 with 30 quadrats per site and 120 quadrats outside of Area E.

On selecting location of a quadrat, using random numbers, and tape measures, GPS (Lat-Long) coordinates are taken for mapping and 2 Supapeg® UV-Treated Polypropylene Sand Pegs are placed on quadrat diagonals for future quadrat placement at subsequent sampling events (Figure 4).

Figure 3: A quadrat used at Area E. Note the tape and pegs used for initial and subsequent sampling events.

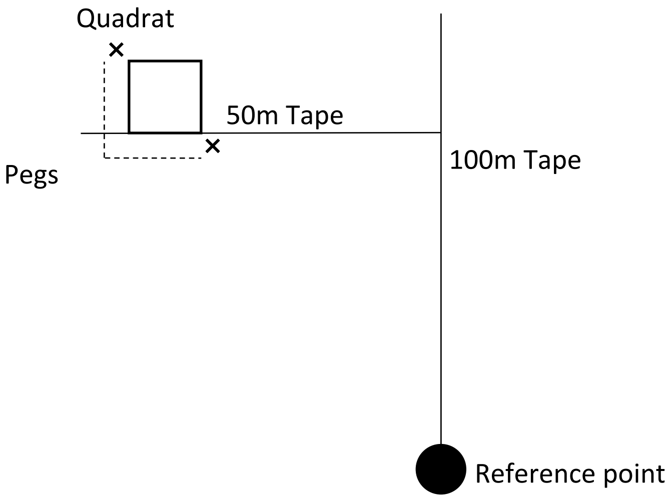


Figure 4: The quadrat placement process used in this study

2.2.2 Infauna Sampling

6cm deep cores extracted by PVC pipes are being used for sampling macro (>1mm) and meio (<1mm) infauna (see Figure 5 for an overview). Internal diameters for the pipes are 6.2cm for the macrofauna and 3.8cm for the meiofauna. In all sites, 8 cores are taken at random points around the site in each of the strata 4-1 (high marsh to mudflat/creek) separately for macro and meio infauna totalling 128 samples from the Hunter River and 32 samples from Twelve Mile Creek for each sampling event. Once collected, the cores are placed in sample jars to be processed in the lab (Figure 6) which includes fixation, staining, extraction, and preservation before the infauna can be identified and counted.

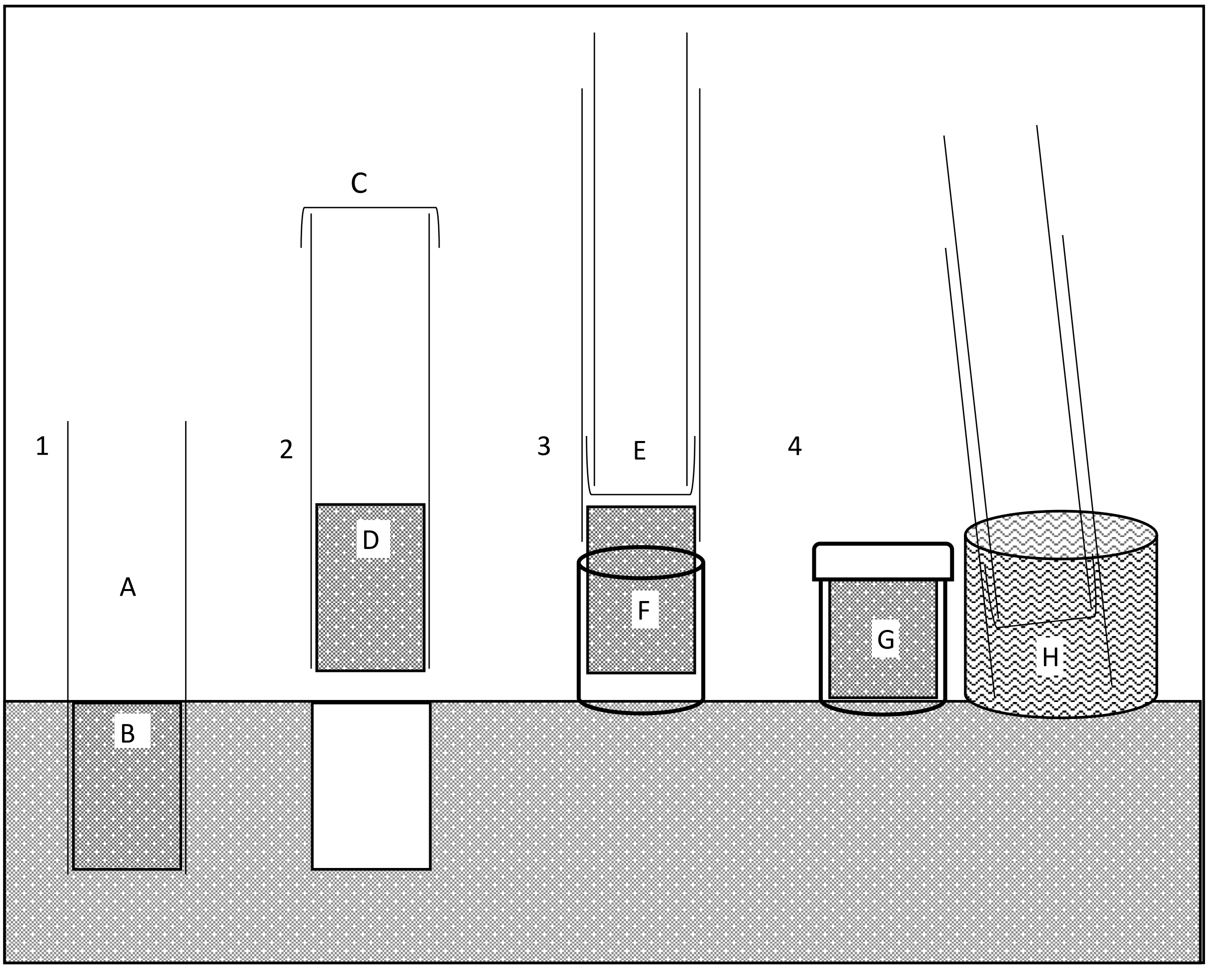


Figure 5: Procedure used for extracting sediment samples. 1 – A hollow PVC pipe (A) is inserted into the sediment (B), 2 – A fitted cap (C) is placed on the pipe and the sample (D) is extracted, 3 – The cap is removed and a plunger, consisting of a smaller pipe with attached cap (E) is used to push the sample into the sample jar (F) if the sample does not slide out by itself, 4 – The sample jar is sealed (G) and the pipes and plunger are washed in filtered sea water (H) before the next sample is taken.

Figure 6: Sieving of the core samples for removing coarse matter and fine sediment. With coarse matter removed macrofauna can be directly identified while meiofauna need further suspension and decanting before identification.

3 Results

While there are few results available to date, with the next sampling event set for the end of July this year, the early data that is interesting to note and gives an indication of the current health of the system and potential trajectories.

3.1 Vegetation, litter, and crabholes

Though not significant, vegetation cover and species richness has slightly decreased overall from the beginning of the study (Figure 7). This is largely due to losses of saltmarsh above the new tidal regime over summer while saltmarsh has increased in the mid and low marsh, which are inundated more frequently. Conversely, there has been an increase in litter throughout the site, contributing organic matter and potentially aiding seedling growth (Figure 8) and crabholes decreased (Figure 9).

Since the February 2018 sampling event, increased numbers of saltmarsh seedlings have been observed (Figure 10), It is worth noting that *S. australis* and *S. quinifora* are recruiting more rapidly than *S. virginicus.* It will be interesting to see with further sampling events how this trend develops and affects crabs, infauna, and shorebirds assemblages.

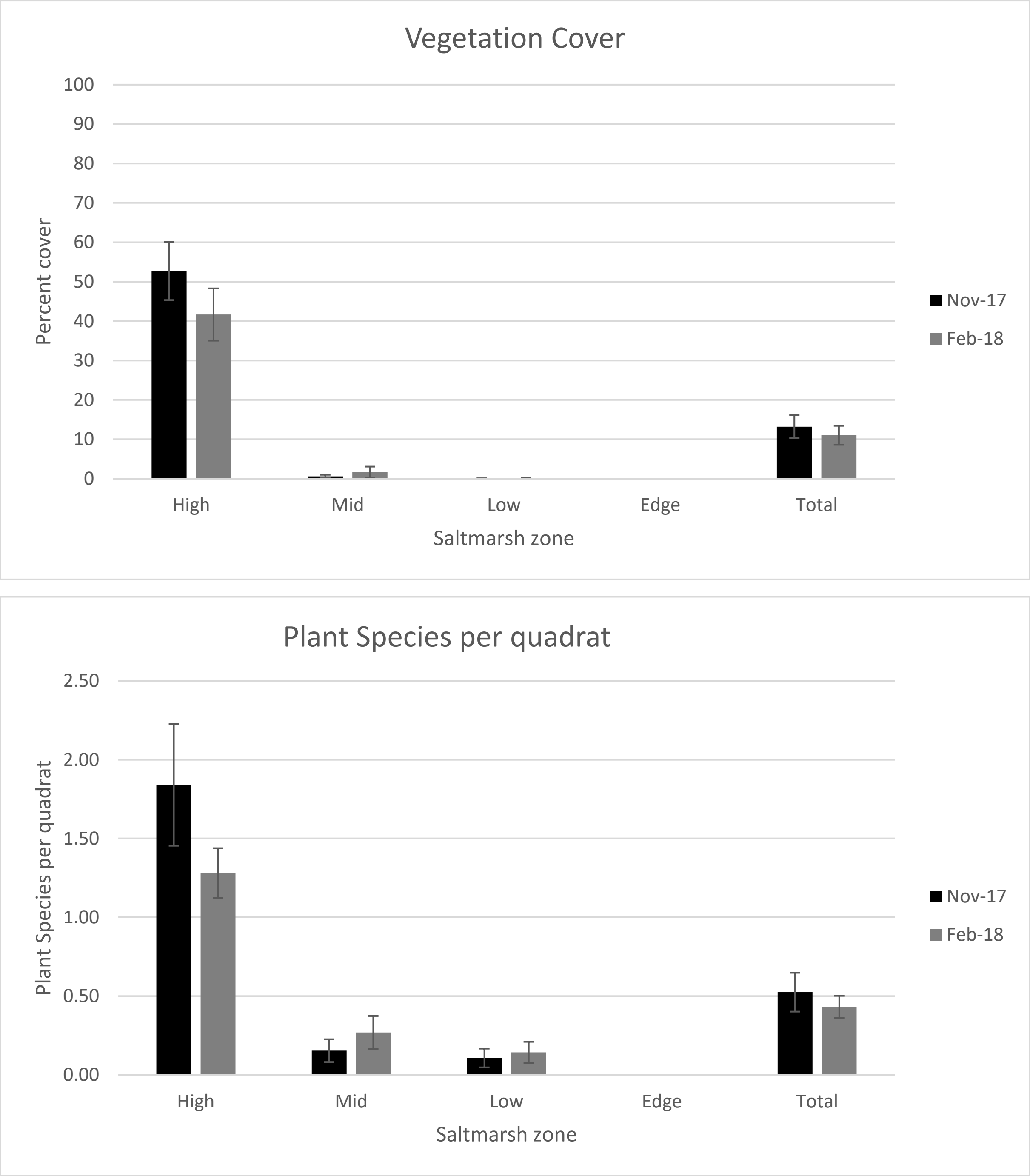
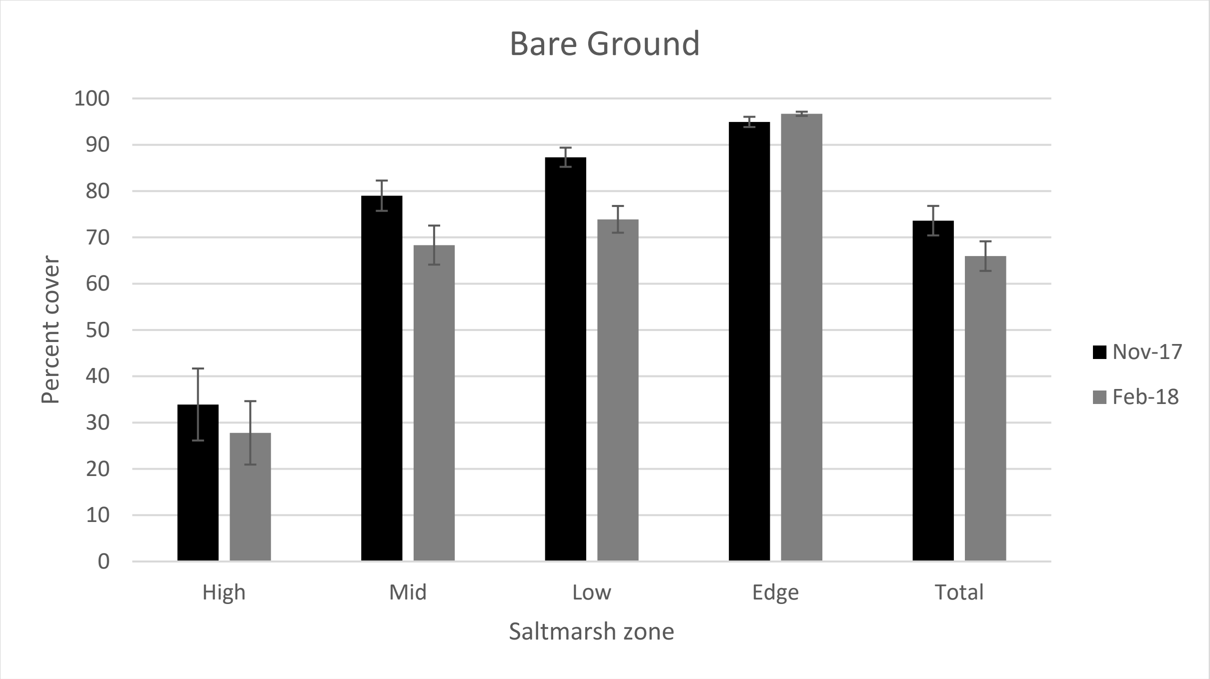


Figure 7: Saltmarsh vegetation cover and number of species per quadrat at each strata sampled in Area E at the sampling events of November 2017 and February 2018.



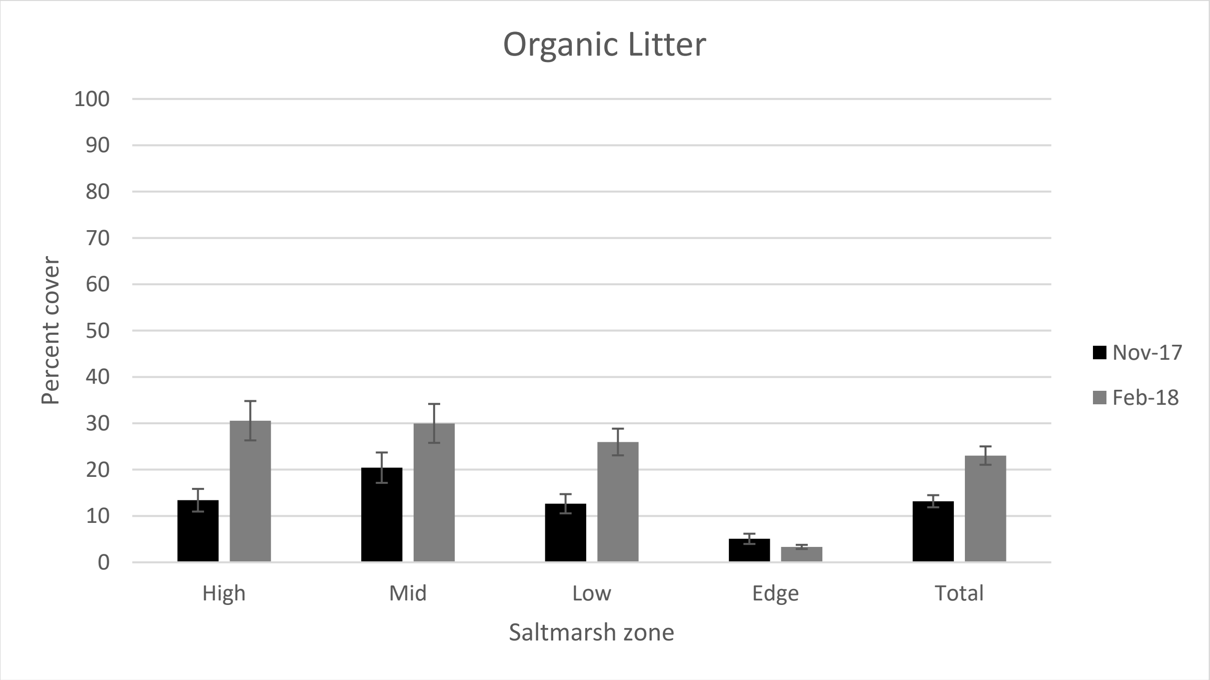


Figure 8: Percentage cover of bare ground and Organic litter per quadrat for each strata sampled in Area E at the sampling events of November 2017 and February 2018.

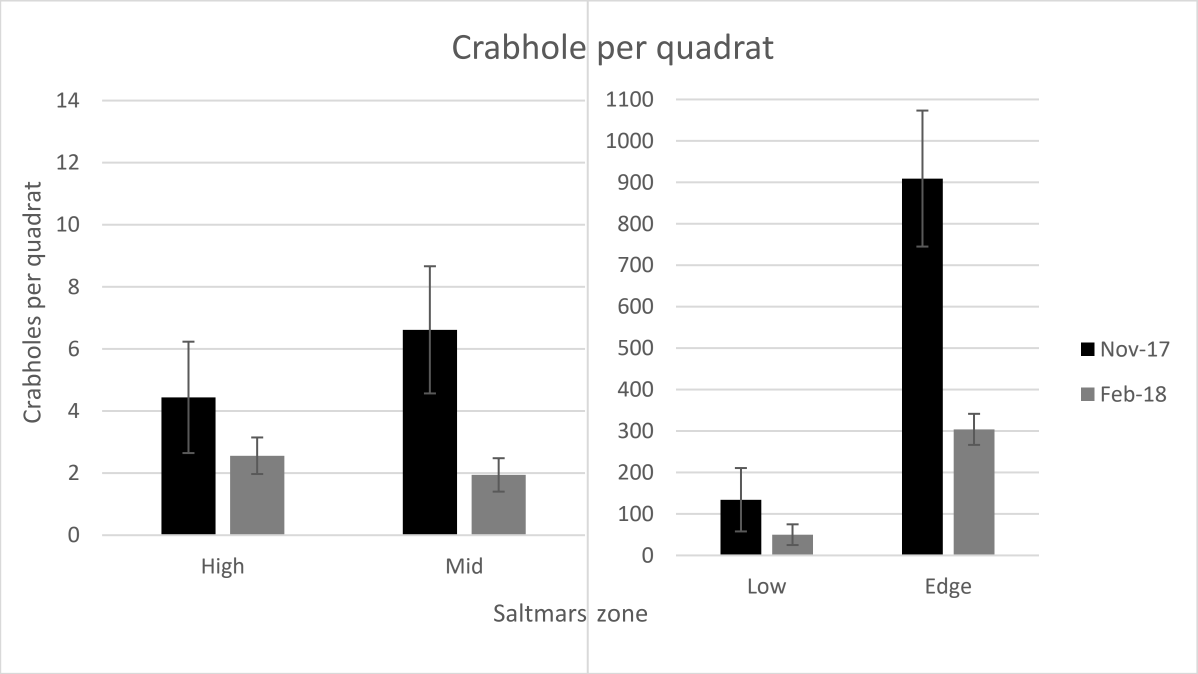


Figure 9: Average number of crabholes per quadrat for each strata sampled in Area E at the sampling events of November 2017 and February 2018. Note that due to high numbers, the crabhole numbers in some edge strata quadrates were estimates.

Figure 10: Carpets of new seedlings seen at Fish Fry Flats on May 2018.

3.2 Infauna

A large variety of infauna has been observed in the samples to date (Figure 11) including various crustaceans such as copepods, isopods, amphipods, and clam shrimp, insect larvae, small bivalves and gastropods and bristle worms. However, with over 100 times more nematodes (roundworms) then other infauna types, the preliminary data indicates a highly stressed and disturbed system. Other infauna mentioned above provide a valuable food source for crabs, fish, and birds, and their will need to be increases in their abundances if the system is to support a robust and healthy saltmarsh community.

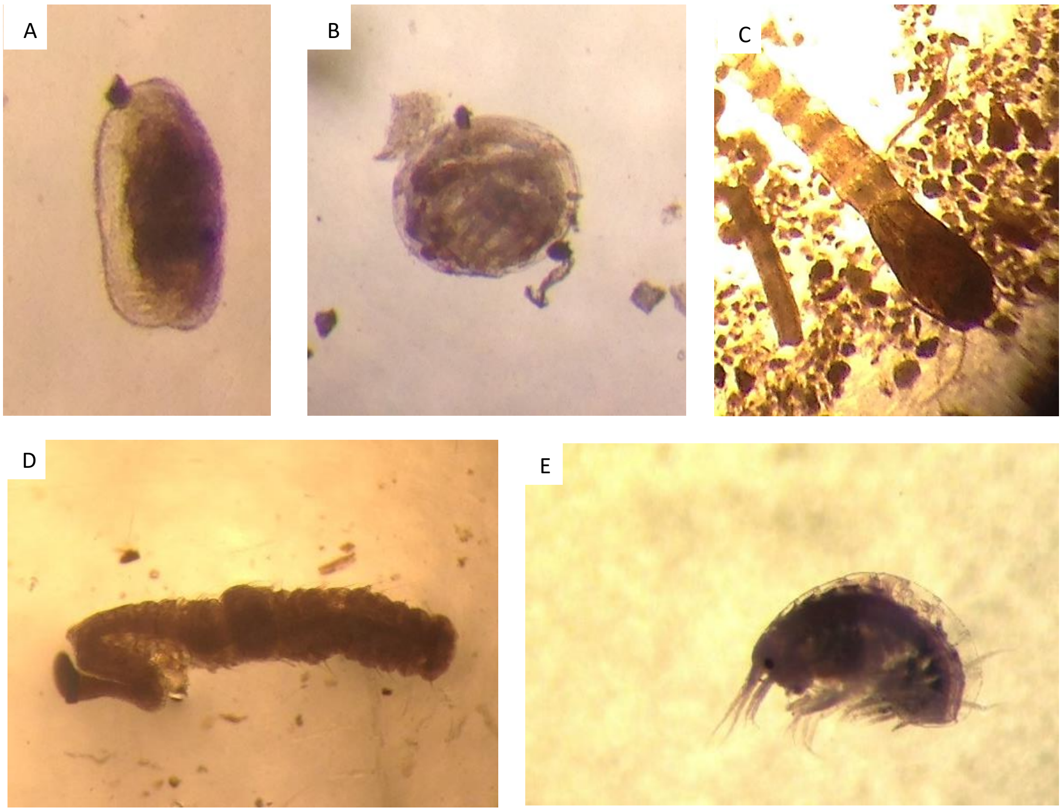


Figure 11: some of the infauna found so far at Area E including crab shrimp (A), bivalve (B), insect larvae (C), bristle worm (D) and amphipod (E)

4 References

Brudvig, L. A. (2017). "Toward prediction in the restoration of biodiversity." Journal of Applied Ecology **54**(4): 1013-1017.

Hobbs, R. J. and J. A. Harris (2001). "Restoration Ecology: Repairing the Earth's Ecosystems in the New Millennium." Restoration Ecology **9**(2): 239-246.

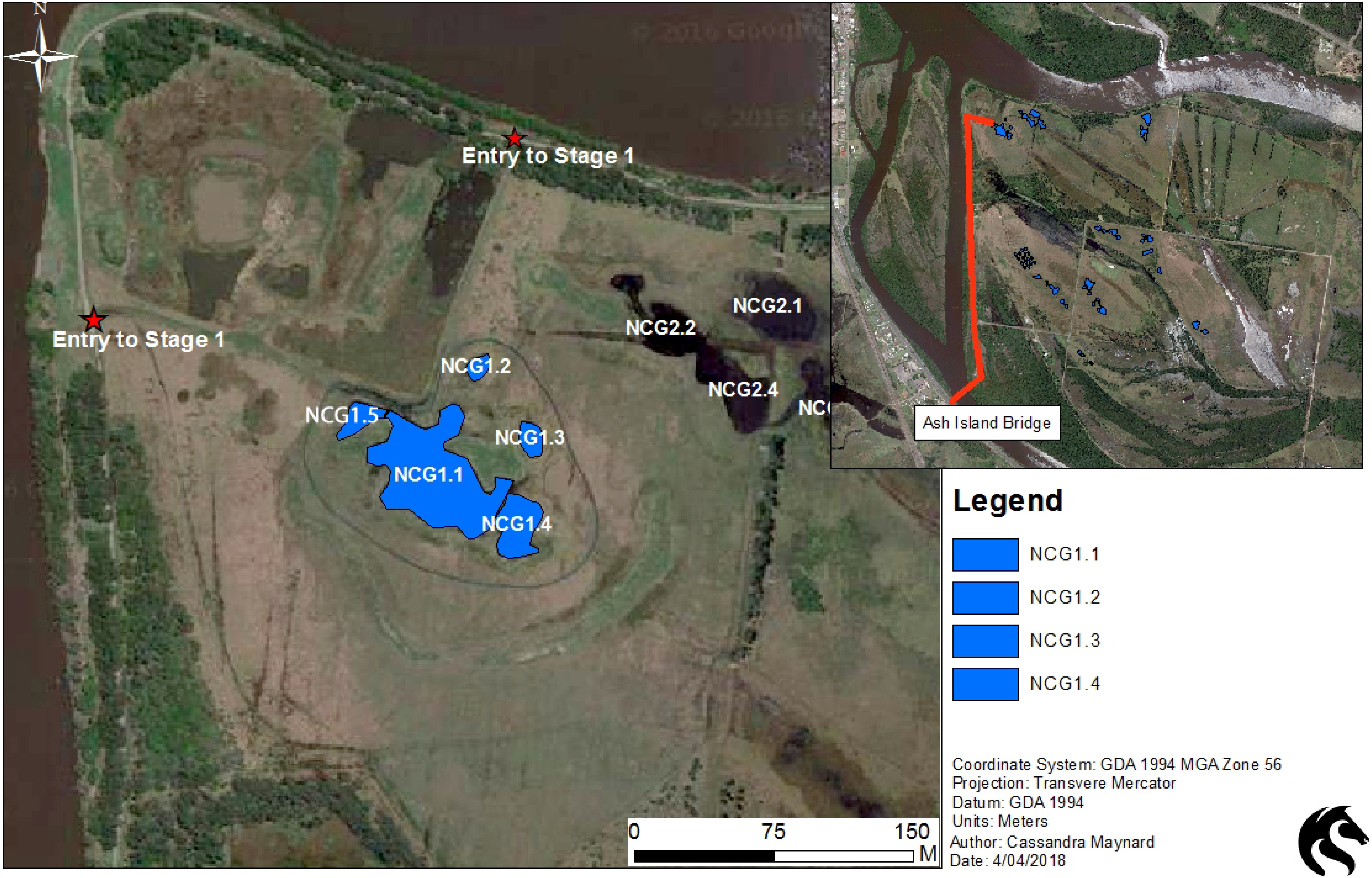
Ruiz-Jaen, M. C. and T. Mitchell Aide (2005). "Restoration Success: How Is It Being Measured?" Restoration Ecology **13**(3): 569-577.

APPENDIX 7

NCIG COMPENSATORY WETLANDS

NCIG Compensatory Wetlands Stage 1

Stage 1 in context to Ash Island Bridge



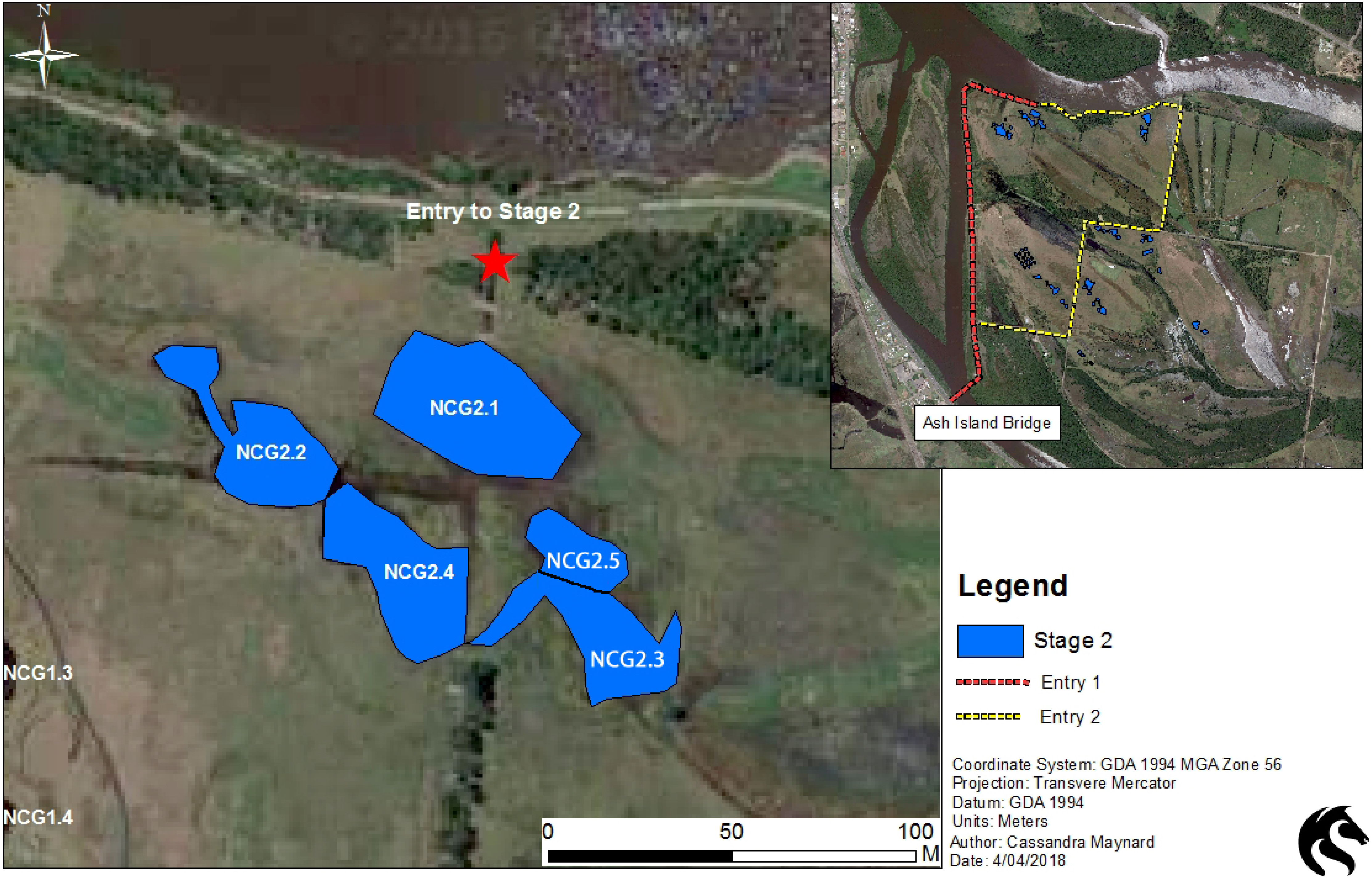
Legend

🟦 NCG1.1
🟦 NCG1.2
🟦 NCG1.3
🟦 NCG1.4

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transvere Mercator
Datum: GDA 1994
Units: Meters
Author: Cassandra Maynard
Date: 4/04/2018

NCIG Compensatory Wetlands Stage 2

Stage 2 in context to Ash Island Bridge



Legend

🟦 Stage 2
Entry 1
Entry 2

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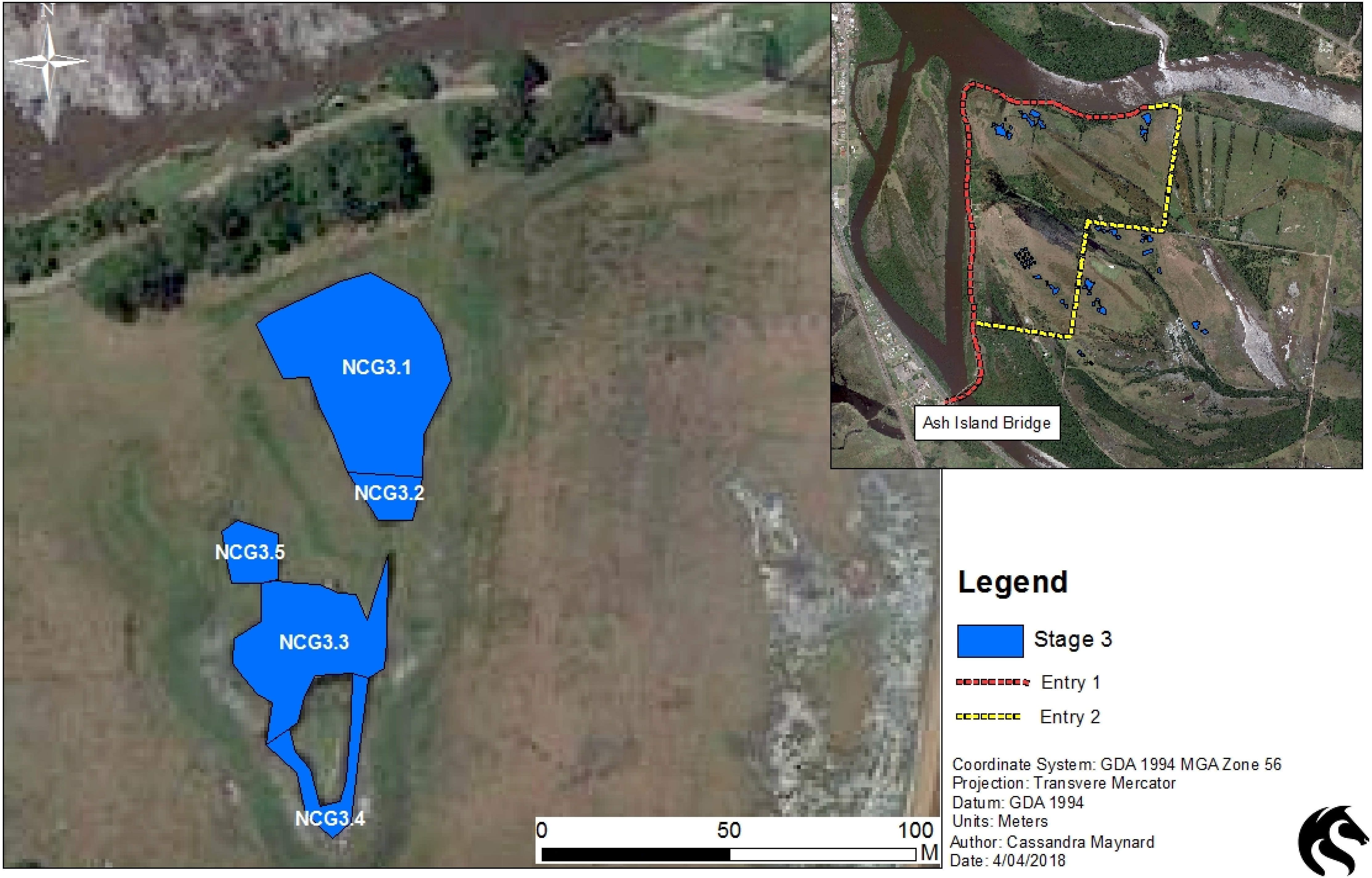
Projection: Transvere Mercator
Datum: GDA 1994
Units: Meters
Author: Cassandra Maynard
Date: 4/04/2018

NCIG Compensatory Wetlands Stage 3



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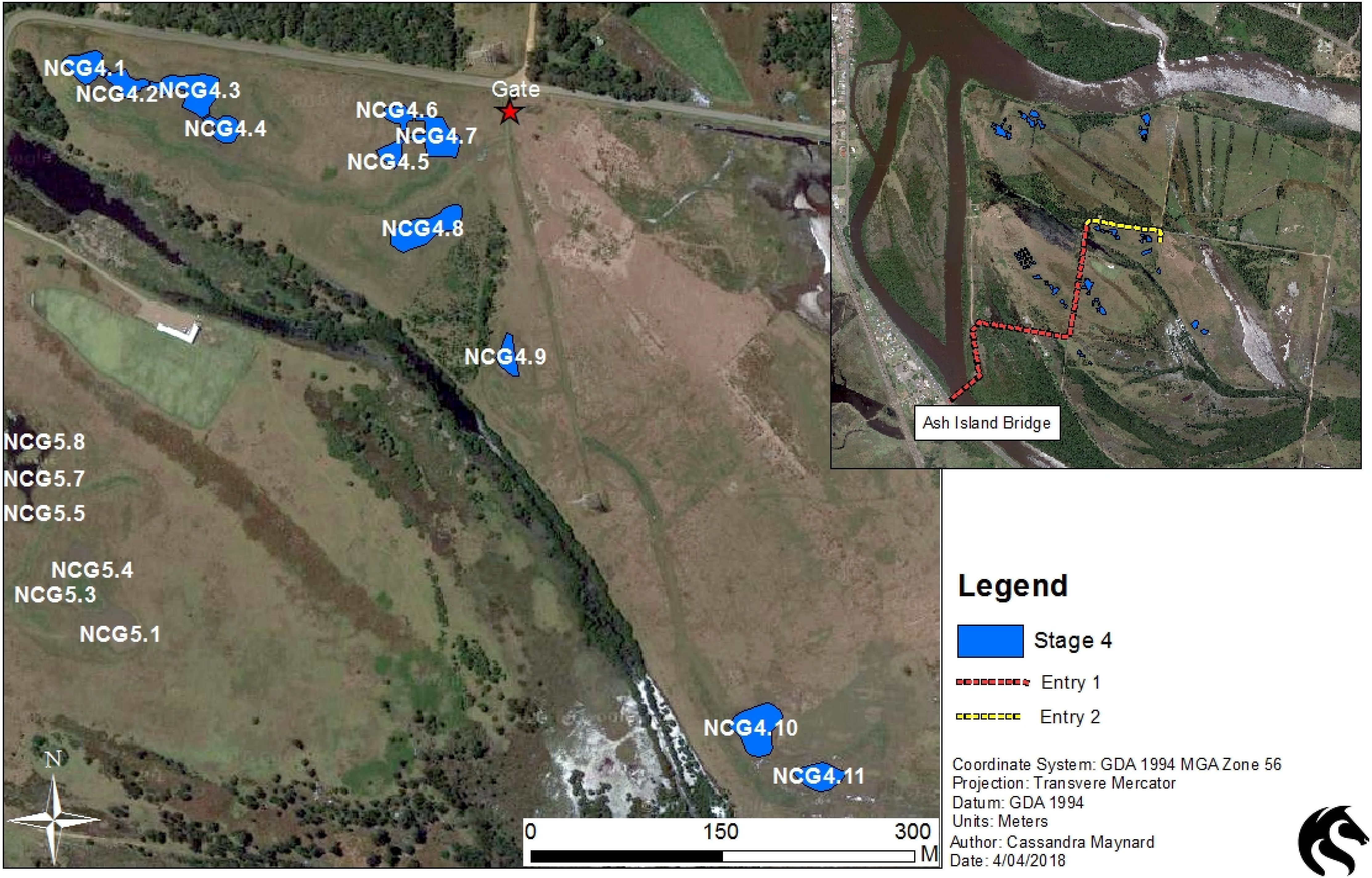
Units: Meters
Author: Cassandra Maynard
Date: 4/04/2018

NCIG Compensatory Wetlands Stage 4

Stage 4 in context to Ash Island Bridge



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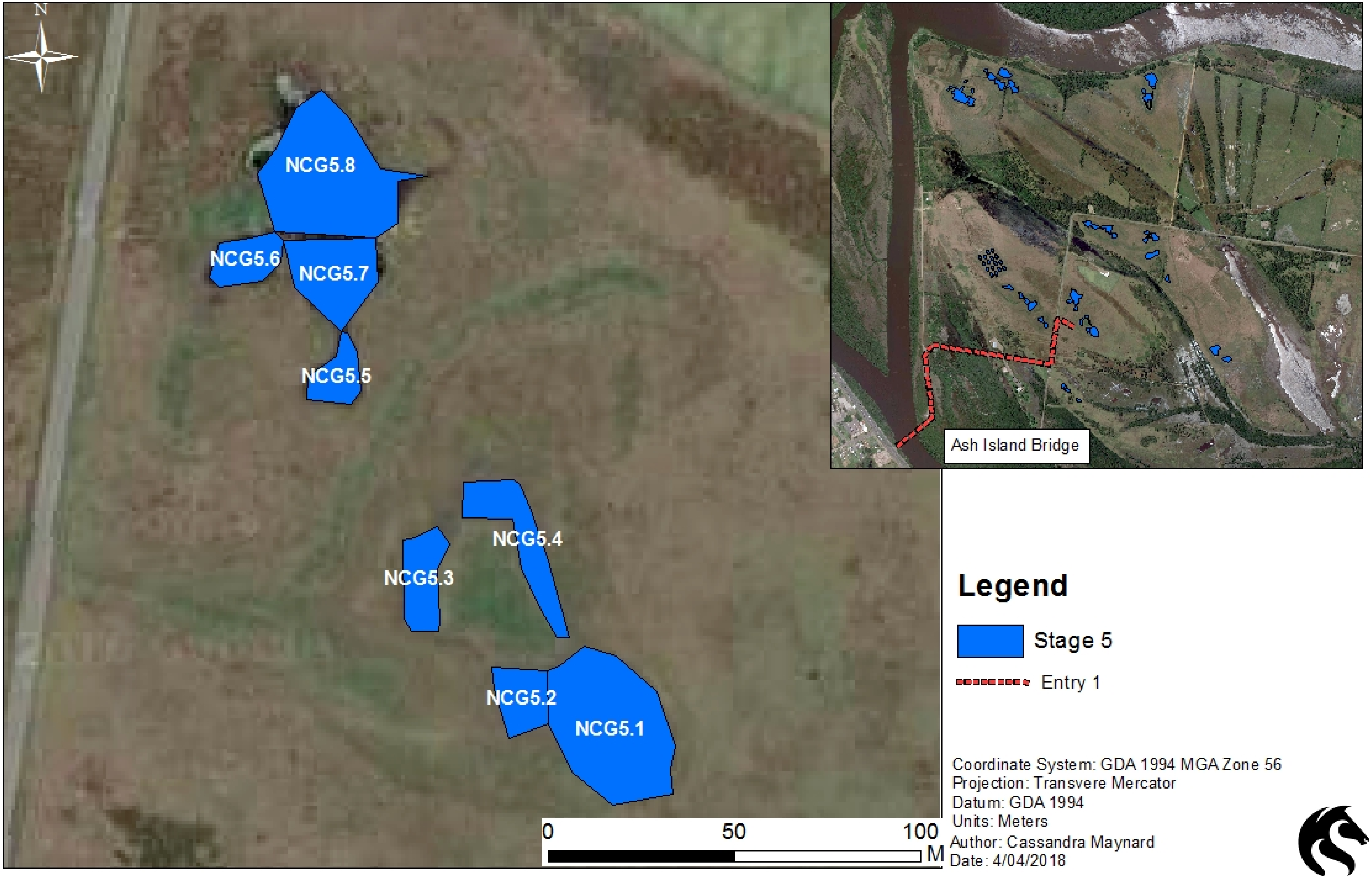
Units: Meters
Author: Cassandra Maynard
Date: 4/04/2018

NCIG Compensatory Wetlands Stage 5

Stage 5 in context to Ash Island Bridge



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▬ Entry 1

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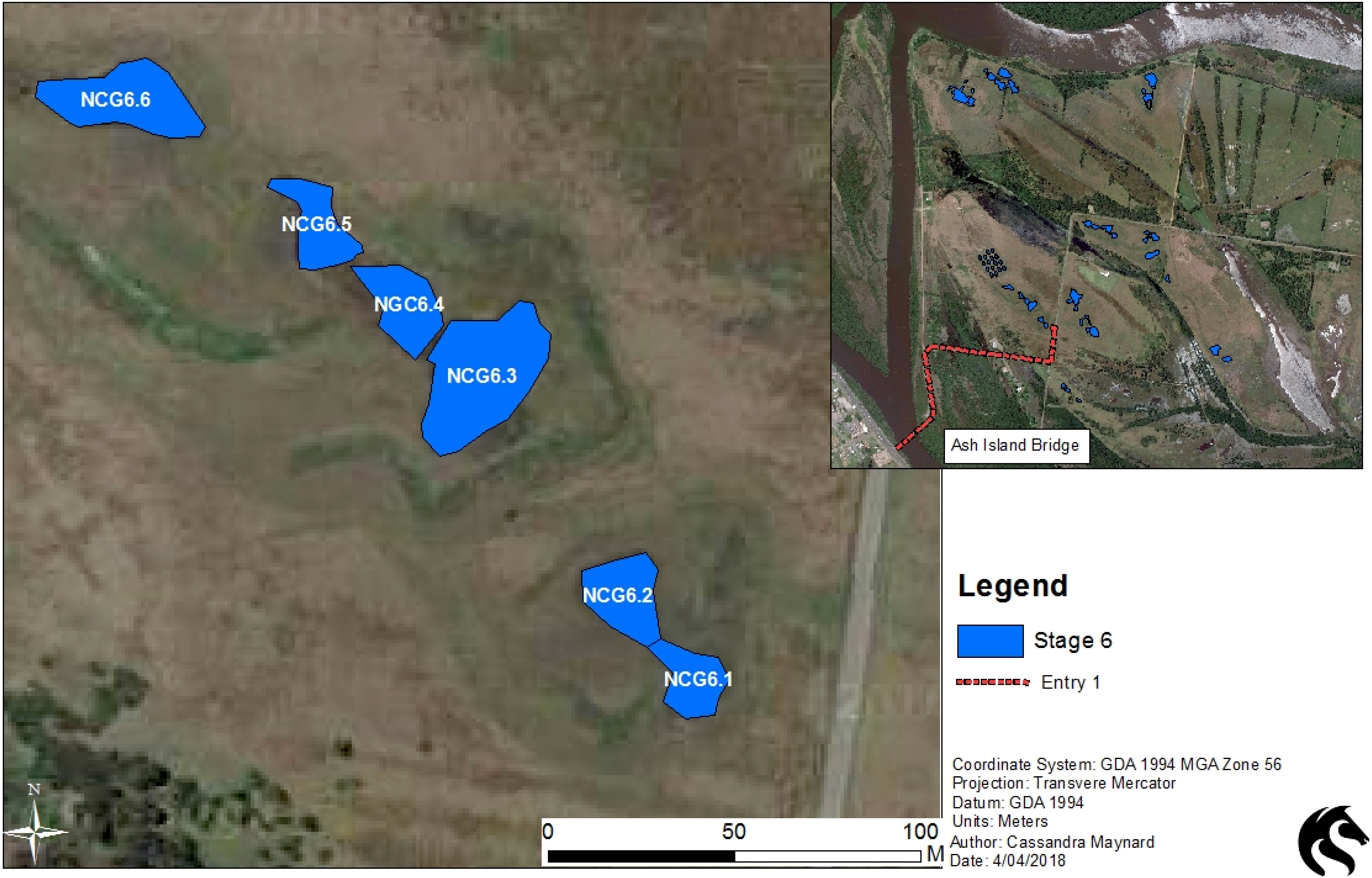
Datum: GDA 1994
Units: Meters
Author: Cassandra Maynard
Date: 4/04/2018

NCIG Compensatory Wetlands Stage 6



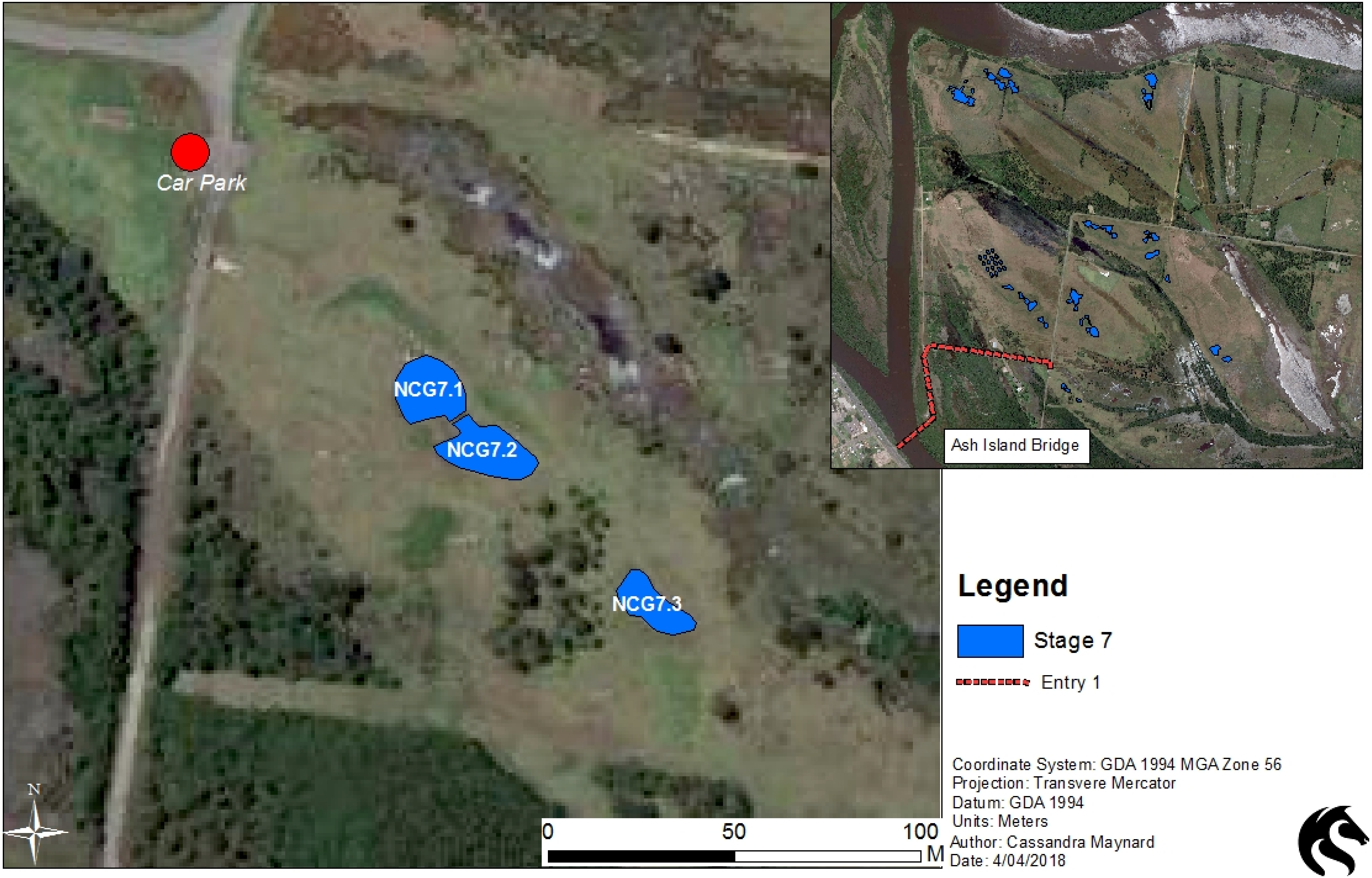
Stage 6 in context to Ash Island Bridge

Legend

🟦	Stage 6
▪▪▪▪▪▪	Entry 1

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transvere Mercator
Datum: GDA 1994
Units: Meters
Author: Cassandra Maynard
Date: 4/04/2018

NCIG Compensatory Wetlands Stage 7



Stage 7 in context to Ash Island Bridge

Legend

🟦 Stage 7

Entry 1

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transvere Mercator
Datum: GDA 1994
Units: Meters
Author: Cassandra Maynard
Date: 4/04/2018

APPENDIX 8

COMMUNITY SUPPORT PROGRAM

March 2018

Recipient	Purpose
Stockton Tennis Club	Weekly Junior Tennis Coaching & School Holiday Tennis clinics
The Cove Men's Shed Inc	Men's Shed Premises
Thornton Junior Football Club	Equipment Replacement
Stockton Junior Rugby League Club	Stockton Junior Rugby League Enrichment Program
Stockton Men's Bowling Club	Sun Safe Hat and Playing Jacket
Variety the Children's Charity NSW	Variety Spin 4 Kids - Community Challenge
St Josephs Primary School Dungog	St Josephs Primary iPad Program
Society of Artists	Newcastle Art Prize
Stockton Northern Districts Cricket Club	Replace and refurbish existing practice nets at Lynn Oval Stockton
Lifeline	World Suicide Prevention Day Walk
Lions Club of Jesmond	Biodiversity Day BBQ
Newcastle National Park Croquet Club	Repair and upgrade of sprinkler system and garden bed
Edgeworth FC-Arnett's Program	Football for children with disabilities
Technical Aid to the Disabled (TAD)	Funding for the workshop shed for volunteers to create equipment for people with disabilities.
Zara's House	Refugee Women and Children's Mother Language Literacy project
Hunter Life Education	World's Biggest Car Boot Sale, Pre-loved to Re-loved Sustainability Stage
Jenny's Place	Creating new counselling rooms
UoN Japanese-English Club	One Thousand Paper Cranes Festival
South Newcastle Junior Girls Hockey Club	Equipment Replacement
Stockton Public School Parents and Citizens' Association	Funding for ipads
Community Helping Community (Salt Ash)	Community activities in the centre
Newcastle Youth Orchestra	Wonderful Town by Leonard Bernstein
Surfing Newcastle	2018 NSW Junior Regional Titles
West Wallsend Senior Football Club	2018 Youth Football Gala Day
Easts Rugby Club	Purchase of commercial quality BBQ and ice machine

Families Supporting Families	Holiday Activity Program

Sep 2018

Recipient	Purpose
The Cove Men’s Shed	Completion of creek bank stabilisation
Stockton Sharks Football Club	Funding for new POS system
Stockton Jellyblubbers	Funding to host Northern Districts Winter Swimming
Christmas Carols in Lambton Park	Carols for 2018
Newcastle Meals on Wheels	Training for volunteers
Soul Café	Christmas with Soul
Soul Café	Soul Café Friday Chill Project
Hunter Region Botanic Gardens	LED Sign at entrance
Fern Bay Public School	Maths conceptual understanding through hands-on activities
Islington Village	Soft Fall material for Fun 4 All Access Spinner (Play equipment for disabled children)
Multiple Sclerosis Limited	MS Symposium in Newcastle