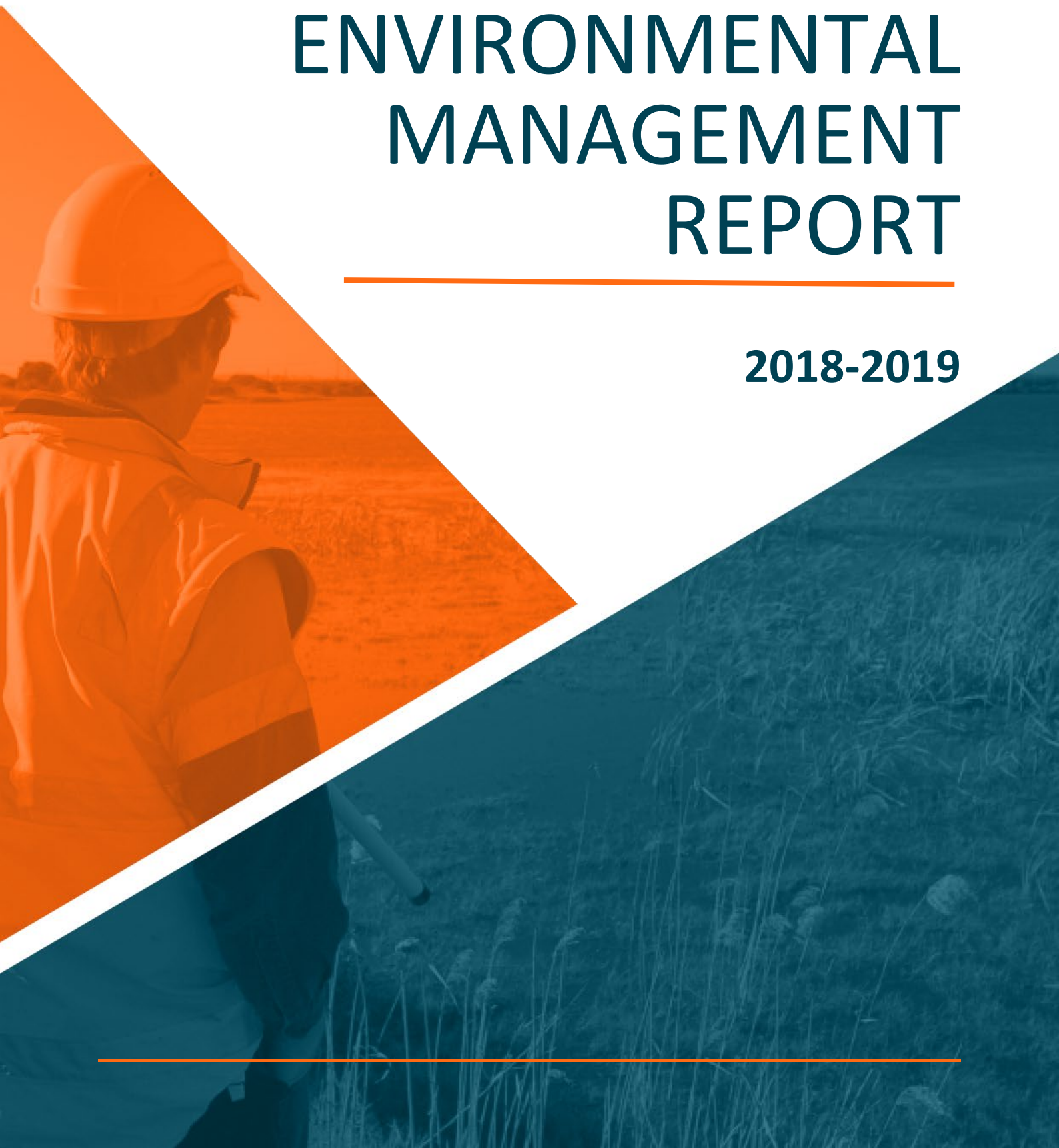
Newcastle Coal
INFRASTRUCTURE GROUP

ANNUAL ENVIRONMENTAL MANAGEMENT REPORT

2018-2019



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Description	**This Annual Environmental Management Report (AEMR) has been prepared for the Newcastle Coal Infrastructure Group (NCIG) Coal Export Terminal project. 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 (July 2018 to June 2019).**

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ACRONYMS AND ABBREVIATIONS

AEMR	Annual Environmental Management Report
ANZECC 2000	Australian and New Zealand Guidelines for Fresh and Marine Water Quality
ANZG 2018	Australian and New Zealand Fresh and Marine Water Quality Guidelines
AQMN	Air Quality Monitoring Network
ARI	Annual recurrence interval
ARTC	Australia Rail Track Corporation
BAMs	Beta Attenuation Monitors
BC Act	NSW Biodiversity Conservation Act 2016
BCD	NSW Biodiversity Conservation Division
CEG	Community Engagement Group
CET	Coal Export Terminal
CHEMP	Compensatory Habitat and Ecological Monitoring Program
CMR	Capture-Mark-Recapture Surveys
CVA	Conservation Volunteers Australia
DEC	Department of Environment and Conservation
DECC	Commonwealth Department of Environment and Climate Change
DO	Dissolved Oxygen
DoEE	Commonwealth Department of the Environment and Energy
DPIE	NSW Department of Planning, Industry and Environment
EC	Electrical conductivity
ELMP	Ecological and Land Management Plan
EMS	Environmental Management System
EPA	NSW Environment Protection Authority
EPBC Act	Commonwealth Environment Protection and Biodiversity Conservation Act 1999
EPL	Environmental Protection Licence
ESCP	Erosion and Sediment Control Plan
g/m^2/month	Grams per square metre per month
GGBF	Green and Golden Bell Frog
GGBFMP	Green and Golden Bell Frog Management Plan
GLR	Gross Load Rate
GULR	Gross Unload Rate
HCCDC	Hunter and Central Coast Development Corporation
HSEC	Health, Safety, Environment and Community.
HVAS	High Volume Air Sampling

IEA	Independent Environmental Audit
kg	Kilograms
KIWEF	Kooragang Island Waste Emplacement Facility
L	Litre
Landcom 2004	Managing Urban Stormwater: Soils and Construction – Volume 1
MERI	Monitoring Evaluation Reporting and Improvement Plan
mm	Millimetres
MOU	Memorandum of Understanding
Mtpa	Million tonnes per annum
NCIG	Newcastle Coal Infrastructure Group
NEPM	National Environment Protection (Ambient Air Quality) Measure
NGER	National Greenhouse and Energy Reporting
NP&WS	NSW National Parks and Wildlife Service
NSW	New South Wales
ODAQMP	Operation Dust and Air Quality Management Plan
OEH	NSW Office of Environment and Heritage
OEMP	Operation Environmental Management Plan
ONMP	Operation Noise Management Plan
OSCMP	Operation Spontaneous Combustion Management Plan
OWMP	Operation Water Management Plan
PA	Project Approval
PAH	Polycyclic aromatic hydrocarbons
PIT	Passive Induction Transponder
PM_{10}	Particulate Matter <10 µm
$PM_{2.5}$	Particulate Matter <2.5 µm
PWCS	Port Waratah Coal Services
Ramboll	Ramboll Australia Pty Ltd
SSTV	Site-specific trigger values
SVL	Snout-vent length
TDS	Total dissolved solids
TSP	Total Suspended Particles
TSS	Total suspended solids
UoN	University of Newcastle
VES	Visual Encounter Surveys
WHS	Work Health and Safety
WMP	Waste Management Plan

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Appendix 1 Meteorological (Other than Rainfall) Summary

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Appendix 4 GroundWater Monitoring Results

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Appendix 6 CHEMP Monitoring Update Reports

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Appendix 8 Community Support Program

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 eleventh AEMR prepared for the Terminal which includes the ninth year of terminal operation and covers the period July 2018 to June 2019 (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
PA 06_0009	NSW Department of Planning and Environment (now Department of Planning, Industry and Environment (DPIE))	13 April 2007	5 years unless substantially commenced
Modification of Minister's Approval MP06_0009	DPIE	27 November 2007	N/A (conditions appended to the PA)
Modification of Minister's Approval MP06_0009 MOD2	DPIE	13 May 2013	N/A (conditions appended to the PA)
Project Lease	State Property Authority	22 January 2008	35 years (until 21 January 2043)
Environmental Protection Licence (EPL) (No. 12693)	NSW Environment Protection Authority (EPA)	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)	Commonwealth Department of the Environment and Energy (DoEE)	11 October 2006	Perpetuity
Maritime Services Act 1935 s13JE	NSW Roads and Maritime Services	02 October 2007	Perpetuity
Environmental Representative	DPIE	03 October 2007	Perpetuity
Project Ecologist	DPIE	02 May 2007 & 25 October 2007	Perpetuity
Licence for Minor Operations – Green and Golden Bell Frog Compensatory Habitat	NP&WS	31 March 2014	5 years (currently in process of renewal)
Determination Notice for External Proponents – Green and Golden Bell Frog Compensatory Habitat (Ref No. CCHR 1317_17)	NP&WS	7 March 2013	Perpetuity
Deed for the provision of compensatory habitat for migratory shorebirds on Kooragang Island (Area E)	(the Minister for) NP&WS	22 February 2016	Cessation of NCIG Coal Export Terminal (CET), surrender of PA 06_0009 or expiry of the lease
Determination (NP&WS) – Shorebird Compensatory Habitat project at Fish Fry Flats (Appl No. CCHR 1415_21)	NP&WS	28 June 2015	Perpetuity
Licence for Minor Operations – Shorebird Habitat Compensation Area E, Kooragang Island	NP&WS	15 December 2015	Up to 35 years (until 14 December 2050)

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 (OEMP) (last updated 26 November 2018, during the reporting period)
- Operation Dust and Air Quality Management Plan (ODAQMP) (last updated 28 November 2018, during the reporting period)
- Operation Noise Management Plan (ONMP)
- Operation Spontaneous Combustion Management Plan (OSCMP) (last updated 3 December 2018, during the reporting period)
- Operation Water Management Plan (OWMP) (last updated 20 November 2018, during the reporting period)

Other Management Plans and Programs

- Ecological and Land Management Plan (ELMP) (last updated 23 November 2018, during the reporting period)
- Waste Management Plan (WMP)
- Spill and Pollution Incident Response Management Plan (SPIRMP)
- Compensatory Habitat and Ecological Monitoring Program (CHEMP)
- Compensatory Habitat Management Plan
- Monitoring, Evaluation, Reporting and Improvement (MERI) Plan for the Migratory Shorebird Habitat Establishment
- Compliance Tracking Program
- Coordinated Environmental Monitoring and Management Protocol (with Port Waratah Coal Services (PWCS))
- Materials Transport Procedure
- Biosecurity Incident Response Procedure (BIRP)
- Community Engagement Plan

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.**

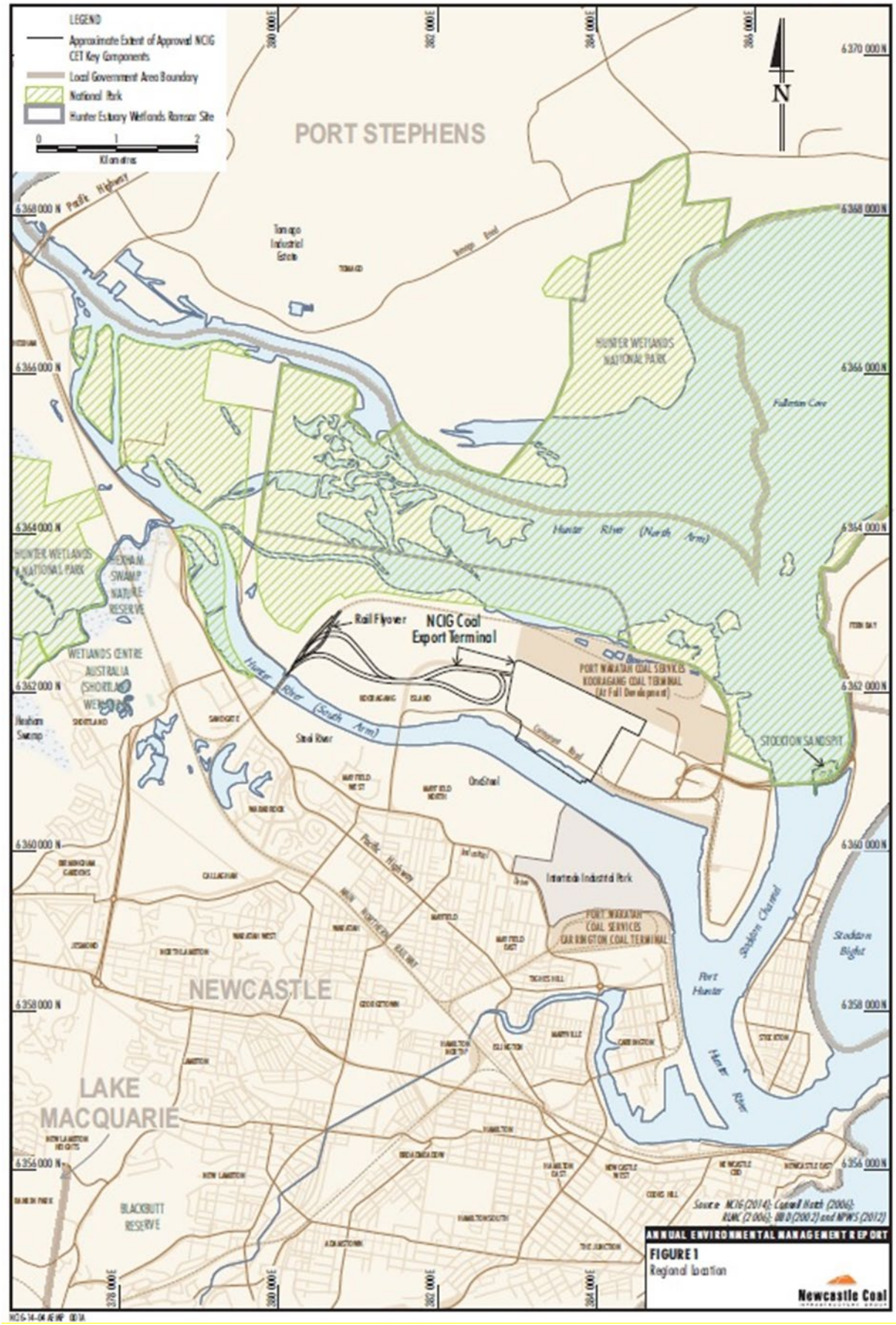


Figure 1-1: Terminal Location

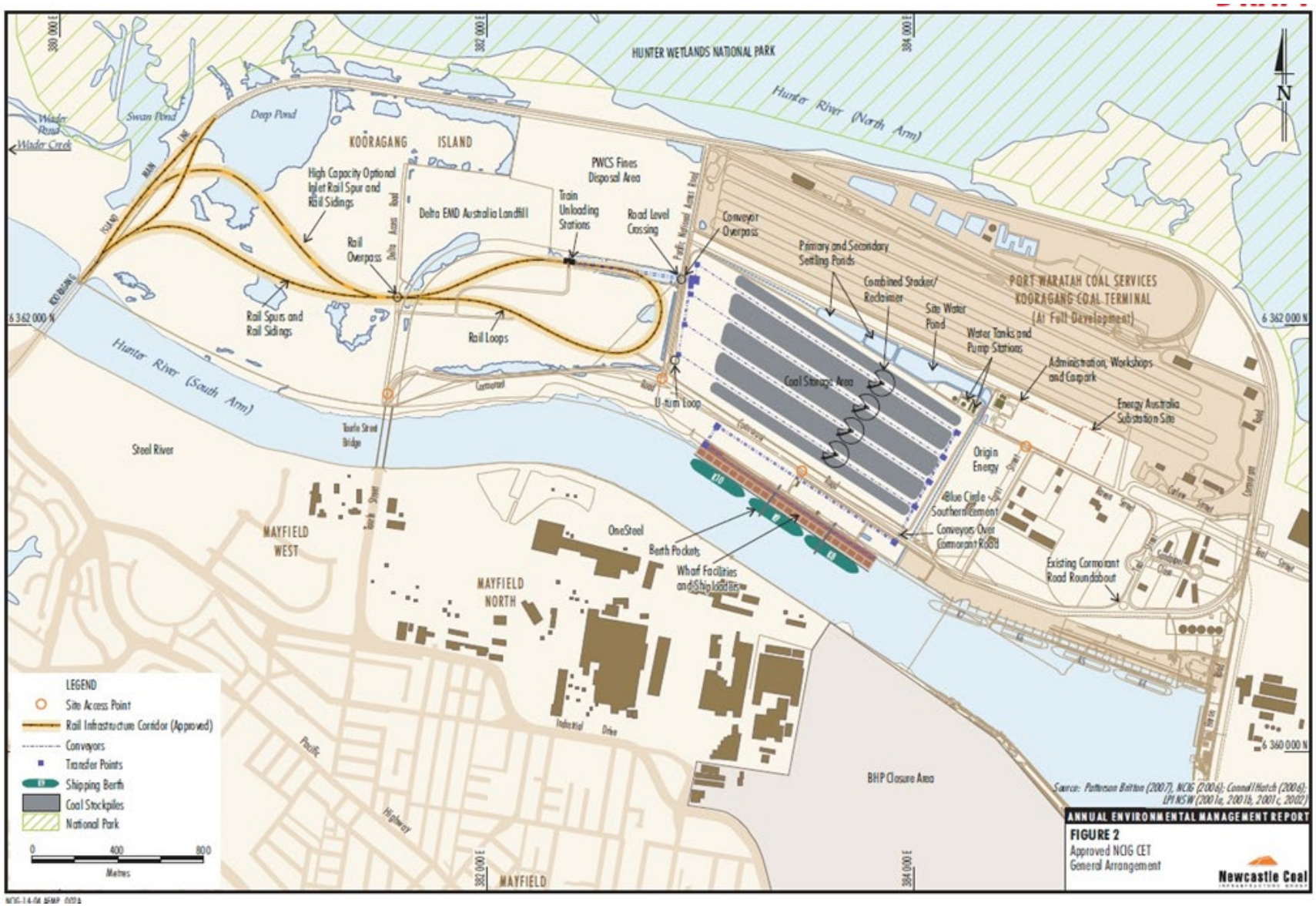


Figure 1-2: Project General Arrangement

2. OVERVIEW OF ACTIVITIES

2.1 OPERATION

The June 2018 to June 2019 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 to NCIG customers
- Loaded 53 million tonnes of coal onto vessels for export

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

Photo 2-1: NCIG Site Overview Facing East

Photo 2-2: NCIG Site Overview Facing North

Photo 2-3: Stockyard with Stacker Reclaimers in Operation

Photo 2-4: Aerial Photograph of NCIG Terminal (June 2017)

3. SUSTAINABLE DEVELOPMENT POLICY

NCIG updated its 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 NCIG 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 program, is provided in **Table 4-1**. The 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	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	Following significant rainfall events (i.e. greater than 20 millimetres (mm) in 24 hours) and during routine site inspections.	N/A
NOISE			
Attended noise monitoring	Fern Bay, Stockton, Mayfield, Carrington per Section 3.2 of the ONMP	6-monthly	See **Section 4.7.2**
Attended noise monitoring in case of complaint	Reference locations proximal to the Project	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[2]	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	Monthly	See **Section 4.4.2**
	Surface water monitoring sites	Monthly	
Water level	Primary and secondary settling ponds	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	Following significant rainfall events (i.e. greater than 20 millimetres (mm) in 24 hours) and during routine site inspections.	
GROUNDWATER			
pH, EC, TDS, TSS, sulfate, polycyclic aromatic hydrocarbons (PAH), As III, Cd, Cu, Pb, Hg, Zn, Cr VI, Mn and Ni	GW1, K9/3S, K9/3N, K11/1S, K11/1, BH20S, BH20D, BH23S, BH23D BH21S, BH21D	6-monthly	See **Section 4.5.2**
Groundwater level		6-monthly	

[1]Dust deposition is 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.

[2]PM_{10} is monitored in accordance with the Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales (EPA,2001).

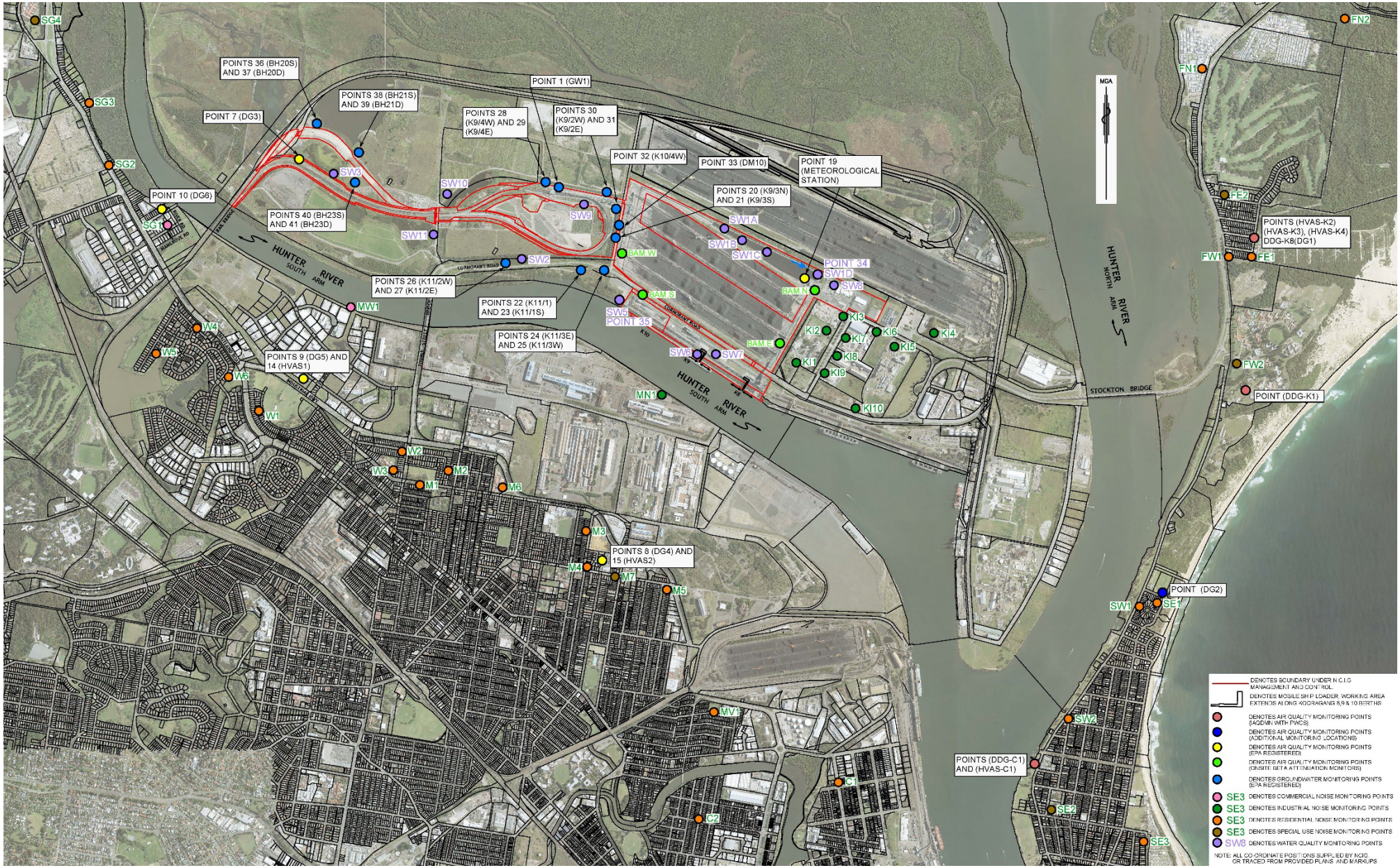


Figure 4-1: Environmental Monitoring Sites

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 receives 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 interface is shown in **Figure 4-2.**

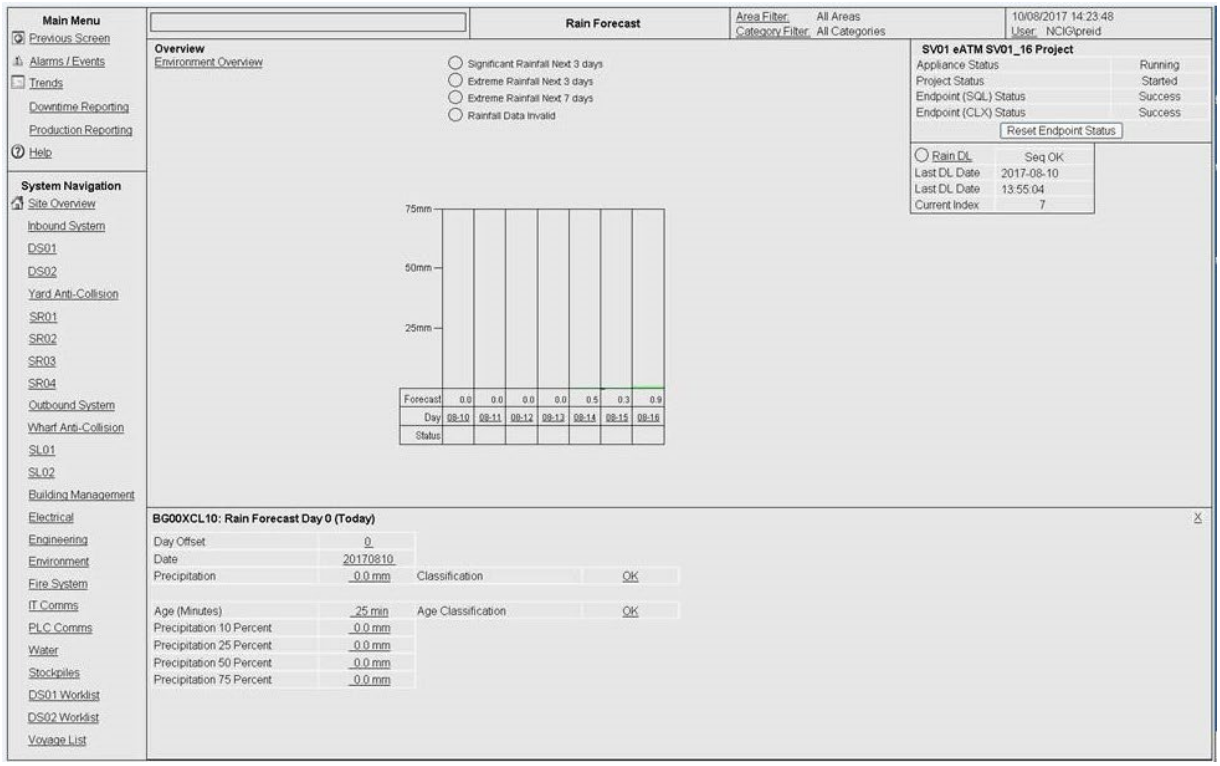


Figure 4-2: Rain Forecasting Interface

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 Meteorological Monitoring Program

Monitoring Parameter	Monitoring Sites	Frequency	Criteria
• Temperature • Relative humidity • Net solar radiation • Rainfall • Wind speed and direction • Sigma theta[2]	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**.

[2] Sigma theta is the standard deviation of wind direction. The variability of wind direction can be used as an indicator or turbulence and mixing of the air.

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.** A total of 667.3 mm of rain was received on the site during the reporting period with the highest rainfall recorded in June 2019. The lowest rainfall was recorded in July 2018 followed by January 2019.

Table 4-3: Rainfall Statistics by Month

Month	Total rainfall (mm)*	Daily average (mm)	Daily maximum (mm)
July 2018	3.8 (70.3)	0.0 (0.3)	1.0 (0.4)
August 2018	18.0 (73.2)	0.0 (6.1)	4.8 (11.2)
September 2018	79.9 (60.6)	0.1 (8.5)	8.6 (34)
October 2018	99.5 (73.5)	0.1 (8.6)	10.2 (38.6)
November 2018	50.7 (81.9)	0.1 (11.0)	10.0 (48.2)
December 2018	22.9 (78.6)	0.0 (5.1)	3.2 (19.4)
January 2019	10.4 (98.7)	0.0 (2.1)	1.6 (5.0)
February 2019	27.6 (117)	0.0 (4.2)	2.6 (12.8)
March 2019	118.4 (120.9)	0.2 (13.3)	12.3 (59.4)
April 2019	57.6 (110.6)	0.1 (3.0)	5.8 (23.8)
May 2019	31.6 (108.7)	0.0 (6.7)	4.3 (23.2)
June 2019	147.0 (125.2)	0.2 (12.1)	6.1 (50.6)
Annual	**667.3 (1123.8)**	**0.1 (6.75)**	**12.3 (59.4)**

*Data shown in brackets refers to the mean monthly rainfall Williamtown data (1942 – 2019) – sourced from the Bureau of Meteorology (BOM). The Williamtown BOM station (station number 061078) is the closest BOM weather station and is located less than 11 km to the north east of the Terminal.

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

Figure 4-3 illustrates the variation in average, minimum and maximum temperature measured during the reporting period. Variations from the winter to summer seasons are the normal expected seasonal variations, with temperatures peaking in January and falling to the lower levels in June and July.

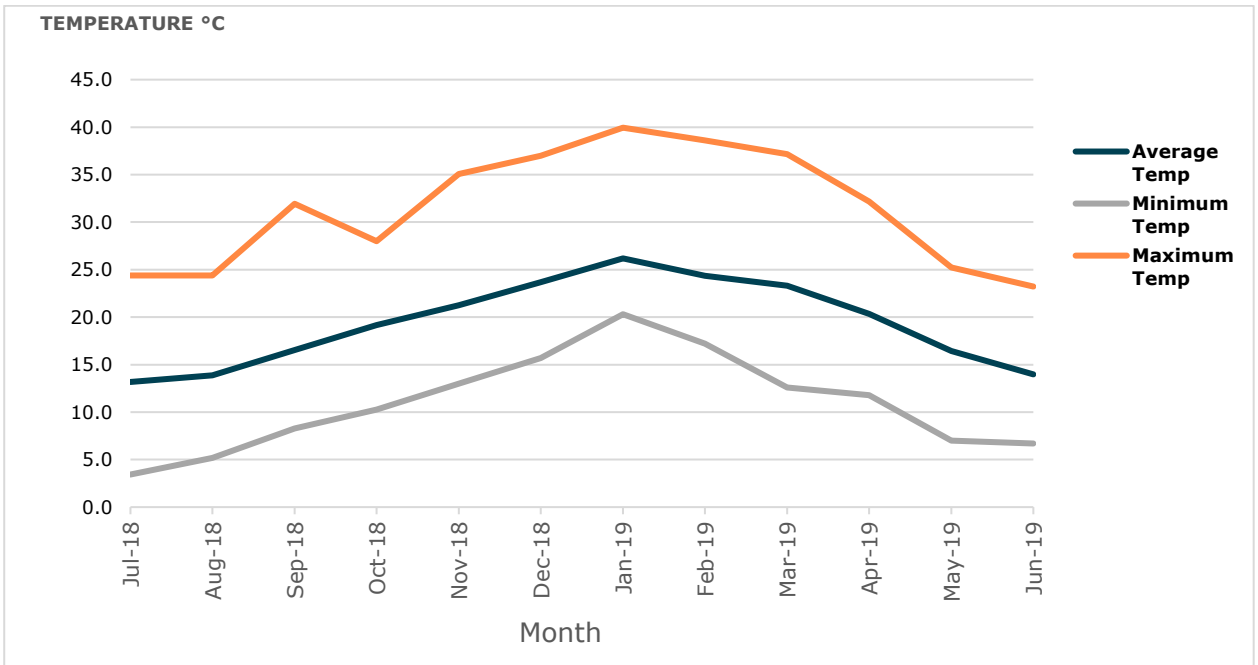


Figure 4-3: Temperature by Month

Figure 4-4 illustrates prevailing wind conditions throughout the reporting period where the length of each spoke represents the frequency of winds from that direction.

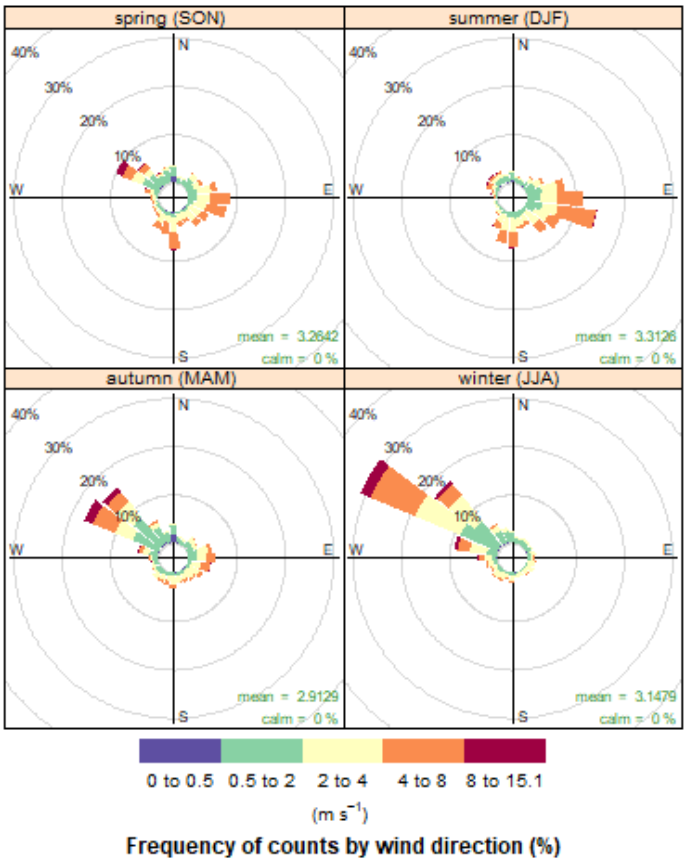


Figure 4-4: Seasonal Wind Conditions

4.2.4 Reportable incidents

No environmental incidents relating to meteorological conditions occurred 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 ODAQMP 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 during operations. 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 used to assist the management of operations.

A review of other dust management technologies and controls was undertaken during the previous reporting period (*Review of the Integrated Dust Management System and Options for Improvements* by Red Planet Innovations (2018)). Key recommendations from the review 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 alternative stockpile treatments.

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.

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 the Dump Station, transfer points 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 to the coal stockpiles. These operate on an automatic sequence, which considers 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 ODAQMP, including programming logic known as an Integrated Dust Management System.

Initial stockpile stacking operations are conducted at 12m, Subsequent stacking is then conducted at 24 m. This two-staged procedure results in a lower stockpile height for a significant period, resulting in a reduction in dust emissions due to lower wind speeds.

The Newcastle Air Quality Monitoring Network was commissioned by the NSW Office of Environment and Heritage (OEH) (now NSW Department of Planning, Industry and Environment – Environment, Energy and Science group) 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 EPL 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/m²/month	Monthly	Stockton – DG2 Kooragang – DG3 Mayfield – DG4 Steel River – DG5 Sandgate – DG6	AS/NZS 3580.10.1[1]
Depositional Dust (Integrated Air Quality Monitoring Network (AQMN) with PWCS)			Fern Bay – DDG-K8 (DG1) Stockton Prawners Club - DDG-C1 Stockton Hospital – DDG-K1	

MONITORING PARAMETER	UNITS	FREQUENCY	LOCATION	METHODOLOGY
HIGH VOLUME AIR SAMPLING				
TSP	µg/m^3	6-daily	Steel River – HVAS1 Mayfield – HVAS2	NSW Approved Methods[2]
Particulate Matter <10 µm (PM_{10})				
TSP (Integrated AQMN with PWCS)			Stockton Prawners Club – HVAS-C1	
PM_{10} (Integrated AQMN with PWCS)			Fern Bay – HVAS-K2 (TSP), HVAS-K3 (PM10), HVAS-K4 (Directional TSP)	
NEWCASTLE LOCAL AIR QUALITY MONITORING NETWORK (ADMINISTERED BY THE EPA, OPERATED BY BCD, FUNDED BY INDUSTRY)				
PM_{10}	µg/m^3	Hourly (average daily values reported)	Stockton Carrington Mayfield Newcastle Wallsend Beresfield	NSW Approved Methods[2]
Particulate Matter <2.5 µm ($PM_{2.5}$)				
Wind Speed	ms^{-1}			AS 3580.1.1[3]
Wind Direction	Degrees			AS 3580.1.1[3]
ONSITE BETA ATTENUATION MONITORING (BAM)				
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 3580.10.1-2016 Methods for Sampling and Analysis of Ambient Air – Determination of Particulate Matter – Depositional Matter – Gravimetric Method (Standards Association of Australia 2016).

[2]PM_{10} is monitored in accordance with the Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/air/07001amsaap.pdf

[3] AS 3580.1.1:2016 Methods for the sampling and analysis of ambient air. Part 1.1: Guide to siting air monitoring equipment., formerly (now superseded) 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 4-5** and **Figure 4-6**.

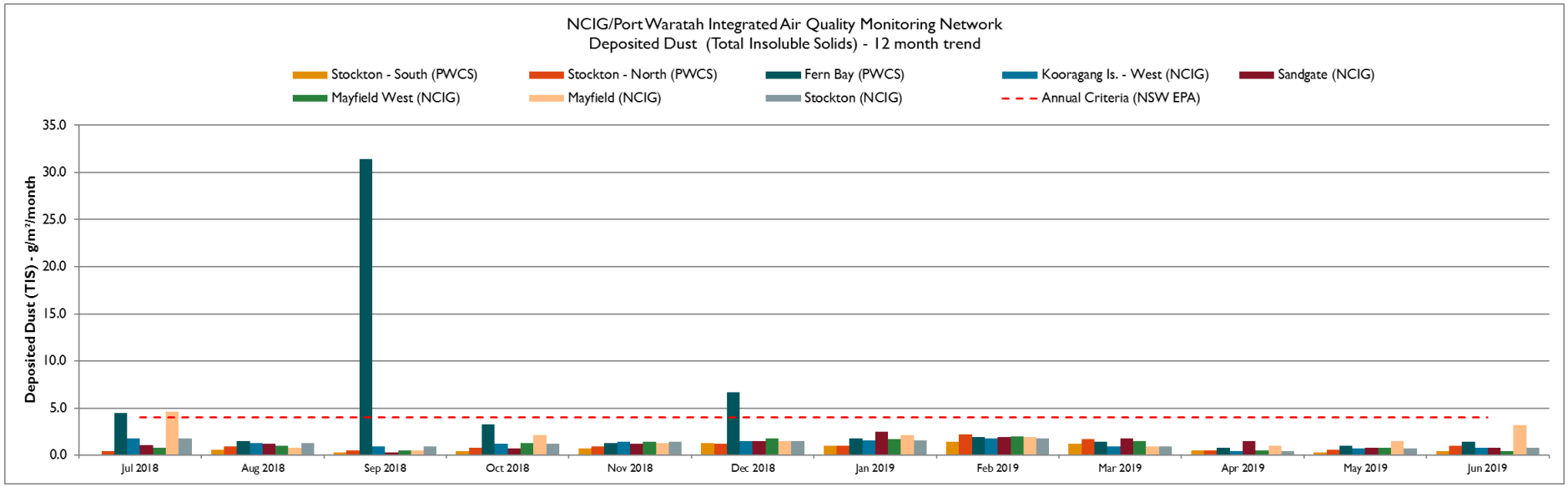


Figure 4-5: Monthly Depositional Dust

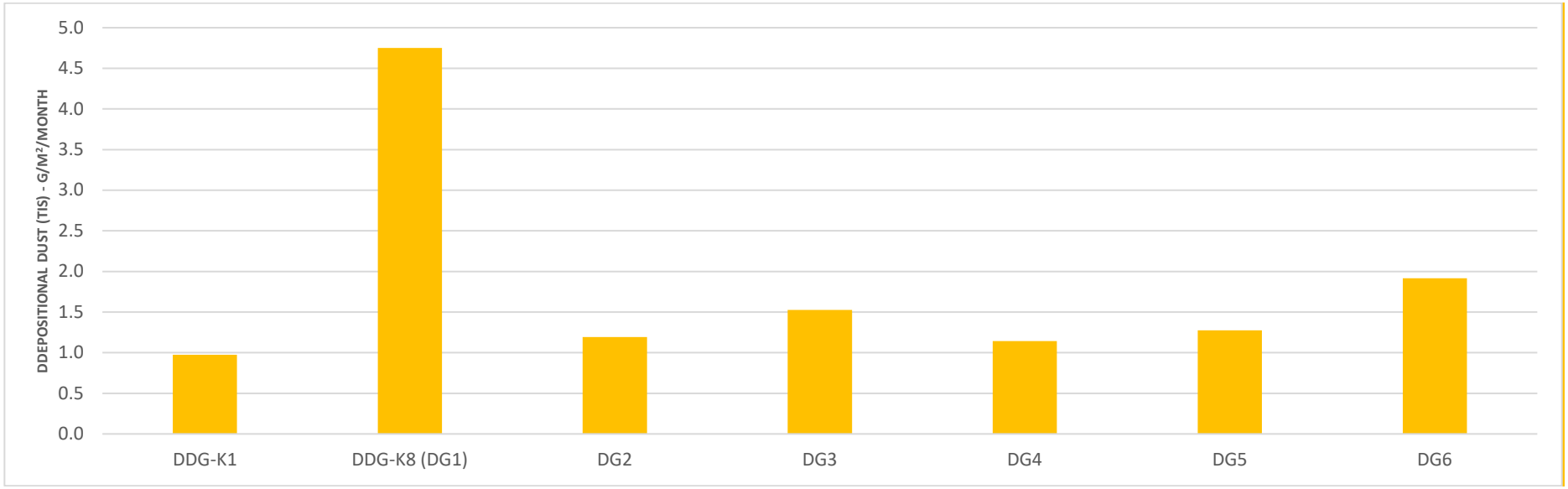


Figure 4-6: Annual Average Depositional Dust

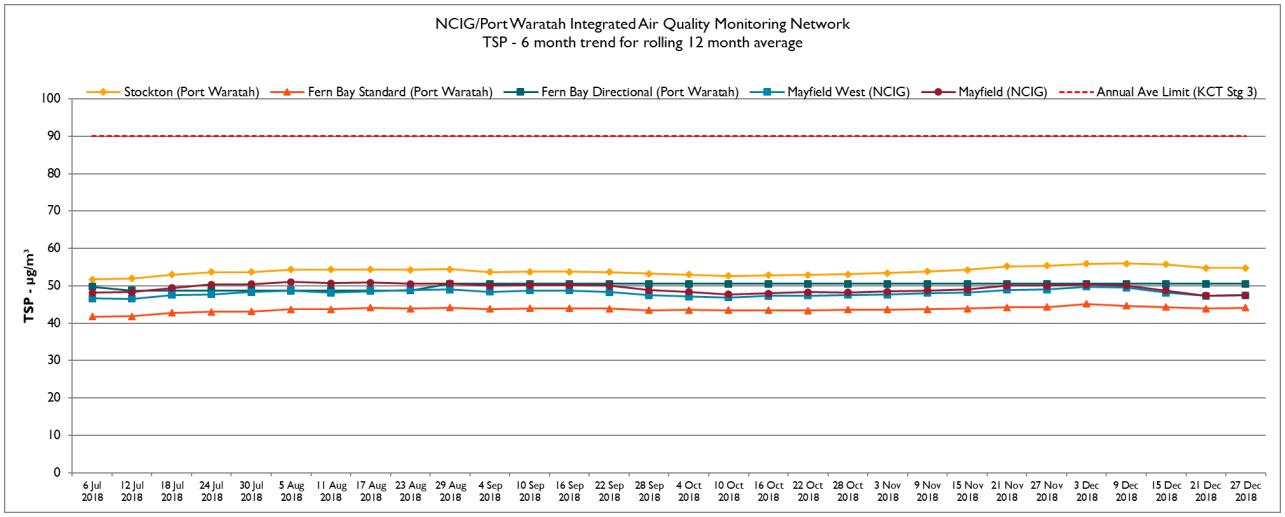
Figure 4-5 shows that individual monthly samples from Fern Bay (DG1) exceeded the 4 grams per square metre per month (g/m^2/month) criteria in July 2018, September 2018 and December 2018. The spike in depositional dust at DG1 was due to the samples containing large quantities of sand. The individual monthly sample at Kooragang (DG3) also exceeded the 4 g/m^2/month criteria in July 2018. This exceedance was due to contamination from bird droppings.

Average depositional dust results were below the monthly criteria of 4 g/m^2/month at all depositional dust gauge locations except DG1 as shown in **Figure 4-6**. The results for DG1 in September are skewed due to a large amount of sand identified in the gauge in July 2018, September 2018 and December 2018.

Air quality monitoring results from High Volume Air Sampling (HVAS), as they relate to both TSP and Particulate Matter with an equivalent aerodynamic diameter less than 10 Microns (PM_{10}), are displayed in **Figure 4-7**, **Figure 4-8** and **Figure 4-9.**

The annual average TSP concentrations for the five monitoring locations were below the DEC Annual Average Limit of 90 µg/m^3, as shown in **Figure 4-7.** The Fern Bay - Directional Site was decommissioned in early January 2019.

The annual average PM_{10} concentrations for the three monitoring locations were below the *National Environment Protection (Ambient Air Quality) Measure* (NEPM) criteria. Daily concentrations of PM_{10} were below the NEPM criteria of 50 µg/m^3 with the exception of Mayfield on 2 January 2019. The Mayfield monitoring station is located south southwest of NCIG and the prevailing winds occurred from midday until late afternoon (up to 5.5m/s) from an east and east southeast/south east direction. As such it is unlikely that NCIG contributed to the elevated concertation on this day. Results were not available for Fern Bay on 20 January 2019, Mayfield on 2 April and Steel River on 20 April 2019 due to power faults, the run event exceeding run time and a programming error, respectively for each occasion.



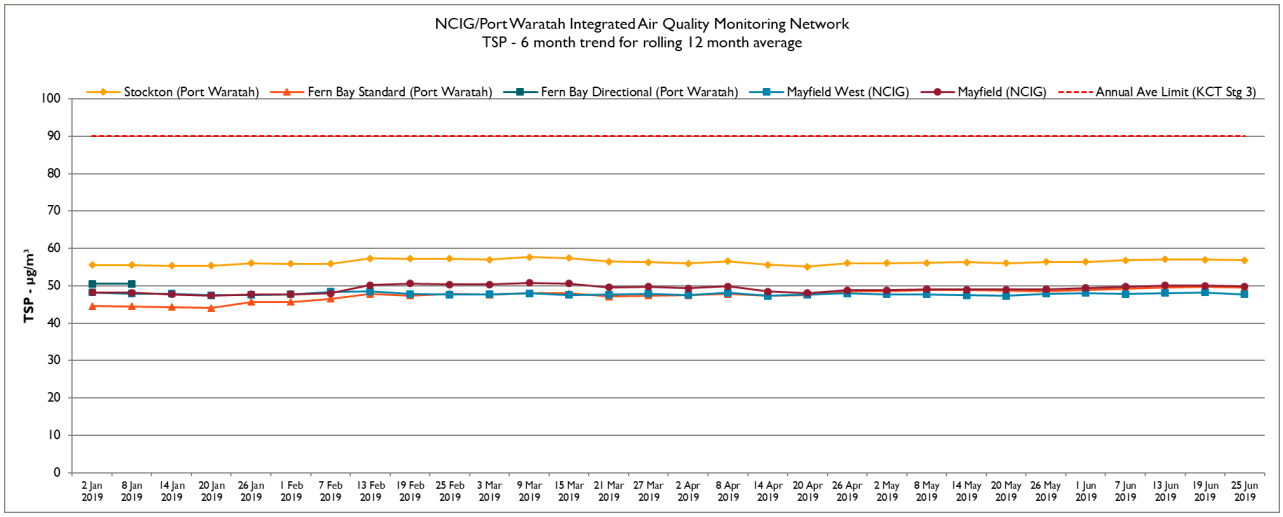
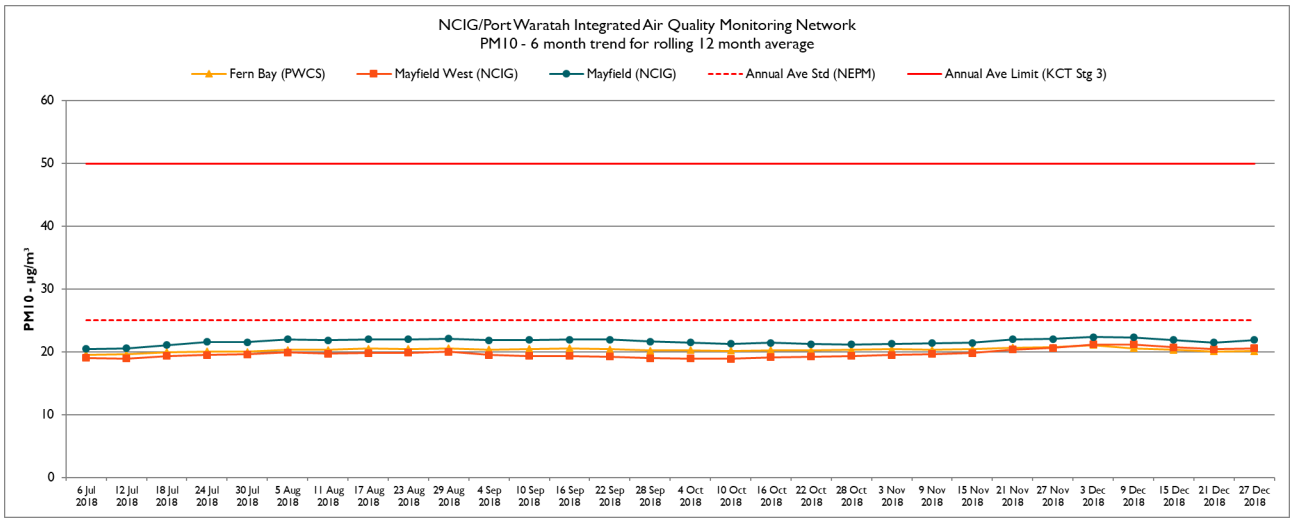


Figure 4-7: Total Suspended Particulates



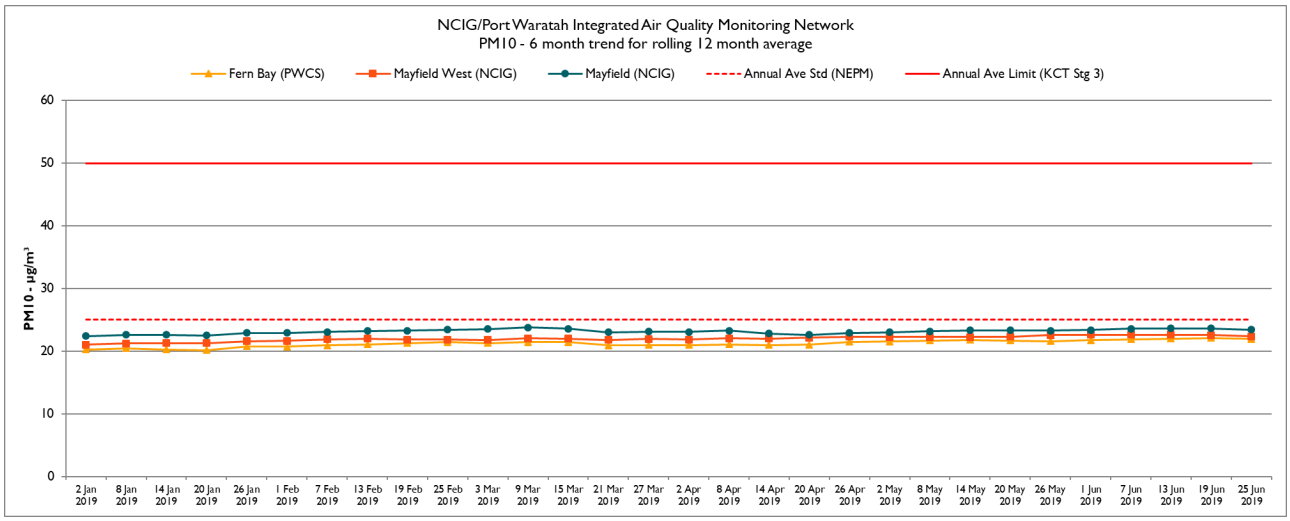
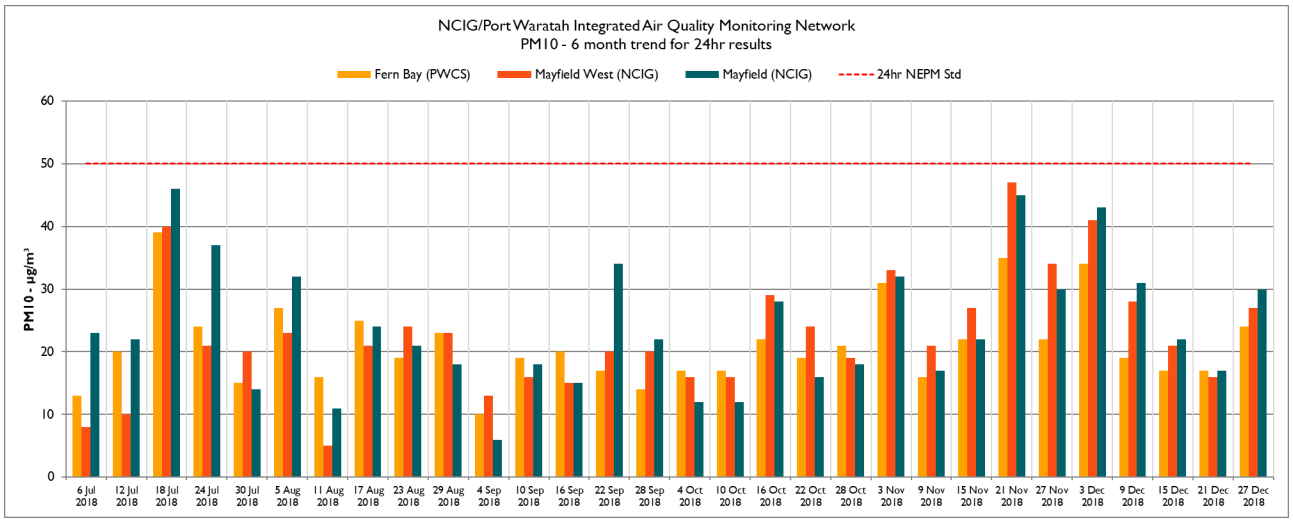


Figure 4-8: Particulate Matter <10 µm (PM_{10}) – Annual Average



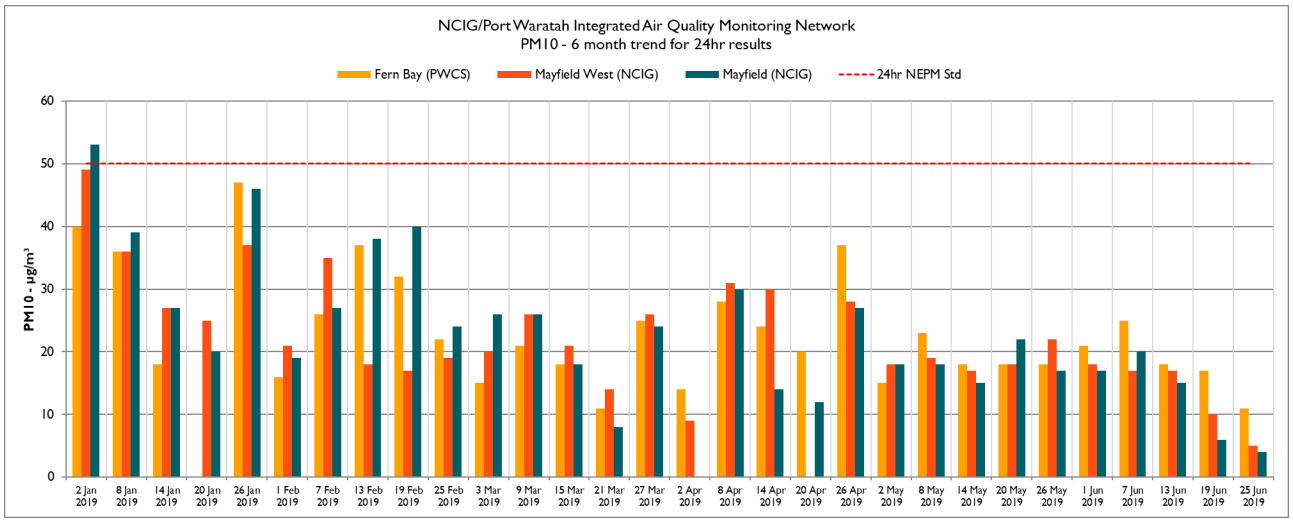


Figure 4-9: Particulate Matter <10 µm (PM_{10}) – 24 Hour Results

4.3.3 Reportable Incidents

No reportable environmental incidents relating to air quality occurred during the reporting period, however two community complaints/enquiries relating to air quality were received by NCIG during the reporting period**.** Further information can be found in Section 4.11.2.

4.3.4 Further Improvements

A review of other dust management technologies and controls was undertaken during the previous reporting period (*Review of the Integrated Dust Management System and Options for Improvements*) by Red Planet Innovations (2018). As noted above, key recommendations from this review have been incorporated into air quality management at the Terminal. During the reporting period further recommendations from the review were implemented including additional air quality notifications to provide improved weather forecasting and dust level notifications to relevant personnel, and improved predictive spray cycles for forecast and live wind events.

During the reporting period the use of stockpile veneering was further investigated as a potential ongoing dust management tool. An assessment will be completed in the 2020 financial year to determine the feasibility and effectiveness of stockpile veneering.

Air quality modelling was undertaken during the reporting period to identify any improvements that can be obtained by rearranging the Stockyard. The results identified that with relocating particular coal types with increased dust potential to less wind susceptible locations in the Stockyard, air quality improvements could be obtained, particularly during high wind events. The Stockyard Rearrangement Project is anticipated to be undertaken 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 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 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 aims to ensure adjacent water bodies are not impacted by NCIG activities. The OWMP was approved by DPIE 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 4-10**).

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

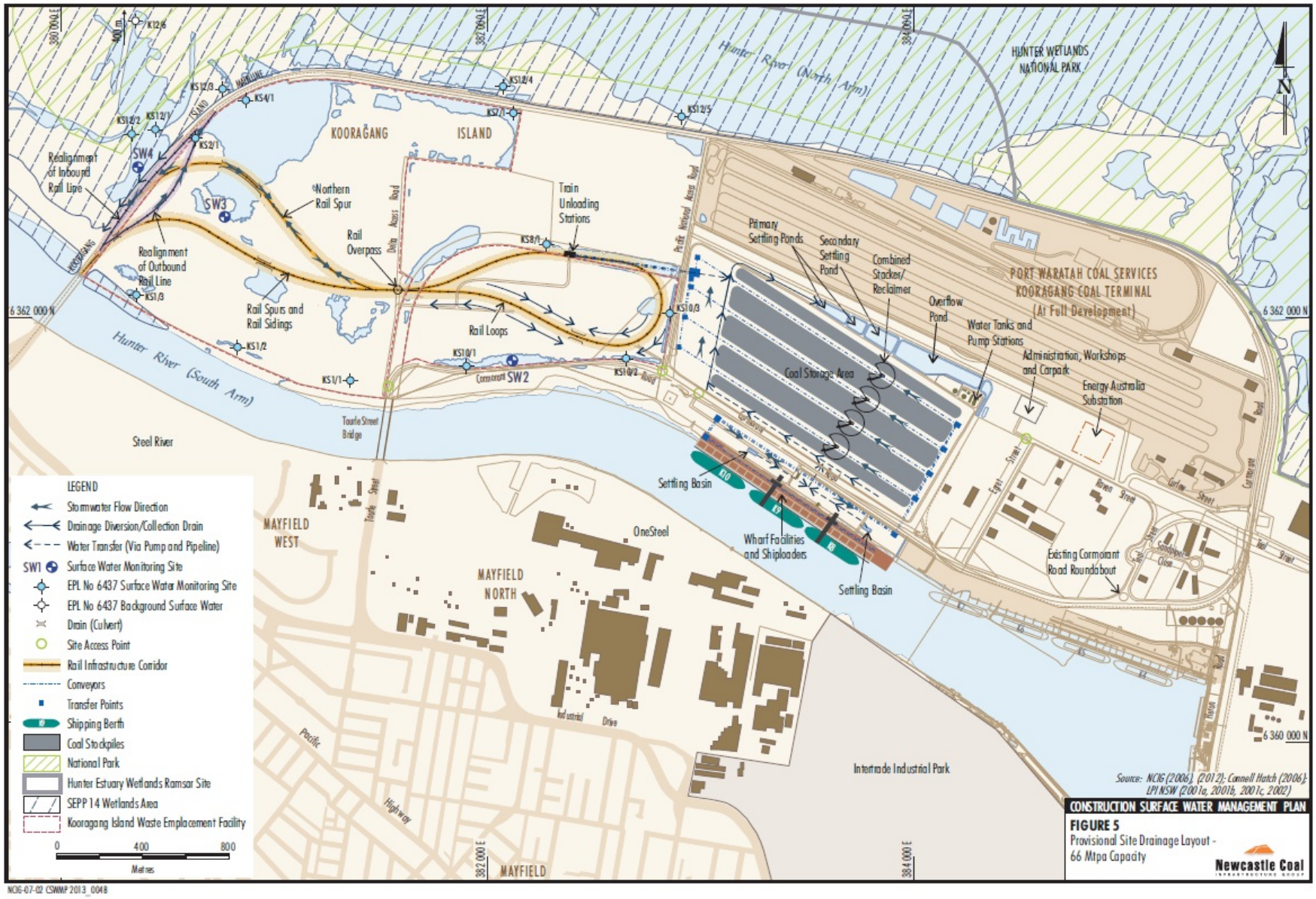


Figure 4-10: Permanent Site Drainage Layout

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	PARAMETER	UNITS	REQUIRED LIMIT OF REPORTING (LOR)
SW1-a, SW1-b, SW1-c, SW1-d (operational sites) SW2, SW3 (reference sites)	Monthly	pH	-	0.1
		EC	µS/cm-1	10
		TDS	mg/L	Not specified
		Turbidity	NTU	10
		Dissolved Oxygen (DO)	% and mg/L	1
		Temperature	°C	Not specified
		Reduction/ oxidation potential (Redox)	mV	Not specified
		TSS	Mg/L	Not specified
SW1-d, SW6, SW7, SW8, SW9 (operational sites) SW2, SW3, SW5, SW10, SW11 (background sites)	6-monthly	pH	-	0.1
		EC	µs/cm-1	10
		Turbidity	NTU	10
		DO	%	1
		Aluminium	mg/L	0.05
		Arsenic (III)	mg/L	0.05
		Boron	mg/L	0.05
		Cadmium	mg/L	0.0001
		Chromium (III)	mg/L	0.01
		Cobalt	mg/L	0.001
		Copper	mg/L	0.001
		Iron	mg/L	0.05
		Lead	mg/L	0.001
		Manganese	mg/L	0.5
		Mercury	mg/L	0.0001
		Molybdenum	mg/L	2
		Nickel	mg/L	0.01
		Selenium	mg/L	0.001
		Zinc	mg/L	0.005
		Total Recoverable Hydrocarbons C6-C9	mg/L	0.02
		Total Recoverable Hydrocarbons C10-C14	mg/L	0.05
		Total Recoverable Hydrocarbons C15-C28	mg/L	0.1
		Total Recoverable Hydrocarbons C29-C36	mg/L	0.1
		Anthracene	µg/L	0.01
		Benzo(a)pyrene	µg/L	0.01
		Fluoroanthene	µg/L	0.01
		Naphthalene	µg/L	0.01
		Phenanthrene	µg/L	0.01

MONITORING LOCATIONS	FREQUENCY	PARAMETER	UNITS	REQUIRED LIMIT OF REPORTING (LOR)
		Ammonia	mg/L	0.5
		Nitrate	mg/L	0.1
		Total Kjeldahl Nitrogen	mg/L	0.5
		Total phosphorous	mg/L	0.01
		Chloride	mg/L	Not specified
SW1-d (discharge) EPL34, SW5 (Background) EPL35	Daily during discharge	pH	-	0.1
		Turbidity	NTU	10
		TSS	mg/L	Not specified
		Oil and Grease	mg/L	Not specified

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

Sampling of surface water ponds was undertaken by RCA Australia in December 2018 and June 2019 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 Surface Water Monitoring Program was 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.

Ramboll (2019) (*NCIG Surface Water Monitoring Data review 2019*) undertook a review of the surface water quality monitoring data from 2018 to early 2019. The monitoring results were compared to trigger values that were either: site-specific trigger values (SSTVs); *Australian and New Zealand Fresh and Marine Water Quality Guidelines* (ANZG 2018) triggers for protection of 95% Aquatic Species; or *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC 2000) triggers for physical parameters (EC, DO, pH and turbidity) in the absence of ANZG 2018 guidance. The review found:

- 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 reference and operational locations. This indicates that these elements are present in the local environment at 'natural' concentrations above the data used to derive the ANZG (2018) trigger.
- EC is highly variable, and the median values both at operational and reference locations exceed the recommended range for freshwater lakes and reservoirs in South-east Australia (ANZECC 2000). The reported EC is within a narrow range at each of the monitoring locations over time. This indicates that although conditions are different between locations, they are not changing and NCIG operations are unlikely to be affecting the EC at each location.
- The median pH values at three of the four operational locations (range between 7.92 and 8.37) and two of the four reference locations (ranged between 7.79 and 8.58) exceed the recommended range for freshwater lakes and reservoirs in south-east Australia (ANZECC 2000). This indicates that these elements are present in the local environment at 'natural' concentrations above the data used to derive the ANZECC (2000) trigger.
- The median DO levels reported at all monitoring locations are within the recommended range for freshwater lakes and reservoirs in South-east Australia (ANZECC 2000) and are sufficient to support aquatic life, depending upon the water temperatures.
- 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. The median turbidity level at the Hunter River Wharf and Hunter River is just above the recommended range for South-east Australia estuaries (ANZG 2018) (10 NTU).

In accordance with recommendations within ANZG (2018), SSTVs were re-evaluated for those parameters where reference site concentrations exceed the generic ANZG triggers (i.e. aluminium, boron, zinc, total phosphorous, conductivity and pH) using the updated 2018/2019 monitoring results. The median concentrations of each parameter within the four operational locations were then compared to the SSTVs.

Table 4-7 provides a summary of the revised SSTVs and comparison to the median concentrations for each parameter at the operational monitoring locations. None of the operational locations exceeded the SSTVs, except for a minor exceedance in pH at WTP01.

Table 4-7: Comparison of Median Surface Water Quality Parameters at Operational Monitoring Locations to Site Specific Trigger Values

Parameter	SSTV	WTP01		Clearwater Pond		Tradewaste Pond		Wharf Sump	
		Median	SD	Median	SD	Median	SD	Median	SD
pH Value	**8.36**	**8.37**	0.55	8.15	0.34	7.92	0.61	8.045	0.37
EC (µS/cm)	**2299**	2240	1969.9	1930	2413.5	181	85.7	429	15214.7
TP (µg/L)	**275**	60	102.2	25	55.1	90	69.1	160	263.8
Aluminium (µg/L)	**1021**	300	1454.7	280	799.7	230	1477.1	625	7876.0
Boron (µg/L)	**890**	340	315.6	270	250.2	38	228.9	128.5	2055.6
Copper (µg/L)	**23**	2	23.3	2	22.6	2.5	23.0	7	23.0
Zinc (µg/L)	**75**	37	57.6	19	21.5	25	51.9	32.5	100.5

Bolded cells indicate median concentrations that exceed the SSTV

4.4.3 Reportable Incidents

During the reporting period one reportable incident against NCIG's EPL (Condition O.71(a)) occurred in relation to the tracking of hydraulic oil onto a public road. In May 2019, a hydraulic line on a Front-end Loader failed causing 2-3 litres of hydraulic oil to be driven onto a public road adjacent to NCIG. After becoming aware of the spill, the oil was contained and immediately cleaned up using drysorb product. Contaminated material was collected and disposed of appropriately. Relevant authorities were notified, including the EPA. It is noted that this incident was assessed as minor and did not cause actual or potential significant off-site impacts on people or the biophysical environment (as outlined in Condition 8.1 of PA 06_0009, nor was the incident considered to have resulted in 'material harm to the environment' as defined under the *Protection of the Environment Operations Act 1997*. This incident and associated learnings and expectations were communicated with staff and contractors.

No discharge events occurred during the reporting period.

4.4.4 Further Improvements

As part of the Discharge Water Management Project as discussed in previous reports, further improvements were made during the reporting period to improve the water quality of NCIG's settling ponds, and potential discharge water during heavy rain events which exceed the design capacity of NCIG's system. Process water from the Dump Station area has been redirected to avoid large detention basins and preferentially directed to existing process water sumps. This measure reduces sedimentation in flood flow paths during heavy rain and allows for greater settlement in sumps, which are cleaned routinely.

Further work will be undertaken as part of the Discharge Water Management Project in the next reporting period, aiming to make additional improvements to management of sediment within the NCIG Surface Water Management System.

During the reporting period NCIG engaged Water Utilities Australia (WUA) for initial discussion regarding options for the use of recycled water on site. NCIG will be working with WUA in FY20 to undertake a feasibility and options assessment

4.5 GROUNDWATER

4.5.1 Environmental Management

Groundwater management is regulated under EPL 12693. Specific groundwater quality trigger criteria have been developed for contaminants of concern, in particular; organic and inorganic contaminants associated with the former KIWEF, upon which parts of the NCIG Rail alignment is constructed. The trigger criteria for Points 20, 21 ,22, 23, 36, 37, 40 or 41 are:

- Trigger Condition 1 – Where monitoring of the parameters required under the licence demonstrates a sudden increase in concentration compared to historical data, or sudden increase in pH is observed. A sudden increase or decrease is defined as a value that is greater than the mean plus twice the standard deviation for the historical data.
- Trigger Condition 2 – Where the trend analysis of the concentration of the parameters required under the licence against time shows an increasing concentration over the most recent four events. Trend analysis tools such as Mann-Kendall may be adopted.

4.5.2 Environmental Performance

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	-
		EC	µS/cm
		Aluminium	mg/L
		Arsenic	mg/L
		Bromide	mg/L
		Cadmium	mg/L
		Copper	mg/L
		Cyanide (free)	µg/L
		Cyanide (total)	µg/L
		Iron	mg/L
		Manganese	mg/L
		Nickel	mg/L
		Zinc	mg/L
		Total Recoverable Hydrocarbons C6-C9	µg/L
		Total Recoverable Hydrocarbons C10-C14	µg/L
		Total Recoverable Hydrocarbons C15-C28	µg/L
		Total Recoverable Hydrocarbons C29-C36	µg/L
		PAHs	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	-
		EC	µS/cm
		Aluminium	mg/L
		Arsenic	mg/L
		Bromide	mg/L
		Cadmium	mg/L
		Copper	mg/L
		Cyanide (free)	mg/L

MONITORING LOCATION[1]	FREQUENCY	PARAMETER	UNITS
		Cyanide (total)	mg/L
		Iron	mg/L
		Manganese	mg/L
		Nickel	mg/L
		PAHs	mg/L
		Total Recoverable Hydrocarbons C6-C9	µg/L
		Total Recoverable Hydrocarbons C10-C14	µg/L
		Total Recoverable Hydrocarbons C15-C28	µg/L
		Total Recoverable Hydrocarbons C29-C36	µg/L
		Zinc	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	-
		EC	µS/cm
		Aluminium	mg/L
		Arsenic	mg/L
		Bromide	mg/L
		Cadmium	mg/L
		Copper	mg/L
		Cyanide (free)	µg/L
		Cyanide (total)	µg/L
		Iron	mg/L
		Manganese	mg/L
		Nickel	mg/L
		Zinc	mg/L
		Total Recoverable Hydrocarbons C6-C9	µg/L
		Total Recoverable Hydrocarbons C10-C14	µg/L
		Total Recoverable Hydrocarbons C15-C28	µg/L
		Total Recoverable Hydrocarbons C29-C36	µg/L
		PAHs	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	EXCEEDANCE OF REQUIREMENTS?		COMMENTS
		EPL	OEMP/ OWMP	
GW1 (EPL 1)	31/12/18 20/06/19	No	No	
BH-21S (EPL 38)	18/12/18 20/06/19	No	No	
BH-21D (EPL39)	18/12/18 20/06/19	No	No	
K9/3N (EPL 20)	19/12/18 30/01/19 (re-sample) 20/06/19 25/07/19 (re-sample)	Yes	Yes	Anomalous EC reported in the December 2018 monitoring round (27,900 µS/cm) exceeded Trigger Condition 2. The well was re-sampled in January 2019 which confirmed the elevated result (27,900 µS/cm). NCIG proceeded to Step 5 of the Contingency Response Procedure in Condition E1.1 of the EPL. Step 5 was completed and based on review of the December 2018 data, EC is considered insignificant and within the normal levels of fluctuation. Nickel concentrations exceeded Trigger Condition 1 in the June 2019 monitoring round (0.005 mg/L). The well was re-sampled on 25 July 2019, forming 'Step 2' of the EPL contingency. A review confirmed the June 2019 result to be anomalous (0.004 mg/L).
K9/3S (EPL21)	19/12/18 20/06/19	No	No	
K11/1 (EPL 22)	19/12/18 20/06/19	No	No	
K11/1S (EPL 23)	19/12/18 20/06/19 25/07/19 (re-sample)	Yes	Yes	Total cyanide concentrations exceeded Trigger Condition 1 in the June 2019 monitoring round (0.024 mg/L). The well was re-sampled in July 2019, forming 'Step 2' of the EPL contingency. A review confirmed the June 2019 result to be anomalous (0.007 mg/L).
BH-20S (EPL 36)	18/12/18 20/06/19 25/07/19 (re-sample)	Yes	Yes	Arsenic concentrations exceeded Trigger Condition 1 in the June 2019 monitoring round (0.013 mg/L). The well was re-sampled in July 2019, forming 'Step 2' of the EPL contingency. The resample result confirmed concentration remains within the ANZECC guidelines. Iron concentrations exceeded Trigger Condition 1 in the June 2019 monitoring round (14.2 mg/L). The well was re-sampled in July 2019 which confirmed the elevated results (57.8 mg/L). More recent results (December 2019) have since shown a decreased concentration (3.98 mg/L).

MONITORING SITES	DATES OF SAMPLING	EXCEEDANCE OF REQUIREMENTS?		COMMENTS
		EPL	OEMP/ OWMP	
				NCIG proceeded to Step 5 of the Contingency Response Procedure in Condition E1.1 of the EPL. Step 5 was completed and based on review there is no guideline value for iron. Iron and pH are closely linked and the increasing Iron concentration may reflect the geochemistry at this location and decreasing pH. These results will be analysed by a groundwater specialist to confirm trends in the next reporting period.
BH-20D (EPL 37)	18/12/18 30/01/18 (re-sample) 20/06/19 25/07/19 (re-sample)	Yes	Yes	pH exceeded Trigger Condition 1 in the December 2018 monitoring round (6.07). The well was re-sampled which confirmed the result (6.06). NCIG proceeded to Step 5 of the Contingency Response Procedure in Condition E1.1 of the EPL. Although within the ANZECC Guidelines, Step 5 was completed and a review of pH data found pH varying between a maximum of 6.53 in June 2018 to a minimum of 6.0 in March 2019, however increased pH occurred during June 2019. The analysis found decreasing pH at the groundwater at both shallow and deep locations, and alkaline pH in the nearby groundwater. On the basis of these results combined with a stable pH in nearby wells, the decreasing pH at sampling point 37 was not considered significant. Sampling point 37 will continue to be monitored as part of the overall monitoring program for NCIG. Continued evaluation of monitoring data for pH should be undertaken to confirm trends. Nickel concentration exceeded Trigger Condition 1 in the December 2018 monitoring round (0.035 mg/L). The well was re-sampled which confirmed the elevated result (0.047 mg/L). NCIG proceeded to Step 5 of the Contingency Response Procedure in Condition E1.1 of the EPL. Step 5 was completed. The review of the data showed fluctuation in nickel concentrations at sampling point 37 (BH20D) are marginally above the 90% freshwater guideline and below all other guidelines, and not considered significant in the site context. The most recent sampling event in June 2019 reported nickel concentrations of 0.043 mg/L. Manganese concentrations exceeded Trigger Condition 1 in the June 2019 monitoring round (12.3 mg/L). The well was re-sampled in July 2019, forming 'Step 2' of the EPL contingency and confirmed the June 2019 result to be anomalous (4.61 mg/L). Iron and nickel concentrations exceeded Trigger Condition 2 in the June 2019 monitoring round. Comparison of results indicated that these values are within the range observed on site and are considered insignificant.

MONITORING SITES	DATES OF SAMPLING	EXCEEDANCE OF REQUIREMENTS?		COMMENTS
		EPL	OEMP/ OWMP	
BH-23S (EPL 40)	18/12/18 30/01/18 (re-sample) 19/06/19 25/07/19 (re-sample)	Yes	Yes	Aluminium concentration exceeded Trigger Condition 1 in the December 2018 monitoring round (0.12 mg/L). The well was re-sampled in January 2019 and confirmed the December 2018 result to be anomalous (<0.005 mg/L). Bromide concentration exceeded Trigger Condition 1 in the June 2019 monitoring round (16.5 mg/L). The well was re-sampled in July 2019 and confirmed the June 2019 result to be anomalous (0.201 mg/L). Iron concentration exceeded Trigger Condition 1 in the June 2019 monitoring round (13.5 mg/L). The well was re-sampled in July 2019 and confirmed the June 2019 result to be anomalous (2.84 mg/L).
BH-23D (EPL 41)	18/12/18 19/06/19 25/07/19 (re-sample)	Yes (initial results)	Yes (initial results)	Arsenic concentration exceeded Trigger Condition 1 in the June 2019 monitoring round (0.006 mg/L). The well was re-sampled in July 2019 and confirmed the June 2019 result to be anomalous (0.002 mg/L). Total cyanide concentration exceeded Trigger Condition 1 in the June 2019 monitoring round (0.095 mg/L). The well was re-sampled in July 2019 and confirmed the June 2019 result to be anomalous (0.014 mg/L). pH exceeded Trigger Condition 1 in the June 2019 monitoring round (6.45). The well was re-sampled in July 2019 and confirmed the June 2019 result to be anomalous (7.39).
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)	December 2019 January 2020	Yes	Yes	Additional monitoring as outlined in Step 4 of the contingency response program was undertaken in December 2019 and January 2020. Results are still being finalised and will be reported in the 2019-20 AEMR.

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

As mentioned above, additional monitoring as outlined in Step 4 of the contingency response program was undertaken in December 2019 and January 2020. A groundwater specialist will continue to review further monitoring to confirm the significance of these results.

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 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;
- Limit soil/material stockpiles and prevent their location within 10 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 wherever possible, or at least 50m away from waterways.

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

While most 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 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

No improvement to erosion and sediment control is proposed or required for the next period.

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**, 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 NSW 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 established noise performance criteria. 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 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 noise monitoring	Fern Bay West, Fern Bay East, Stockton West, Stockton East, Mayfield West, Mayfield, Carrington	6-monthly	See below
Attended noise monitoring	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 EPL 12693, 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 m above ground level
b) temperature inversion conditions of up to 3 degrees Celsius (°C) pert 10 m and 2 m/s at 10 m above ground level.

Table 4-13: Industrial Noise Criteria

NON-RESIDENTIAL LOCATION	LAND USE	INTRUSIVE $L_{AEQ(15\ MINUTE)}$ DAY/EVENING/NIGHT	ACCEPTABLE AMENITY $L_{AEQ(PERIOD)}$[1]			MAXIMUM AMENITY $LA_{EQ(9\ HOUR)}$
			Day	Evening	Night	Night
Mayfield West	Commercial Steel River	Intrusive noise not applicable	65	65	65	70
Kooragang Island	Industrial		70	70	70	75
Mayfield North			70	70	70	75
Any	School		External 45 when in use	50	-	-
Any	Hospital		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 surveys were conducted at each noise logger location to assist in defining noise sources and the character of noise in the area. 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 2018 and June 2019. These reports concluded that offsite noise monitoring indicated compliance was achieved at both selected residential and industrial locations under prevailing conditions (SLR 2019a and SLR 2019b).

4.7.3 Reportable Incidents

No environmental incidents were reported relating to noise or vibration during the reporting period. One complaint relating to noise was received during the reporting period. **Section 4.11.2** provides further discussion on community complaints and NCIG's response.

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 NSW Biodiversity Conservation Division (BCD) 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 management is required for the next period.

4.9 ECOLOGY

4.9.1 Environmental Management

The Green and Golden Bell Frog (*Litoria aurea*) (GGBF) is listed as Endangered under the NSW *Biodiversity Conservation Act 2016* (BC Act) and Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The GGBF is estimated to have disappeared from 90% of its former range within NSW. Known and potential GGBF 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 GGBF.

A management plan for the relocation of GGBF individuals was prepared in accordance with Condition 2.16, Schedule 2 of PA 06_0009. The GGBFMP was developed in consultation with the Department of Environment and Climate Change (DECC) (now DoEE) and the Regional Land Management Corporation (now the Hunter and Central Coast Development Corporation (HCCDC)). This plan has now been incorporated into the site ELMP.

In June 2017, a Memorandum of Understanding (MOU) on the GGBF on Kooragang Island was executed between the former OEH and NCIG, PWCS, HCCDC, BHP Billiton and University of Newcastle (UoN). 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 BCD for conservation activities to protect the GGBF. The MOU was developed to assist with data sharing from GGBF population and habitat monitoring programs completed by UoN for different stakeholders.

Monitoring and characterisation of the GGBF population on Kooragang Island, in and surrounding the industrial part of the island has been completed for the eighth year by the Conservation Biology Research Group, UoN. This work is being co-funded by NCIG, BHP, PWCS and the HCCDC. Monitoring continued throughout the summer season and the annual report was finalised in August 2019, including population estimates for the island. A copy of the report is included in **Appendix 5**. Monitoring of the GGBF was conducted in areas adjacent to Terminal, particularly areas surrounding the NCIG Rail Facility, as shown in **Figure 4-11**.

The objectives of the monitoring on Kooragang Island are to:

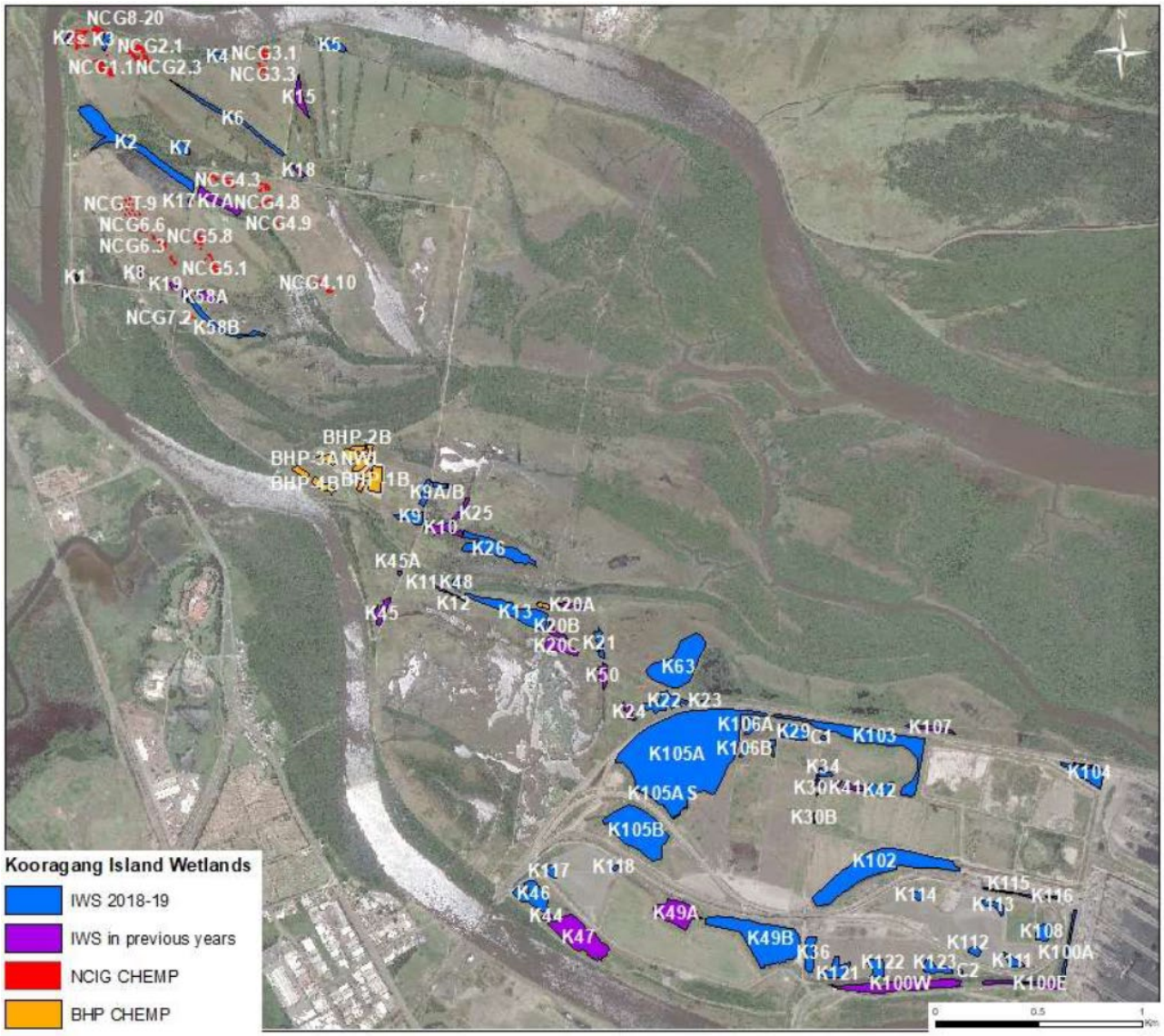
- Calculate a robust evaluation of total GGBF population size within Kooragang Island Management Zone.
- Determine the demographic composition of these populations, specifically the ratio of adults to sexually immature juveniles and the ratio of males to females.
- Define the spatial distribution of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

In accordance with Condition 2.20, Schedule 2 of PA 06_0009 NCIG developed and submitted for approval a 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 ongoing ecological management. CHEMP update monitoring reports are attached in **Appendix 6** for the reporting period. These include:

1. Kooragang Island GGBF Population monitoring, including the quarterly reporting undertaken by UoN (Conservation Biology Group): *Green and Golden Bell Frog Research and Monitoring Program on Ash Island;*
2. NCIG GGBF Compensatory Habitat monitoring and management; and
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 GGBF and the importance of not touching GGBF 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* (NP&WS, 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.



Wetlands of Kooragang Island – showing the 48 wetlands surveyed in each round of the 'island wide' surveys of 2018-19. The positions of NCIG and BHP CHEMP wetlands are also shown; 16 of these wetlands were surveyed in each round of the island-wide surveys in 2018-19, making a total of 64 wetlands.

The location of wetlands that were surveyed in previous years is also shown.

Figure 4-11: Green and Golden Bell Frog Surveyed Areas

4.9.2 Environmental Performance

4.9.2.1 UoN Research Program on the Green and Golden Bell Frog on Kooragang Island

Two methods were used to estimate the population per surveyed pond, namely Visual Encounter Surveys (VES) and Capture-Mark-Recapture Surveys (CMR). 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 two to six people. A full methodology is provided in **Appendix 5**.

A total of 64 wetlands were surveyed during the 2018/2019 breeding season. Three principal rounds of surveys were completed: Round 1 in October 2018; Round 2 in November to December 2018; and Round 3 in January to February 2019 and Round 4 March to April 2019. An additional round was completed in September 2018 for the Save Our Species surveys. The 2018-19 survey season was characterised by low levels of summer rainfall.

A summary of the results from the 2018/2019 surveys are summarised in **Table 4-14**.

Table 4-14: Summary of Green and Golden Bell Frog Research Program Findings 2018/19

Area	Characteristic	Summary of Findings
Population	Size	Comparing estimates of robust modelling-derived population size with counts from visual encounter surveys indicates that the ratio of 'frogs present' to 'frogs detected' is approximately 5:1. Extrapolating visual encounter surveys data from the island-wide survey gives a population estimate of approximately 4,000-5,000 individual GGBF (adults and >40 mm SVL juveniles on Kooragang Island) in early summer. This represents an increase on the estimated population size in recent years.
Demography	Age/sex class structure	The proportion of adult males to females is similar to recent years, with two males detected for every adult female. Slightly less than half of the GGBF detected across the season were juveniles.
	Recruitment	Thirteen wetlands within the Industrial Zone held either tadpoles and/or metamorphs at some point during the 2018-19 breeding season, the largest number recorded in the last five seasons. Breeding was also recorded in many of the BHP CHEMP wetlands.
	Gravid Females	Data from candling adult female GGBF indicates that females may achieve sexual maturity at sizes above 54 mm snout-vent length (SVL), although the proportion of gravid females at that size is low. Approximately 50% of examined 60 mm SVL females were gravid; for animals of 65 mm or greater, that figure was greater than 70%.
Longitudinal Data	Persistence	Less than 10% of the tagged GGBF that are recaptured are recaptured more than one year after their first capture, and less than 2% are recaptured after more than 2 years. This indicates a low rate of survival.
	Movement	Although most recaptures of marked individuals find them in the same wetland, GGBF who persist for more than 12 months after initial capture have a 34% probability of being recaptured in a different wetland. More than twice as many movements were detected by males compared to females.
	Growth	Longitudinal data from two cohorts of GGBF, for whom spawning dates can be estimated with confidence, indicates rapid early growth. Males reach a maximum size, between 50 and 60 mm SVL, in their second year, whilst females have a maximum size greater than 60 mm which is approached in their third year.
Landscape Use	Distribution	The highest abundance of GGBF on Kooragang Island continues to be in the Industrial Zone. In the Northern Zone (defined in Appendix 6), abundance was higher in 2018-19 than in any previous seasons, due principally to increased occupancy at the NCIG CHEMP wetlands.
	Habitat	Data from recent Island-wide surveys suggests that small, permanent well-vegetated wetlands ('stepping stone' or 'small refuge' wetlands) are an important habitat type, and in the very dry summer of 2018-19 these evidently played an important role in providing aquatic habitat as the system dried out, especially after grass fires damaged certain areas. During the driest part of the summer, the largest numbers of GGBF were in those wetlands that are well shaded by trees.
	Gambusia	Although adult GGBF can coexist with even high densities of *Gambusia*, successful breeding requires access to wetlands that are largely free of *Gambusia*. Three consecutive dry years have substantially reduced the distribution of *Gambusia* across the island from a peak in 2015-16.

Area	Characteristic	Summary of Findings
	Chytrid	Infection by the pathogenic fungus *Batrachochytrium dendrobatidis* can result in the disease chytridiomycosis (commonly known as chytrid), which affects amphibians and has caused population declines and extinction worldwide. Average chytrid load across Kooragang can be assessed via swabbing of GGBF during late winter and early spring. 120 samples were collected in the 2018-19 season (the analysis of those is pending).
	Habitat Mosaic	A single large wetland, or an array of smaller very similar wetlands, is much less suitable than an array of different wetlands. This concept of multiple heterogeneous wetlands within a small area has been termed the 'habitat mosaic'**.** This area requires further investigation to determine effects on the GGBF.
	Northern Zone of Island	This has long been the zone with the lowest abundance of GGBF, but numbers improved markedly in the 2018-19 season, due mainly to increased occupancy at the NCIG CHEMP wetlands.
Specific Strategies Relevant to NCIG	Rail infrastructure mitigation strategy	Longitudinal data from marked GGBF shows that they frequently cross railways and associated infrastructure; 26 out of 110 'significant' movements from 2014-19 involved movements over or under rail lines. It appears that the railway infrastructure does not constitute an impassable obstacle for GGBF and the rail infrastructure on Kooragang is not expected to lead to fragmentation of the population, especially where connectivity across the landscape is maintained or improved through well-designed constructed wetlands.
Other Issues	Fire	For the second consecutive year GGBF habitat was impacted by a grass fire during the latter part of the summer. The grass fire in the 2018-19 was more severe than the previous one, burning out several wetlands that usually support large numbers of adult GGBF, including the BHP CHEMP wetlands, K22, K23, and K29. The C1 cluster ponds were also heavily damaged. The grass fire in turn ignited a ground fire in Area 2 of the Industrial Zone. That ground fire burnt for several months; it posed a significant environmental hazard and health and safety risk before being brought under control in April-May 2019. A series of consecutive dry summers, as experienced over the three most recent seasons, can be expected to increase the risk of summer grass fires on Kooragang. Increased frequency and severity of fire can in turn be expected to impact GGBF habitat and the safety of personnel. The risks posed by grass fires seem to be increasing and this is an issue that needs a coordinated response from all stakeholders on Kooragang Island.
	Drought and Climate Change	The summer of 2018-19 was the hottest on record and much of NSW was in drought. Even though the wetland system on Kooragang Island was fully charged at the start of summer as a result of good spring rainfall, by the end of the summer the majority of wetlands on the island were dry. The small number of wetlands that did hold water through the summer are understood to have provided important refuge habitat; many of these were constructed wetlands, highlighting the significance of restoration efforts. The potential risks and benefits of the expected changes to wetland hydroperiod, temperature, average rainfall, salinity, vegetation and sea level, combined with the likely increases in extreme weather events, are complex and should be a focus in the near future so that medium and long-term actions can be planned.

4.9.2.2 NCIG Green and Golden Bell Frog Compensatory Habitat Monitoring and Management

The Green and Golden Bell Frog Research and Monitoring Program on Ash Island was undertaken by the UoN (Conservation Biology Group) over the 2018/2019 season. A total of 59 GGBF were observed across 10 of 44 constructed ponds in the NCIG Compensatory Habitat during the reporting period (September to December 2018). Breeding was confirmed in two ponds and 19 records of calling males across five ponds. The majority of GGBF observations occurred in Gambusia free, ephemeral water bodies. The breeding events occurring in ephemeral waterbodies supports the view that high, rapid recharge of ephemeral waterbodies is an important driver of GGBF breeding (refer to **Appendix 6**).

Fox Management

NCIG's annual Fox Baiting program was undertaken between November 2018 and January 2019, in collaboration with BHP's Compensatory Habitat fox baiting program. During this three-month period, 24 runs were undertaken across 18 bait stations, 10 in NCIG's licence area and eight in BHP's licence area. Preliminary results provided by Conservation Volunteers Australia (CVA) show the program has been successful, with 89 baits taken across NCIG's and BHP's habitats and evidence of fox activity at majority of stations.

Weed Control

Weed control was also undertaken by CVA throughout NCIG's Compensatory Habitat during the reporting period. Priority weeds were targeted including Alligator Weed, Blackberry, Groundsel Bush, *Juncus acutus*, Bitou Bush, Lantana and Pampas.

Fence Repairs and Bunding

Repair of the Frog Fence in Stage 1 was completed in October 2018. This fence was damaged following a deliberately lit fire in February 2018 (see **Photo 4-1**). Prior to the Frog Fence repairs, bunding works were undertaken in Stage 1 and were completed in June 2018, however, a couple of areas slumped during heavy rain. This was rectified in September 2018 once the water levels reduced. Bunding has also been completed in Stage 2 (**Photo 4-2**). Bunding is to prevent water bodies connecting during periods of high rainfall, reducing the spread of *Gambusia.* In March 2019 vegetation was slashed within 2 m either side of the frog fence.

Photo 4-1: New Frog Fence after February 2018 Fires

Photo 4-2: New Bunding in Stage 2

4.9.2.3 NCIG Shorebird Compensatory Habitat monitoring and management

Monthly monitoring of migratory shorebirds and other waterbird species is conducted on the NCIG site. This is completed primarily in the ponds around the NCIG rail facility, such as Deep Pond, Blue-billed Duck Pond and BHP Pond. These surveys are conducted to understand potential impacts on wader birds from the NCIG Terminal site and to take appropriate management action to reduce impacts on these species.

Area E Shorebird Monitoring

In accordance with the Shorebird Monitoring Evaluation Reporting and Improvement Plan (MERI), fortnightly surveys are taken in September-April (high tide, low tide and nocturnal roosting), and monthly in April-September (high tide and low tide). A summary of the results is presented in **Table 4-15**. In the 2018 survey period, 37 shorebird species were recorded from the survey locations including 11 migratory shorebirds. 22 shorebird species were recorded during January to June 2019 from all sites in Area E. A total of 46 shorebird species have been recorded, by this survey project, for Area E during the 2017, 2018 and the January to June 2019 surveys. This includes a range of wetland and migratory shorebird species. No new species have been recorded for Area E so far in 2019.

Specifically, 27 shorebird species including six migratory shorebirds were observed at Fish Fry Flats during the 2018 surveys, increasing the count to eight migratory shorebirds in total at Fish Fry Flats since the removal of mangroves. Four (4) migratory shorebird species were recorded at Fish Fry Flat during January to June 2019. The results show that migratory shorebirds are using Fish Fry Flats during the day and night, on high and low tides, with no obvious preference observed. Additionally, White-fronted Chats were observed on three occasions in 2018, this is the first time they have been observed at Fish Fry Flats since mangrove removal.

The results thus far indicate that Fish Fry Flats is primarily used as foraging habitat for migratory shorebirds, particularly the mudflat portion of the habitat. In future surveys, the habitat will be further divided to allow better comparison between UoN's vegetation sampling zones. To allow comparison with UoN's vegetation survey zones, whist still being practical for shorebird count surveys, the new habitat zones will be categorized as (1) above saltmarsh, (2) saltmarsh, (3) mud with old pneumatophores, (4) mud with no pneumatophores and exposed by daily tides and (5) water. These results are expected to determine the preferred habitat for shorebirds in Area E.

Table 4-15: Migratory Shorebird Species Recorded in Area 2017/18

Species	All Sites Area E			Fish Fry Flat		
	2017	2018	Jan-Jun 2019	2017	2018	Jan-Jun 2019
Curlew, Eastern	p	p	P	p	p	
Godwit, Bar-tailed	p	-		-	-	
Greenshank, Common	p	-		p		P
Knot, Red	p	-		-	-	
Plover, Double-banded	p	p	P	p		P
Plover, Pacific Golden	p	p		p	p	
Sandpiper, Curlew	p	p		-	p	
Sandpiper, Marsh	-	p		-	-	
Sandpiper, Sharp-tailed	p	p	P	p	p	P
Snipe, Lathams	-	p		-	p	
Stint, Red-necked	p	p	P	p	p	P
Total	**9**	**8**	**4**	**6**	**6**	**4**

p = Present

Area E Wetland Hydrology Monitoring

UNSW Water Laboratories were commissioned to develop hydrological controls and SmartGate Trigger Levels for 2019. Following the stakeholder meeting in September 2018, it was concluded that the existing tidal triggers will remain the same and active monitoring will be undertaken, including water level monitoring before any alterations are made to tidal trigger levels. A detailed investigation was conducted from July 2018 to June 2019 to better understand groundwater movement and interactions with surface water, as well as water quality, under different conditions including:

1. Wetland in natural tidal conditions;
2. Wetland flooded, with flushing restricted by the SmartGate; and
3. Wetland drained, with the gates preventing inundation.

Overall, the results show that groundwater and surface water systems in Fish Fry Creek are closely linked, and groundwater seepage occurs under various conditions.

During natural conditions, it was clearly observed that tidal variation controlled the water quality and hydrodynamics within Fish Fry Flats. During the flooded conditions, the EC decreased over the 24-hour period, potentially due to groundwater seepage containing lower EC. The average groundwater conductivity at the site was around 56,000 µS/cm for 2018 and 61,000 µS/cm for 2019 (expect for piezometers 1 which was slightly lower at 56,000 µS/cm). Typical ocean water conductivity is around 55,000 µS/cm, therefore the average conductivity of groundwater at the site is above oceanic values, indicating evaporation. UNSW (2019) note that the observed increase is not significant and may be due to different rainfall amounts during 2018 and 2019.

Chlorophyll showed a similar trend to natural tidal conditions, indicating processes other than tidal variation may be driving chlorophyll dynamics in Fish Fry Flats. A sharp increase for temperature, dissolved oxygen, pH and chlorophyll, and a decrease for EC was observed after the gate was opened and the water drained from the wetland.

In general, groundwater levels at Area E are greatly affected by tides and follow the tidal regime. Groundwater level data for the second half of 2018 and the first half of 2019 did not show any long-term trend and no obvious decline or incline trend was observed in the graph, indicating stable conditions throughout 2018 and 2019. Observations throughout the reporting period showed a general trend in which the groundwater hydraulic heads decrease in winter months.

Mangrove Removal

New mangrove growth was removed in November 2018 by CVA. This was the second removal event since the mangroves were initially removed from Area E in late 2016. Mangrove regrowth density and distribution was mapped prior to removal to allow comparison with the 2017 removal data (**Figure 4-12**). The 2018 results show a reduction of more than 85% mangrove seedlings/propagules/regrowth in comparison to the 2017 data.

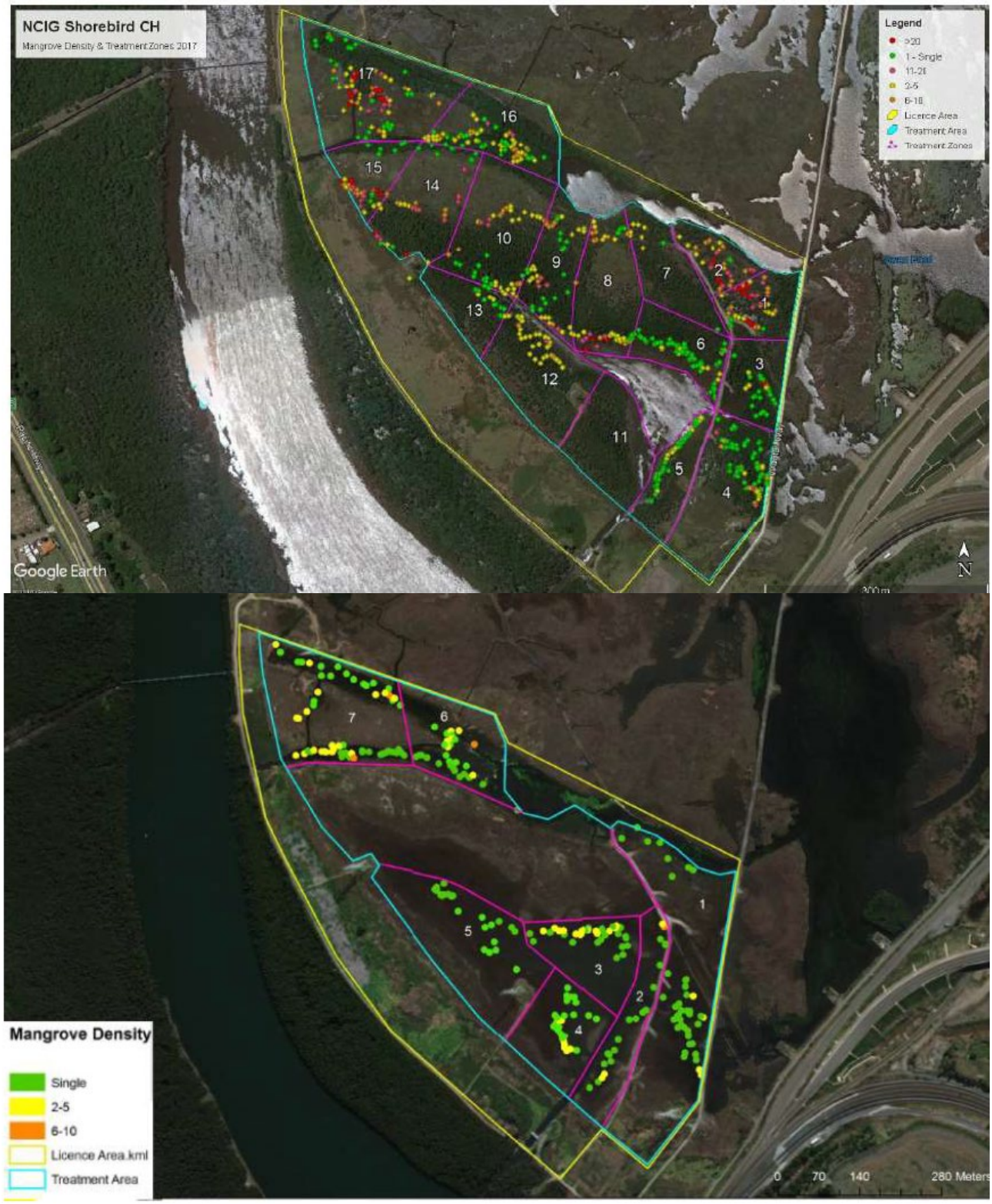


Figure 4-12: Comparison of Mangrove Density in November 2018 (top) and November 2017 (bottom)

4.9.2.4 Avifauna Monitoring Program

The results of the monthly surveys conducted on Deep Pond North and Deep Pond South during the 2018 calendar year are illustrated by **Table 4-16** and **Table 4-17.** 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.

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

- The count of migratory and resident shorebirds using Deep Pond in 2018 was high comparative to previous years, both in terms of the number of species and individual birds.
- Four migratory shorebird species were recorded at Deep Pond in 2018, compared to two in 2017.
- Including incidental observations, a total of twelve species of migratory shorebirds have now been recorded on Deep Pond between 2008-2018 (with a total of fourteen species between 1993-2008).
- Five species of resident shorebird were recorded at Deep Pond during 2018, being Masked Lapwing, Black-fronted Dotterel, Black-winged Stilt, Red-capped Plover and Red-necked Avocet.
- Numerous waterfowl such as ducks, swans and grebes and other waterbirds such as herons, egrets and ibis were recorded in 2018.
- Several species listed as under the BC Act or EPBC Act were observed utilising Deep Pond during 2018, including White-bellied Sea Eagles, Black-tailed Godwit, Freckled Duck, Red Knot, and Curlew Sandpiper (recorded outside of survey times).

Table 4-16: Avifauna 2018 Monitoring Results – Deep Pond North

Species	12/01	16/02	16/03	13/04	18/05	15/06	13/07	10/08	7/09	19/10	9/11	7/12	Total
Australasian Grebe						1			6			6	13
Australasian Shoveler	8				130		8	10				3	159
Australian Magpie									1				1
Australian Pelican	11			5					3		9	15	43
Australian Raven								1	1				2
Australian White Ibis	9			11	4						1	30	55
Bar-shouldered Dove									2				2
Black Swan	4			9	16	6	38	45	53	67	188	187	613
Black-fronted Dotterel				14	13				1				28
Black-shouldered Kite		1											1
Black-tailed Godwit*	66	71		27	1								165
Black-winged Stilt	650	337		46	22	2			5			315	1377
Cattle Egret						1							1
Chestnut-breasted Mannikin			8										8
Chestnut Teal	4							6			6		16
Common Greenshank												29	29
Common Myna								1	10				11
Eurasian Coot											70	360	430
Fairy Martin								6	30				36
Fan-tailed Cuckoo								1					1
Freckled Duck*												5	5
Golden-headed Cisticola								2					2

Species	12/01	16/02	16/03	13/04	18/05	15/06	13/07	10/08	7/09	19/10	9/11	7/12	Total
Great Egret					1					2			3
Grey Teal	28				105					6		2	141
Hardhead											1	450	451
Horsefield Bronze-Cuckoo										1			1
Hoary-headed Grebe	2											8	10
Intermediate Egret												2	2
Little Black Cormorant										1		1	2
Little Grassbird									6				6
Little Pied Cormorant											1	2	3
Magpie-lark						1		2	2				5
Masked Lapwing	4	61	23		2	5		2	2			2	101
Musk Duck									1	1			2
Pacific Black Duck	12				13			20	25		4		74
Pallid Cuckoo											1		1
Pink-eared Duck												1	1
Purple Swamphen	3												3
Red Knot*		1											1
Red-capped Plover				1									1
Red-necked Avocet	749	127		215	220								1311
Royal Spoonbill	13												13
Sharp-tailed Sandpiper												15	15
Silver Gull		1										1	2
Superb Fairy-wren								4	10				14

Species	12/01	16/02	16/03	13/04	18/05	15/06	13/07	10/08	7/09	19/10	9/11	7/12	Total
Swamp Harrier	2								3	2			7
Welcome Swallow							150	28	10				188
Whistling Kite		1	1	1					1				4
White-bellied Sea-Eagle*	1	1				1					1		4
White-breasted Woodswallow				2									2
White-faced Heron			2			1					6	1	10
Willie Wagtail						1		1	1				3
Total	1566	601	34	331	527	19	196	129	173	80	288	1435	5379

*Listed as threatened under the BC Act and/or the EPBC Act

Table 4-17: Avifauna 2018 Monitoring Results – Deep Pond South

Species	12/01	Dry	Dry	13/04	18/05	15/06	13/07	10/08	7/09	19/10	9/11	7/12	Total
Australasian Grebe					2			5		11	8	5	31
Australasian Shoveler					2								2
Australian Magpie									1				1
Australian Pelican	17												17
Australian White Ibis					25						11	12	48
Black Swan	4			2	11	40	77	51	13			1	199
Black-winged Stilt								8					8
Chestnut Teal					2						6		8
Common Myna								4					4
Fairy Martin								15	8				23
Glossy Ibis												8	8

Species	12/01	Dry	Dry	13/04	18/05	15/06	13/07	10/08	7/09	19/10	9/11	7/12	Total
Great Egret	1										2	1	4
Grey Teal									83				83
Hardhead					1								1
Intermediate Egret												2	2
Little Grassbird									2				2
Magpie-lark								2	4				6
Masked Lapwing	39				1			1			2		43
Pacific Black Duck					7		4	18			2		31
Purple Swamphen					9	28		11	11	2	3	20	84
Royal Spoonbill											1		1
Straw-necked Ibis					2						8	3	13
Superb Fairy-wren								2	6				8
Swamp Harrier	1									1		1	3
Welcome Swallow								10	4				14
Whiskered Tern											1		1
Whistling Kite					1								1
White-bellied Sea-Eagle*									1				1
White-faced Heron							1	1					2
White-necked Heron									1		1		2
Willie Wagtail								8	2				10
Total	62	0	0	2	63	68	82	136	136	14	45	53	661

*Listed as threatened under the BC Act and/or the EPBC Act

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 2019/ 2020 will include the following:

- Revision of the NCIG Green and Golden Bell Frog Compensatory Habitat Management Plan was completed within the current reporting period. This revised version of the plan has been reviewed by the National Parks and Wildlife Service for comments and is expected to be approved in the 2020 financial year
- Continued fox baiting program in collaboration with BHP including NCIG GGBF habitat, BHP GGBF habitat and NCIG shorebird habitat.
- The Shorebird Habitat Monitoring, Evaluation, Reporting and Improvement Program has been reviewed by a contracted shorebird expert during the current reporting period. Recommendations will be reported and incorporated as appropriate in the 2019/20 AEMR.
- Emergent vegetation removal in ponds to promote preferred GGBF habitat will continue.

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 (NCIG Waste Audit Report (Cross Connections Consulting Pty Ltd (2019) sighted by Ramboll).

A WMP 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.

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 previous reporting period. Waste streams at NCIG now include: scrap metal, general, paper and cardboard, soft plastics, timber, co-mingle recycling, E-waste, fluorescent tubes, aerosol cans, waste oil, oil rag/ dry-sorb, grease and effluent.

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 compositional waste audit was conducted by Cross Connections Consulting Pty Ltd in April 2019. The purpose of this audit was to identify and assess the waste streams generated on site still typically ending up in landfill and identify opportunities to reduce waste to landfill. Of the 2,800 kilograms (kg) of waste assessed, 1,080 kg (39%) was categorised as genuine landfill waste and the remaining 1,720 kg (61%) was categorised as potentially recyclable/recoverable materials. Of the recyclable/recoverable materials, the largest contributors identified were rubber (45% or 1,252 kg) and mixed plastics (7% or 196 kg). These two new recycling streams have since been implemented on site.

Figure 4-13 and **Figure 4-14** present the recycling statistics for the reporting period, including for soft plastics. The annual recycling target of 65% was exceeded for the reporting period, with a rate of 75%.

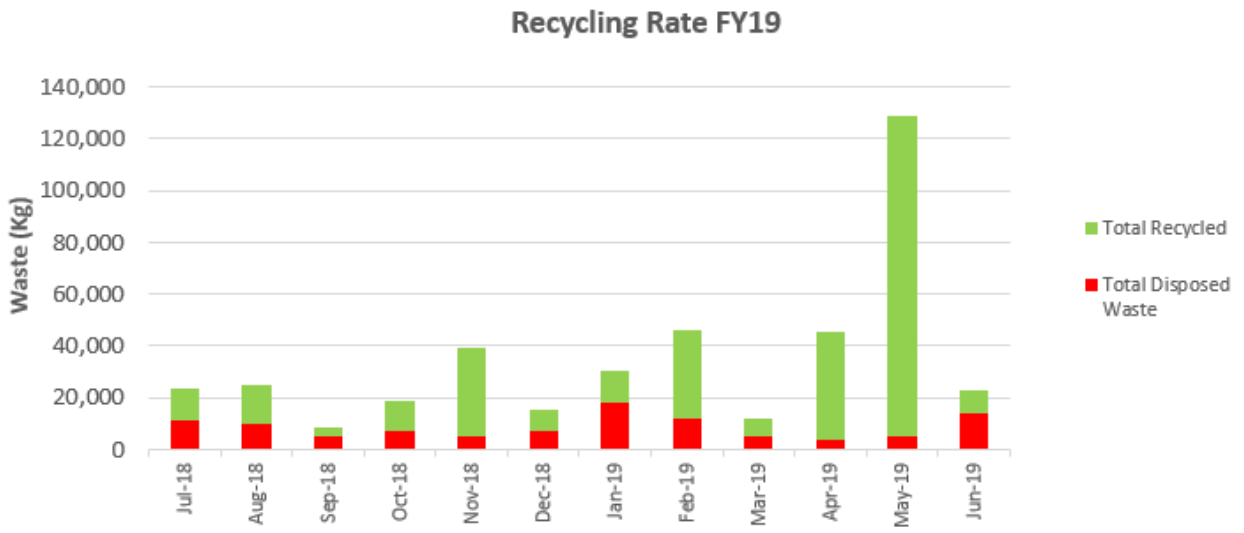


Figure 4-13: Recycling Rate for FY19

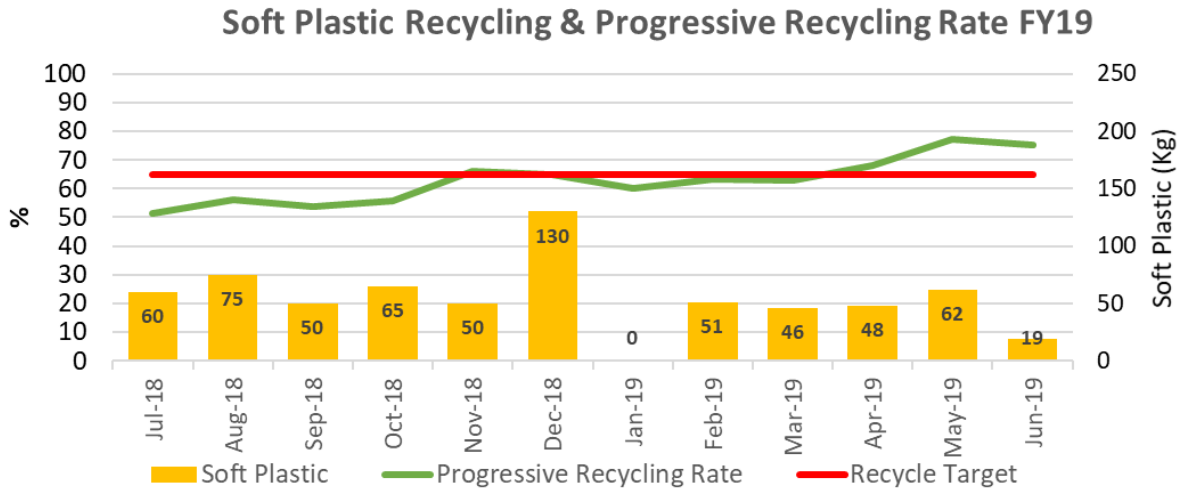


Figure 4-14: Soft Plastics Recycling and Progressive Recycling Rate FY19

A significant spike in total waste was recorded in May 2019. This spike was associated with replacement of a rubber conveyor belt. As evidenced by **Figure 4-13**, the conveyor belt was recycled. The December and January volumes of soft plastic recycling are combined due to there being a single collection over the holiday season.

4.10.3 Reportable Incidents

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

4.10.4 Further Improvements

Improvements related to waste management at the Terminal will be pursued consistent with the recommendations of the Waste Audit Report (Cross Connections Consulting 2019).

4.11 COMMUNITY RELATIONS

4.11.1 Environmental Management

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

- 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 at 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 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).

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

4.11.2 Environmental Performance

4.11.2.1 Complaints Management

Table 4-18 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.

NCIG's objective was to address the concerns of the complainant in a manner that resulted in a mutually acceptable outcome.

Table 4-18: Community Complaints Register Summary

DATE OF COMPLAINT	ENVIRONMENTAL CONCERN RAISED	ISSUE	DATE OF FOLLOW UP	ACTION TAKEN
09/09/2018	Site Security	A passerby called the NCIG enquiries line regarding people gathering at the corner of the stockyard on Cormorant Road on Sunday at approximately 1:15pm. Caller was ringing to ensure NCIG was aware of this.	09/09/2018	HSEC Manager returned the call to confirm details. Ten cars were gathering outside the Terminal fence at the turnaround bay on PN road near TH02. Approximately 30 people, all dressed in Yellow were having their photos taken with our stockyard as a backdrop. The group dispersed after 30 minutes. HSEC Manager then notified Process Leader and an Incident was entered. Increased security measures were then put into place as NCIG were aware of increased protestor action over the coming week.

DATE OF COMPLAINT	ENVIRONMENTAL CONCERN RAISED	ISSUE	DATE OF FOLLOW UP	ACTION TAKEN
22/11/2018	Air Quality	The EPA received a community complaint at 10:40am. The complainant had advised that NCIG stockpiles were not receiving water from sprays, and that they were concerned about coal dust blowing from stockpiles in windy conditions. Concern regarding addition of coal dust to the already poor air quality (during the dust storm at the time), including health impacts to the community. The EPA Officer requested that the incident be investigated and action taken where appropriate.	22/11/2018	Environmental Advisor returned EPA Officer's call on the afternoon of the 22nd to obtain additional information. Internal investigation undertaken to review control system trends. It was confirmed that stockyard sprays were running throughput the day as intended. The passer-by likely passed NCIG site as the phase of the spray cycle was not visible from the road. Follow up email to the EPA was sent on the morning of the 23rd, confirming the use of stockpile sprays in the yard during this time. No further information requested from EPA.
20/12/2018	Noise	A complaint was made about the noise coming from coal trains shunting overnight. The complainant thought they were trains going into Carrington Coal terminal. He said it was like a 'bomb going off' and was typically happening in the early hours of the morning and has been occurring frequently over the last 2-3 weeks.	20/12/2018	HSEC Manager provided the complainant the ARTC Enquiries and Complaints Line and suggested he give them a call as they were responsible for managing the rail. No further action required or requested.
02/01/2019	Vegetation Screening	Local resident (resident of The Cove retirement village), called the NCIG reception at approximately 3.30pm. The resident spoke with Process Leader on shift and explained they were concerned about the trees on the visual berm, seen from Cormorant Road, and that some appeared to be dying.	2/01/2019	Environmental Advisor returned a call to the local resident. The resident explained they had seen the trees along the visual berm grow since the terminal was built. They were pleased with the growth and believed it provided a good visual screen. They did not want to see any of the trees die off, given the good progress made. Discussion was also had about the suitability of the species and the growth of recently planted tubestock. Environmental Advisor thanked the resident for their concern and committed to reviewing the watering regime of the irrigation along the visual berm. External Enquiry added to incident register, including an action to review watering regime and coverage of the visual berm plants.
31/01/2019	Air Quality	Member of the public called NCIG enquiries line regarding visible dust coming off conveyor on Kooragang Island.	31/01/2019	HSEC Manger returned call and ascertained that the location described was a transfer house from a neighbouring business. The NCIG Process Leader contacted the Shift Supervisor of the neighbouring business who then investigated. Neighbouring business Shift Supervisor notified NCIG Process Leader that after inspection, no dust was evident. However, he advised that they had just completed loading vessel in area that could have been the problem. The Shift Supervisor advised that he would escalate the matter to the Superintendent.

4.11.2.1 Community Engagement Group

During the reporting period, NCIG established a Community Engagement Group (CEG). The CEG aims to provide a forum to provide the local community with information about NCIG's operations and give a voice to the community in matters such as operational activities, environmental performance and community investment initiatives. Minutes from each CEG Meeting are published on the NCIG website (https://www.ncig.com.au/community/community-engagement).

The first meeting was held on 30 April 2019. Topics of interest raised during the meeting included dust management, logistics of tracking coal in the Stockyard, the use of LED lighting, water management and NCIG's community investment activities. Going forward it is proposed that meetings will be held every four months (three times per year).

4.11.2.2 Community Support Program

NCIG conducted two rounds of community funding in the 2019 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 $246,257 was contributed through the Community Support Program during the reporting period to groups within the four NCIG community investment focus areas (community, environment, health and education). In particular, investments aim to meet one or more of the following objectives:

- Promote overall community involvement
- Implement community-generated programs to improve local amenity and the environment
- Promote physical or mental health through activity
- Promote and assist in education of our local community.

NCIG has two funding programs:

- The Community Support Program: caters for community organisations looking for funding assistance with an event, small project or purchase of equipment; and
- Community Partnership Program: 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.

Figure 4-15 provides a breakdown of the contributions made to each of the focus areas. A full list of recipients is provided in **Appendix 8**.

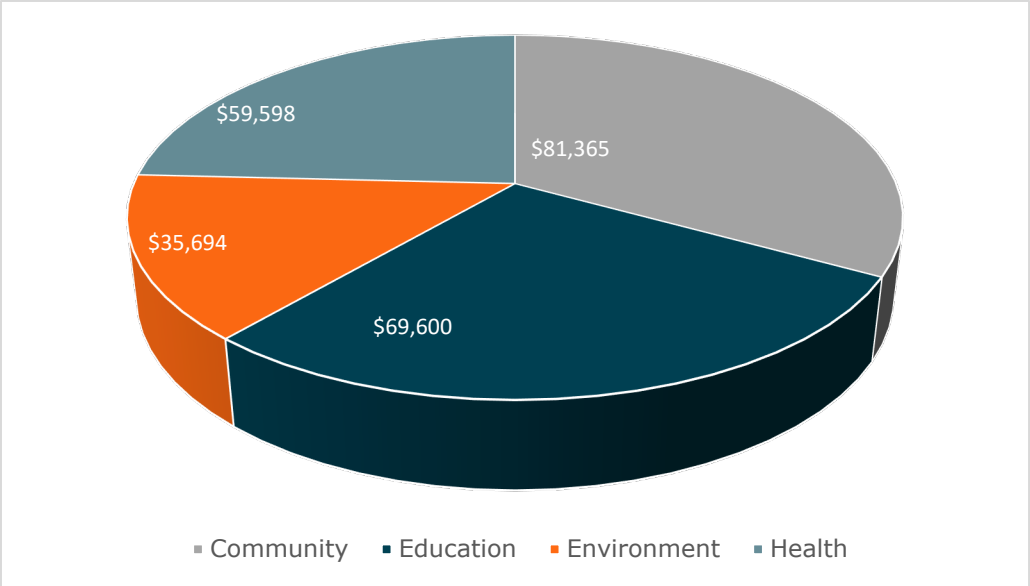


Figure 4-15: Focus area breakdown of contributions through the Community Support Program

4.11.2.3 Sustainability

NCIG prepared a Sustainability Report for the reporting period. 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 annual Sustainability Reports are maintained on the NCIG website at: https://www.ncig.com.au/business/corporate-sustainability

4.11.2.4 Community Engagement Summary

The chronology of community liaison held during the reporting period is outlined in **Table 4-19**.

Table 4-19: Community Liaison Summary

DATE	TYPE
Winter 2018	Community Newsletter
September 2018	Community Support Program – submissions called, 11 successful
Spring 2018	Community Newsletter
March 2019	Community Support Program – submissions called, 21 successful
30 April 2019	First CEG meeting held
September 2019	Community Partnership Program - Sponsoring Newcastle High and Callaghan College Waratah Technology Campus STEM Outreach Development Program (HunterWiSE)
Autumn 2019	Community Newsletter
December 2019	Release of the 2019 Sustainability Report

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

NCIG will prioritise 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.

Funding rounds will continue to open every six months in March and September for the Community Support Program, with funding of up to $10,000 available for applicants, and funding up to $90,000 over the three-year period for the Community Partnership Program will be open for applications each year.

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):

> *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.

5.1 COMPLIANCE TRACKING PROGRAM UPDATED APRIL 2019

A Compliance Tracking Program was set up for the NCIG CET in accordance with Condition 5.1, Schedule 2 of PA 06_0009. The Compliance Tracking Program was updated in April 2019. The Compliance Tracking Program indicated that project compliance has been achieved for each condition of the Project Approval with the exception of one item as described in **Table 5-1.** Note: At the time of finalising this report, the below non-compliance has now been resolved with DPIE.

Table 5-1: Compliance Status Summary

REF	CONDITION	COMPLIANCE DETAILS	COMPLIANCE STATUS
2.42	Unless otherwise agreed by the Director General, the Proponent shall design, construct, maintain and operate surface water and stormwater management infrastructure on the Site to accommodate a 1 in 100 ARI rainfall event, and shall not permit the discharge of any water from the Site to the Hunter River unless expressly provided under the provision of an EPL.	NCIG have designed, constructed, maintained and operated surface water and stormwater management infrastructure to accommodate a 1 in 100 ARI rainfall event of two hour duration (Drainage Assessment Report for the Stockyard and Wharf Areas, 2014). During this reporting period, stormwater overflow from NCIG's Clearwater Pond occurred in June 2018, during a period of prolonged heavy rainfall which exceeded the design volumetric capacity of NCIG's surface water infrastructure (NCIG Water Quality Monitoring Database). Previous evidence includes correspondence with the EPA and DPIE since 2015 as follows: • Overflow event communicated with EPA (15/05/15). • The EPA responded stating no EPL compliance issues with recent overflow event, based on the water quality monitoring results. The EPA stated there is no need for a specific licence condition to authorise the discharge of water from the premises where waters are not being polluted (24/08/15). • EPL varied by EPA to include discharge and ambient water monitoring (10/03/16). • DPIE provided acknowledgement of works NCIG had completed to date in relation to this condition (24/10/16). The 2018 IEA identified this condition to be non-compliant as EPL 12693 does not expressly provide for the discharge of water from site. NCIG is currently in the process of clarifying this condition as outlined in NCIG's Response to Auditor Recommendations.	As mentioned above, at the time of finalising this report this non-compliance has been rectified. NCIG have recently received a response from DPIE recognising that discharge occurs from the NCIG site during major stormwater events or prolonged rainfall events that exceed the holding capacity of the NCIG stormwater management system. It has also been recognised that as a licenced facility, any water pollution resulting from discharge events is regulated by the EPA.

5.2 INDEPENDENT ENVIRONMENTAL AUDIT

An IEA 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 IEA 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 IEA was conducted within 12 months of the commencement of construction. This has been conducted annually until 2015, with the most recent IEA conducted in December 2018. The next IEA will be conducted in December 2021.

Table 5-2 provides a summary of the non-compliances identified in the most recent IEA. A progress report has been provided to DPIE on a 3 monthly basis to provide an update on each of the below actions. At the time of finalising this report, all actions have been closed.

Table 5-2: Independent Environmental Audit Compliance Status Summary

	CONDITION	COMPLIANCE STATUS	AUDIT RECOMMENDATION	NCIG RESPONSE	CURRENT COMPLIANCE STATUS
Project Approval (MP 06_009)					
2.42	Unless otherwise agreed by the Director-General, the Proponent shall design, construct, maintain and operate surface water and stormwater management infrastructure on the Site to accommodate a 1 in 100 ARI rainfall event, and shall not permit the discharge of any water from the Site to the Hunter River unless expressly provided under the provision of an Environment Protection Licence.	Non-compliance (low risk level)	It is recommended that NCIG apply for a variation of the EPL to establish a licenced discharge point or alternatively seek a variation to the Approval to permit water discharges from site during rain events that exceed a 1 in 100 ARI event.	NCIG has designed, constructed, maintained and operated surface water and stormwater management infrastructure to accommodate a 1 in 100 ARI rainfall event of two hour duration. However, discharge has occurred from the site on occasion, during extreme or prolonged rainfall events that exceed the design volumetric capacity. In regard to this condition, NCIG has corresponded with the EPA and DPIE since 2015. On 13 May 2015 NCIG contacted the EPA regarding an overflow event which occurred during an extreme weather event that impacted the Hunter Region. In this letter, NCIG requested the EPA to advise if a modification to EPL 12693 would be considered as the most appropriate means of rectifying the inconsistency between the EPL and this condition of the Project Approval. The EPA's response stated "*Condition A3.1 did not appear to have been contravened"* (Condition A3.1: T*he works and activities must be carried out in accordance with the proposal contained in the licence application* (PA 06_0009)). Additionally, the EPA responded "*Condition L1.1 reiterates Section 120 of the Protection of the Environment Operations Act (1997) which prohibits water pollution. Based on the water quality monitoring results provided, there is no evidence that the discharge from NCIG's premises polluted waters. There is no need for a specific licence condition to authorise the discharge of water from the premises where waters are not being polluted."* On 10 March 2016, additional monitoring points were added to EPL 12693, requiring NCIG to sample overflow and ambient (background) water quality during overflow events (monitoring points 34 and 35). This above modification to the EPL, and details of the specific actions NCIG has undertaken to satisfy the requirements of Condition 2.42 (PA 06_0009) was communicated to DPIE on 26 August 2016, in response to a letter from DPIE regarding the IEA undertaken in 2015. The DPIE provided acknowledgment of the works that NCIG had completed to date in relation to Condition 2.42. NCIG will seek to obtain clarity from the EPA in regard to this matter and will re-engage DPIE before 30 June 2019.	As mentioned above, at the time of finalising this report this non-compliance has been rectified. NCIG have recently received a response from DPIE recognising that discharge occurs from the NCIG site during major stormwater events or prolonged rainfall events that exceed the holding capacity of the NCIG stormwater management system. It has also been recognised that as a licenced facility, any water pollution resulting from discharge events is regulated by the EPA.
2.50	In the event that stormwater runoff collection cannot meet the water demand of the Site,	Compliant	It is recommended that should NCIG determine that the use of the	In the past, NCIG has held discussions with Hunter Water Corporation in relation to utilising treated wastewater on site.	At the time of finalising this report this action is considered

	CONDITION	COMPLIANCE STATUS	AUDIT RECOMMENDATION	NCIG RESPONSE	CURRENT COMPLIANCE STATUS
	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.		available recycled water is not practical, seek a modification to this Approval Condition to remove the absolute requirement for preferential use of recycled water.	These discussions have revealed that while treated wastewater is available for utilisation, it could not be supplied in a manner that is in line with the water demand cycle, making it an unviable option. NCIG developed a Water Efficiency Management Plan with Hunter Water in 2018. The Action Plan contained within this management plan includes commitment to investigate the use of alternate process water supplies, including discussion with Hunter Water regarding the compatibility of NCIG's usage profile with Hunter Water's supply capability of recycled water. NCIG will engage with Hunter Water regarding the feasibility of using recycled water over the next 12 months.	closed - NCIG have continued investigations regarding the feasibility of utilising treated wastewater through WUA. Pending the outcome of these technical investigations, NCIG will seek to pursue a commercial agreement with WUA in line with the usual business project management and commercial framework.
Environmental Protection Licence No. 12693					
L3.1	All site preparation, filling/preloading and construction works that may generate an audible noise at any residential receptor shall only be undertaken between 7.00 am and 6.00 pm. This condition does not apply in the event of a direction from police or other emergency authority for safety or emergency reasons.	Compliant	It is recommended that when the current EPL is next reviewed with the EPA, that NCIG seek to have the now redundant construction phase conditions removed from the licence.	NCIG believes there is merit in retaining the construction related condition in the EPL should construction activities be undertaken in the future.	N/A
L3.2	Notwithstanding any other condition of this licence, piling works shall not be conducted on Sundays or public holidays.	Compliant			
NCIG Draft Statements of Commitment (Environmental Assessment 2006)					
Section 4.4.3	Construction and operational air quality and odour Greenhouse Gas - Mitigation Measures would include: • regular on-site energy audits to optimise energy efficiency; • consideration of energy efficiency in plant and equipment selection/purchase; • regular maintenance of plant and equipment to minimise fuel consumption and associated emissions; • planting of native vegetation, as part of visual screens in select locations around the site; and	Non-compliant (administrative non-compliance)	It is recommended that an energy efficiency audit be undertaken, and an energy / greenhouse minimisation plan be developed for the operation.	As outlined in NCIG's Operation Dust and Air Quality Management Plan, NCIG continues to implement further operational improvements to increase the efficiency of the plant. NCIG undertakes annual auditing and reporting of greenhouse gas emissions and submits them to the National Greenhouse and Energy Reporting (NGER) annually. In recent months, NCIG has had preliminary discussions with a consultant to conduct an environmental footprint assessment, including energy efficiency assessment and provide options for improvement. Moving forward, NCIG will undertake an annual internal energy efficiency review and engage an external consultant to undertake an energy efficiency assessment biennially.	At the time of finalising this report this action is considered closed – A greenhouse gas and energy efficiency assessment commenced in June 2019 and was finalised in October 2019. The outcome of the assessment and opportunities for improvement have been reviewed in detail. NCIG will assess the feasibility of further pursing options to reduce greenhouse gas emissions and improve energy efficiency. This action is now closed.

	CONDITION	COMPLIANCE STATUS	AUDIT RECOMMENDATION	NCIG RESPONSE	CURRENT COMPLIANCE STATUS
	• installation of solar-powered monitoring equipment and other instrumentation where practicable.				
Section 4.13.3	Socio-economics The Project would continue to consult with the local community and would establish a Community Consultative Committee for the Project as an on- going channel for communication between the local community and NCIG. The CCC would comprise a similar membership to the current SFG and would meet to discuss development progress, to review the general environmental performance of the Project and to discuss any issues raised by the community.	Non-compliance (low risk level)	It is recommended that NCIG establish a Community Consultative Committee/Group.	NCIG established a Community Reference Group prior to construction of the Terminal. Towards completion of construction, the interest from community members declined. Due to the declining number of members in NCIG's Community Reference Group, NCIG became involved in community consultation via alternate means including Port Waratah Coal Service's Community Consultation Committee in early operational years, and more recently NCIG has participated in Port of Newcastle's Community Liaison Group, of which NCIG is still a member. NCIG is currently in the process of establishing a new Community Engagement Group due to potential for greater community interest in NCIG operations and community engagement activities. Terms of Reference have been finalised and Expressions of Interest advertising commenced in February 2019. The Community Engagement Meetings will be structured around NCIG's internal Terms of Reference.	At the time of finalising this report this action is considered closed – NCIG have held regular Community Engagement Group (CEG) over the previous 12 months. CEG Meetings will continue as business as usual moving forward.

6. STANDARDS

Accreditation of the NCIG Environmental Management System (EMS) against the ISO14001 standard was maintained throughout the reporting period. This included an onsite audit conducted by SAI Global on 11 June 2019 to 14 June 2019. The audit revealed that the NCIG Work Health and Safety (WHS) and Environmental Management System (EMS) continues to be effectively implemented and improved, with effective processes in place to manage WHS and environmental risks. No for further recommendations were identified.

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 EMS.
- Ongoing incorporation of dust management technologies and controls to continue to improve the management practices for air quality.
- An assessment of alternative stockpile treatments will be undertaken in the first half of the 2020 financial year to determine their feasibility and effectiveness.
- Further improvements to sediment management within onsite water management infrastructure.
- NCIG has engaged Water Utilities Australia to undertake a feasibility and options assessment for the use of recycled water onsite. This investigation will continue throughout the next reporting period.
- Revision of the NCIG Compensatory Habitat Management Plan was completed within the current reporting period. Approval is expected to be obtained from National Parks and Wildlife Services (NPWS) in the next reporting period.
- Continued fox baiting program in collaboration with BHP including NCIG GGBF habitat, BHP GGBF habitat and NCIG shorebird habitat.
- The Shorebird Habitat Monitoring, Evaluation, Reporting and Improvement Program has begun to be reviewed by a contracted shorebird expert during the current reporting period. Recommendations will be reported and incorporated as appropriate in the 2019/20 AEMR.
- Continued emergent vegetation removal in ponds to promote preferred GGBF habitat.
- Funding rounds will continue to open every six months in March and September, with funding of up to $10,000 available for applicants of the Community Support Project and up to $90,000 over the three-year period for the Community Partnership Program.

8. REFERENCES

Amphibian Research Group, University of Newcastle (2019). *Green and Golden Bell Frog (Litoria aurea) Research Program on Kooragang Island: Annual Report (2018-2019)*.

Hunter Bird Observers Club (2019). *Deep Pond (Kooragang Island) Avifauna Data Summary 2018*.

NCIG (2019). *Compensatory Habitat and Ecological Monitoring Program – Half-yearly Report (June 2018 – December 2018)*.

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Ramboll (2019). Draft *NCIG Surface Water Monitoring Data Review 2019*.

SAI Global (2018). *Surveillance audit for Newcastle Coal Infrastructure Group Pty Ltd*.

SLR (2019a). *Newcastle Coal Export Terminal, Biannual Off-site Noise and On-site Sound Power Monitoring, July 2018 to December 2018*.

SLR (2019b). *Newcastle Coal Export Terminal, Biannual Off-site Noise and On-site Sound Power Monitoring, January 2019 to June 2019*.

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

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 2019 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	Hourly min	Hourly max	Monthly average	Hourly min	Hourly max	Monthly average	Hourly min	Hourly max
	m/s	m/s	m/s				W/m²	W/m²	W/m²
July 2018	3.3	0.2	12.1	16.4	2.9	91.4	119.9	0.0	620.0
August 2018	3.5	0.3	12.4	16.1	2.8	91.7	148.4	0.0	895.0
September 2018	2.8	0.1	11.0	21.5	3.8	99.6	189.2	0.0	940.0
October 2018	3.2	0.3	8.8	19.2	5.0	88.5	196.9	0.0	1095.0
November 2018	3.7	0.1	15.1	19.0	4.1	98.0	251.5	0.0	1173.0
December 2018	3.2	0.2	10.5	20.6	5.5	83.6	285.8	0.0	1183.0
January 2019	3.2	0.5	9.7	19.5	6.1	96.9	261.1	0.0	1146.0
February 2019	3.5	0.2	10.8	17.4	5.4	92.9	253.7	0.0	1043.0
March 2019	3.1	0.3	12.2	20.0	4.4	92.5	195.9	0.0	1070.0
April 2019	2.4	0.1	8.4	21.0	4.0	98.3	167.9	0.0	905.0
May 2019	3.2	0.2	13.3	17.1	3.3	94.4	119.9	0.0	732.0
June 2019	2.6	0.4	8.3	19.0	2.9	91.2	89.2	0.0	612.0

*Equipment malfunction

TABLE A1.2 METEOROLOGICAL STATISTICS BY MONTH

MONTH	TEMPERATURE AT 2M ELEVATION (T2)			TEMPERATURE AT 10 M ELEVATION (T10)				
	Monthly average	Hourly min	Hourly max	Monthly average	Hourly min	Hourly max	Number of hours when $T_{10}>T_2$.	
	°C	°C	°C	°C	°C	°C	Hours	% of month
July 2018	13.2	3.4	24.4	12.5	2.0	24.2	13.2	3.4
August 2018	13.9	5.2	24.4	13.0	4.0	23.9	13.9	5.2
September 2018	16.5	8.3	31.9	15.4	6.7	31.2	16.5	8.3
October 2018	19.1	10.3	28.0	18.0	8.1	27.7	19.1	10.3
November 2018	21.2	13.0	35.1	20.5	11.5	34.5	21.2	13.0
December 2018	23.7	15.7	37.0	22.7	14.0	37.3	23.7	15.7
January 2019	26.2	20.3	39.9	25.2	19.1	38.5	26.2	20.3
February 2019	24.4	17.2	38.6	23.5	15.3	37.3	24.4	17.2
March 2019	23.3	12.6	37.2	22.4	12.1	35.7	23.3	12.6
April 2019	20.3	11.8	32.2	19.6	10.5	32.1	20.3	11.8
May 2019	16.4	7.0	25.2	15.8	6.3	24.8	16.4	7.0
June 2019	14.0	6.7	23.2	13.3	5.1	24.4	14.0	6.7

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

MONTHLY SURFACE WATER MONITORING RESULTS

Analysis	Units	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19
SW1-A Pond												
Sample Number	-	071810481001	081810481001	091810481001	101810481A001	111810481A001	121810481A013	011910481a001	021910481a001	031910481a001	041910481a055	051910481a005
Date Sampled	-	02-07-18	02-08-18	03-09-18	03-10-18	02-11-18	04-12-18	04-01-19	01-02-19	05-03-19	05-04-19	05-04-19
Sampled By		KH/LS	KH/CR	KH/LS	KH/LS	KH/LS	LS/KH	KH/LS	KH/LS	KH/LS	KH/LS	KH/LS
Time		11:24	13:54	11:49	11:47	12:12	12:47	11:10	11:12	12:26	12:26	10:23
pH	pH	7.96	8.31	7.96	8.47	8.39	8.46	8.06	8.11	8.51	7.57	7.94
Conductivity	µS/cm	1220	2140	1520	1890	1820	1410	1110	913	1220	1540	1490
Turbidity	NTU	87	81	292	277	226	147	213	682	216	334	391
Total Dissolved Solids	mg/L	768	1179	843	1017	964	787	555	456	629	779	831
Total Suspended Solids	mg/L	46	19	67	49	65	26	28	69	26	64	82
Redox**	mV	182	-34	139	197	123	245	222	124	171	149	156
Dissolved Oxygen	%	69	112	99	87	89	96	78	79	89	63	94
Dissolved Oxygen	mg/L	7	10	9	8	7	8	6	6.6	7.1	5.4	8.4
Temperature	°C	15.7	17.7	16	21	27.0	29.5	30.0	24.3	28	22	16
SW1-B Pond												
Sample Number	-	071810481002	081810481002	091810481002	101810481A002	111810481A002	121810481A014	011910481a002	021910481a002	031910481a002	041910481a056	051910481a006
Date Sampled	-	02-07-18	02-08-18	03-09-18	03-10-18	02-11-18	04-12-18	04-01-19	01-02-19	05-03-19	05-04-19	05-04-19
Sampled By		KH/LS	KH/CR	KH/LS	KH/LS	KH/LS	LS/KH	KH/LS	KH/LS	KH/LS	KH/LS	KH/LS
Time		11:27	13:58	11:45	11:45	12:10	12:45	11:05	11:07	12:24	12:24	10:20
pH	pH	8.05	8.6	7.89	8.4	8.35	8.48	7.91	8.2	8.31	7.79	7.98
Conductivity	µS/cm	1070	1870	1360	1900	1550	1050	1290	1300	1200	1200	904
Turbidity	NTU	71	75	160	64	95	183	143	292	108	175	105
Total Dissolved Solids	mg/L	675	1078	780	1084	859	604	652	672	631	644	521
Total Suspended Solids	mg/L	23	29	31	18	27	25	16	22	13	29	21
Redox**	mV	180	-21	154	200	120	277	237	137	167	126	126
Dissolved Oxygen	%	68	117	100	83	96	110	86	84	84	62	62
Dissolved Oxygen	mg/L	6	11	9	7	7	10	7	6.8	6.7	5.2	5.6
Temperature	°C	15.7	17.3	16	21	27.0	30.0	30.0	25.6	29	22	16
SW1-C Pond												
Sample Number	-	071810481003	081810481003	091810481003	101810481A003	111810481A003	121810481A015	011910481a003	021910481a003	031910481a003	041910481a057	051910481a007
Date Sampled	-	02-07-18	02-08-18	03-09-18	03-10-18	02-11-18	04-12-18	04-01-19	01-02-19	05-03-19	05-04-19	05-04-19
Sampled By		KH/LS	KH/CR	KH/LS	KH/LS	KH/LS	LS/KH	KH/LS	KH/LS	KH/LS	KH/LS	KH/LS
Time		11:30	14:04	11:40	11:43	12:08	12:43	11:00	11:03	12:22	12:22	10:17

Analysis	Units	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19
pH	pH	8.07	8.71	7.95	8.22	8.32	8	8.22	8.11	8.38	7.74	7.9
Conductivity	µS/cm	1010	1630	1540	1350	1280	884	1500	1610	1450	753	874
Turbidity	NTU	68	56	217	405	66	220	227	290	211	158	123
Total Dissolved Solids	mg/L	629	961	897	762	723	491	785	806	770	417	483
Total Suspended Solids	mg/L	23	16	52	107	15	30	42	36	25	21	25
Redox**	mV	180	1	151	202	114	281	200	155	166	117	127
Dissolved Oxygen	%	68	109	78.4	104	93	86	55	90	90	60	62
Dissolved Oxygen	mg/L	6	10	7	9	7	7	4	7.4	7.1	5	5.6
Temperature	°C	15.7	17.7	17	22.5	26.5	30	31.0	23.9	29		16
SW1-D Pond												
Sample Number	-	071810481004	081810481004	091810481004	101810481A004	111810481A004	121810481A016	Dry	Dry	Dry	041910481a058	051910481a008
Date Sampled	-	02-07-18	02-08-18	03-09-18	03-10-18	02-11-18	04-12-18				05-04-19	05-04-19
Sampled By		KH/LS	KH/CR	KH/LS	KH/LS	KH/LS	LS/KH				KH/LS	KH/LS
Time		11:21	14:09	11:34	11:35	12:00	12:40				12:20	10:10
pH	pH	7.72	8.37	8.23	8.42	8.35	9				7.93	7.97
Conductivity	µS/cm	672	1120	2360	1850	1050	1950				779	1780
Turbidity	NTU	66	57	66	359	164	36				98	59
Total Dissolved Solids	mg/L	396	686	1361	1016	600	1096				436	981
Total Suspended Solids	mg/L	22	9	10	94	79	6				10	9
Redox**	mV	184	16	143	200	112	279				111	133
Dissolved Oxygen	%	39	97	102	81	90	79				54	62
Dissolved Oxygen	mg/L	7	9	9.1	7	7	7				4.6	5.6
Temperature	°C	16	17.9	16	25.5	28.5	33				23.0	15.0
SW2 Pond												
Sample Number	-	071810481005	081810481005	091810481005	101810481A005	111810481A005	121810481A017	011910481a005	Dry	Dry	041910481a059	051910481a009
Date Sampled	-	02-07-18	02-08-18	03-09-18	03-10-18	02-11-18	04-12-18	04-01-19			05-04-19	05-04-19
Sampled By		KH/LS	KH/CR	KH/LS	KH/LS	KH/LS	LS/KH	KH/LS			KH/LS	KH/LS
Time		10:34	10:16	9:55	11:18	11:30	11:20	9:23			11:30	9:50
pH	pH	7.13	9.31	9.55	10.07	9.26	9	7.79			7.69	9.12
Conductivity	µS/cm	1830	1520	1650	1780	1240	1620	2650			6720	6040
Turbidity	NTU	1	3	<1	3	7	58	416			7	4
Total Dissolved Solids	mg/L	995	819	898	934	670	866	1340			4256	4962
Total Suspended Solids	mg/L	17	<5	8	<5	12	47	152			<5	<5
Redox**	mV	228	73	99	153	49	258	194			133	118
Dissolved Oxygen	%	32	87	102	111	69	49	35			50	66

Analysis	Units	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19
Dissolved Oxygen	mg/L	3	8	9	10	5	4	3			4.1	5.9
Temperature	°C	12.8	16.5	15	24.5	25.0	30	26.0			24.0	16.0
SW3 Pond												
Sample Number	-	071810481006	081810481006	091810481006	101810481A006	111810481A006	121810481A018	011910481a006	021910481a006	Dry	041910481a060	Inaccesible
Date Sampled	-	02-07-18	02-08-18	03-09-18	03-10-18	02-11-18	04-12-18	04-01-19	01-02-19		05-04-19	
Sampled By		KH/LS	KH/CR	KH/LS	KH/LS	KH/LS	LS/KH	KH/LS	KH/LS		KH/LS	
Time		11:50	11:42	12:12	12:05	12:43	13:09	10:50	11:41		12:40	
pH	pH	6.79	8.05	7.64	8.37	9.07	9	7.72	8.7		8.14	
Conductivity	µS/cm	3260	1280	3400	4010	3800	4830	6970	11200		13600	
Turbidity	NTU	53	10	18	14	11	50	38	103		27	
Total Dissolved Solids	mg/L	1728	783	1976	2262	2070	2697	3596	6027		7277	
Total Suspended Solids	mg/L	22	11	<5	<5	7	24	9	39		86	
Redox**	mV	-93	114	146	197	35	250	202	102		125	
Dissolved Oxygen	%	7	81	80	94	89	88	37	90		61	
Dissolved Oxygen	mg/L	<2	7	7	8	7	7	3	7.2		5	
Temperature	°C	16.1	18	19	25	30.0	34	31.0	24.6		26.0	

SIX-MONTHLY SURFACE WATER MONITORING RESULTS

ANALYSIS	UNITS	LOR	Hunter River		Black Swan Pond		Hunter River Wharf		Wharf Sump		Trade Waste Pond	
			Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19
Sample Number	-	-	121810481A003	061910481a059	121810481A004	061910481a060	121810481A005	061910481a061	121810481A006	061910481a062	121810481A007	061910481a063
Date Sampled	-	-	04-12-18	19-06-19	04-12-18	19-06-19	04-12-18	19-06-19	04-12-18	19-06-19	04-12-18	19-06-19
Sampled By	-	-	LS/KH	KH/CR	LS/KH	KH/CR	LS/KH	KH/CR	LS/KH	KH/CR	LS/KH	KH/CR
pH Value	pH unit	-	8.21	7.53	9.2	8.62	8.23	7.2	Dry	7.84	7.8	7.52
Conductivity	µS/cm	1	53700	49100	1700	3390	56500	47300		3670	193	103
Dissolved Oxygen	%	2	72	87	42	113	83	92		100	51	69
Turbidity	NTU	1	98	3	56	<1	36	36		12	37	16
Chloride	mg/L		1700	19000	296	408	19300	17600		660	12	10
TRH C6-C9	µg/L	40	<20	<20	<20	<20	<20	<20		<20	<20	<20
TRH C10-C14	µg/L	50	<50	<50	<50	<50	<50	<50		<50	<50	<50
TRH C15-C28	µg/L	200	<100	<100	<100	<100	<100	<100		<100	<100	<100
TRH C29-C36	µg/L	200	<50	<50	<50	<50	<50	<50		<50	<50	<50
TRH C10-C36	µg/L	450	<50	<50	<50	<50	<50	<50		<50	<50	<50
Naphthalene	µg/L	0.02	<5	<1.0	<5	<1.0	<5	<1.0		<1.0	<5	<1.0
Phenanthrene	µg/L	0.01	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0	<1.0	<1.0
Anthracene	µg/L	0.01	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0	<1.0	<1.0
Fluoranthene	µg/L	0.01	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.01	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5
Total PAH	µg/L	0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5
Nitrate	mg/L	0.005	<0.05	0.1	<0.05	<0.05	0.06	0.16		1.5	<0.05	0.06
Nitrite	mg/L	0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05
Total Kjeldahl Nitrogen	mg/L	0.05	0.4	0.4	3.2	1	0.2	0.6		0.3	0.4	0.1
Ammonia	mg/L	0.01	0.05	0.2	0.21	<0.05	0.11	0.36		<0.05	0.05	<0.05
Total Phosphorus	mg/L	0.05	0.13	0.08	0.29	0.05	0.07	0.09		0.24	<0.05	<0.05
Total Arsenic (III)	mg/L	0.0005	<0.005	<0.005	<0.0005	<0.0005	<0.005	<0.005		<0.0005	<0.0005	<0.0005
Trivalent Chromium (III)	mg/L	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01
Total Aluminium	mg/L	0.005	3.03	<0.10	0.16	0.06	1.8	0.44		0.11	0.07	0.11
Total Boron	mg/L	0.005	4.07	5.1	0.5	0.74	4.34	5.26		0.32	<0.05	<0.05
Total Cadmium	mg/L	0.0001	<0.0010	<0.0010	<0.0001	<0.0001	<0.0010	<0.0010		<0.0001	<0.0001	<0.0001
Total Cobalt	mg/L	0.001	<0.010	<0.010	<0.001	<0.001	<0.010	<0.010		<0.001	<0.001	<0.001
Total Copper	mg/L	0.001	<0.010	<0.010	<0.001	0.005	<0.010	<0.010		<0.001	0.001	0.003
Total Lead	mg/L	0.001	<0.010	<0.010	<0.001	<0.001	<0.010	<0.010		<0.001	<0.001	<0.001

ANALYSIS	UNITS	LOR	Hunter River		Black Swan Pond		Hunter River Wharf		Wharf Sump		Trade Waste Pond	
			Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19
Total Iron	mg/L	0.005	4.01	0.18	0.3	0.29	3.39	1.04		0.15	0.4	0.16
Total Manganese	mg/L	0.001	0.098	0.026	0.219	0.049	0.125	0.233		0.026	0.347	0.037
Total Molybdenum	mg/L	0.001	<0.010	<0.010	0.008	0.079	0.01	<0.010		0.01	<0.001	<0.001
Total Nickel	mg/L	0.001	<0.010	<0.010	0.001	0.004	<0.010	<0.010		0.002	0.001	0.001
Total Selenium	mg/L	0.001	<0.10	<0.10	<0.01	<0.01	<0.10	<0.10		<0.01	<0.01	<0.01
Total Zinc	mg/L	0.005	<0.052	<0.052	0.009	0.023	<0.052	<0.052		<0.005	0.006	0.03
Total Mercury	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001

ANALYSIS	UNITS	LOR	Clear Water Pond		WTP01		Delta Pond		Deep Pond		Pond 1	
			Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19
Sample Number	-	-	121810481A008	061910481a064	121810481A009	061910481a065	121810481A010	061910481a066	121810481A011	061910481a067	121810481A012	
Date Sampled	-	-	04-12-18	19-06-19	04-12-18	19-06-19	04-12-18	19-06-19	04-12-18	19-06-19	04-12-18	
Sampled By	-	-	LS/KH	KH/CR	LS/KH	KH/CR	LS/KH	KH/CR	LS/KH	KH/CR	LS/KH	
pH Value	pH unit	-	8.86	7.96	8.62	9.21	Dry	7.73	8.49	8.29	Dry	Dry
Conductivity	µS/cm	1	1930	977	1780	1360		4990	4510	12400		
Dissolved Oxygen	%	2	75	75	77	122		111	62	113		
Turbidity	NTU	1	42	147	112	55		40	50	8		
Chloride	mg/L		344	132	408	228		480	100	2700		
TRH C6-C9	µg/L	40	<20	<20	<20	<20		<20	<20	<20		
TRH C10-C14	µg/L	50	<50	<50	<50	<50		<50	<50	<50		
TRH C15-C28	µg/L	200	<100	<100	<100	<100		<100	<100	<100		
TRH C29-C36	µg/L	200	<50	<50	<50	<50		<50	<50	<50		
TRH C10-C36	µg/L	450	<50	<50	<50	<50		<50	<50	<50		
Naphthalene	µg/L	0.02	<5	<1.0	<5	<1.0		<1.0	<5	<1.0		
Phenanthrene	µg/L	0.01	<1.0	<1.0	<1.0	<1.0		<1.0	<1.0	<1.0		
Anthracene	µg/L	0.01	<1.0	<1.0	<1.0	<1.0		<1.0	<1.0	<1.0		
Fluoranthene	µg/L	0.01	<1.0	<1.0	<1.0	<1.0		<1.0	<1.0	<1.0		
Benzo(a)pyrene	µg/L	0.01	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5		
Total PAH	µg/L	0.1	<0.5	<0.5	<0.5	<0.5		<0.5	<0.5	<0.5		
Nitrate	mg/L	0.005	<0.05	0.22	<0.05	<0.05		<0.05	<0.05	<0.05		
Nitrite	mg/L	0.005	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05		
Total Kjeldahl Nitrogen	mg/L	0.05	0.3	0.2	0.4	0.3		0.9	2.8	1.8		
Ammonia	mg/L	0.01	0.07	<0.05	<0.05	0.05		<0.05	0.05	<0.05		
Total Phosphorus	mg/L	0.05	<0.05	<0.05	<0.05	0.24		0.11	0.22	<0.05		

ANALYSIS	UNITS	LOR	Clear Water Pond		WTP01		Delta Pond		Deep Pond		Pond 1	
			Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19
Total Arsenic (III)	mg/L	0.0005	<0.0005	<0.0005	<0.0005	<0.0005		0.0008	<0.0005	0.0012		
Trivalent Chromium (III)	mg/L	0.05	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01		
Total Aluminium	mg/L	0.005	0.11	0.15	0.28	0.21		0.21	0.05	0.03		
Total Boron	mg/L	0.005	0.27	0.09	0.21	0.34		1.38	1.3	1.96		
Total Cadmium	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001		0.0002	<0.0001	<0.0001		
Total Cobalt	mg/L	0.001	<0.001	<0.001	<0.001	<0.001		0.001	<0.001	<0.001		
Total Copper	mg/L	0.001	<0.001	<0.001	<0.001	<0.001		0.002	0.002	0.002		
Total Lead	mg/L	0.001	<0.001	<0.001	<0.001	<0.001		0.004	<0.001	<0.001		
Total Iron	mg/L	0.005	<0.05	0.1	0.18	0.18		0.27	0.32	0.15		
Total Manganese	mg/L	0.001	0.016	0.039	0.039	0.017		0.438	0.719	0.063		
Total Molybdenum	mg/L	0.001	0.011	0.007	0.006	0.013		0.18	0.016	0.067		
Total Nickel	mg/L	0.001	0.001	0.002	0.002	0.002		0.006	0.002	0.003		
Total Selenium	mg/L	0.001	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01		
Total Zinc	mg/L	0.005	<0.005	0.013	0.031	0.031		0.25	0.015	0.017		
Total Mercury	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001		

APPENDIX 4

GROUNDWATER MONITORING RESULTS

ANALYSIS	UNITS	LOR	GW1		K9/3N				K9/3S		K11/1		K11/1S			BH20S		
			Dec-18	Jun-19	Dec-18	Jan-19 (re-sample)	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Jul-19 (re-sample)
Sample Number			121810481A042	061910481A075	121810481A023	011910481a024	061910481A076	-	121810481A024	061910481A077	121810481A025	061910481A078	121810481A026	061910481A079	-	121810481A027	061910481A080	-
Date Sampled			31-12-18	20-06-19	19-12-18	30-01-19	20-06-19	25-07-19	19-12-18	20-06-19	19-12-18	20-06-19	19-12-18	20-06-19	25-07-19	18-12-18	20-06-19	25-07-19
Sampled By			CR	CR	CR/LS	KH/LS	CR	CR	CR/LS	CR	CR/LS	CR	CR/LS	CR	CR	CR/LS	CR	CR
Time Sampled			13:20	12:59	14:40	13:47	13:53	12:38	12:51	14:20	13:30	16:10	14:33	15:45	13:15	14:15	10:45	10:41
pH Value	pH unit		7.38	7.5	7	--	7.08	-	7.94	8.1	7.32	7.44	7.79	7.87	-	6.67	6.84	-
Conductivity	µS/cm		15200	12800	27900	27900	24500	-	5340	5360	1490	2280	12700	10300	-	2490	4380	-
Temperature	°C		21.3	21.2	21.9	--	20.7	-	23	19	22.2	18.5	21.4	17.5	-	20.2	21	-
Bromide	mg/L	0.01	11.9	6.13	20.5	--	16.2	-	3.41	3.72	0.755	1.38	9.39	4.63	-	0.799	1.3	-
Dissolved Metals																		
Aluminium	mg/L	0.01	<0.01	<0.01	<0.01	--	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	3.95	<0.01	-
Arsenic	mg/L	0.001	<0.001	<0.001	<0.001	--	0.002	-	0.003	0.004	<0.001	0.002	<0.001	0.002	-	0.002	0.013	0.01
Cadmium	mg/L	0.0001	<0.0001	<0.0001	<0.0001	--	0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	<0.0001	-
Copper	mg/L	0.001	<0.001	<0.001	<0.001	--	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.003	<0.001	-
Manganese	mg/L	0.001	0.199	0.252	1.01	--	1.24	-	0.166	0.166	0.799	0.784	0.114	0.123	-	4.68	5.47	-
Nickel	mg/L	0.001	<0.001	<0.001	0.002	--	0.005	0.004	0.002	<0.001	<0.001	0.001	<0.001	0.003	-	0.007	0.002	-
Zinc	mg/L	0.005	<0.005	0.006	<0.005	--	<0.005	-	<0.005	0.01	<0.005	0.007	<0.005	<0.005	-	0.04	<0.005	-
Iron	mg/L	0.05	<0.05	<0.05	<0.05	--	0.08	-	0.16	<0.05	0.25	0.11	<0.05	0.06	-	0.21	14.2	57.8
Cyanide																		
Free Cyanide	mg/L	0.004	<0.004	<0.004	<0.004	--	<0.004	-	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	-
Total Cyanide	mg/L	0.004	<0.004	0.007	<0.004	--	0.009	-	<0.004	<0.004	<0.004	<0.004	<0.004	0.024	0.007	<0.004	<0.004	-
Polynuclear Aromatic Hydrocarbons																		
Naphthalene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Acenaphthylene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Acenaphthene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Fluorene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Phenanthrene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	1.7	<1.0	-
Anthracene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Fluoranthene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Pyrene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Benz(a)anthracene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-

ANALYSIS	UNITS	LOR	GW1		K9/3N				K9/3S		K11/1		K11/1S			BH20S		
			Dec-18	Jun-19	Dec-18	Jan-19 (re-sample)	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Jul-19 (re-sample)
Chrysene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Benzo(b+j)fluoranthene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Benzo(k)fluoranthene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Benzo(a)pyrene	µg/L	0.5	<0.5	<0.5	<0.5	--	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	<0.5	-
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Dibenz(a.h)anthracene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Benzo(g.h.i)perylene	µg/L	1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	<1.0	<1.0	-
Sum of PAHs	µg/L	0.5	<0.5	<0.5	<0.5	--	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	1.7	<0.5	-
Total Petroleum Hydrocarbons																		
C6 - C9 Fraction	µg/L	20	<20	<20	<20	--	<20	-	<20	<20	<20	<20	<20	<20	-	<20	<20	-
C10 - C14 Fraction	µg/L	50	<50	<50	<50	--	<50	-	<50	<50	<50	<50	<50	<50	-	<50	<50	-
C15 - C28 Fraction	µg/L	100	<100	<100	<100	--	<100	-	<100	<100	<100	<100	<100	<100	-	<100	<100	-
C29 - C36 Fraction	µg/L	50	<50	<50	<50	--	<50	-	<50	<50	<50	<50	<50	<50	-	<50	<50	-
C10 - C36 Fraction (sum)	µg/L	50	<50	<50	<50	--	<50	-	<50	<50	<50	<50	<50	<50	-	<50	<50	-
BTEX																		
Benzene	µg/L	1	<1	<1	<1	--	<1	-	<1	<1	<1	<1	<1	<1	-	<1	<1	-
Toluene	µg/L	2	<2	<2	<2	--	<2	-	<2	<2	<2	<2	<2	<2	-	<2	<2	-
Ethylbenzene	µg/L	2	<2	<2	<2	--	<2	-	<2	<2	<2	<2	<2	<2	-	<2	<2	-
meta- & para-Xylene	µg/L	2	<2	<2	<2	--	<2	-	<2	<2	<2	<2	<2	<2	-	<2	<2	-
ortho-Xylene	µg/L	2	<2	<2	<2	--	<2	-	<2	<2	<2	<2	<2	<2	-	<2	<2	-
Total Xylenes	µg/L	2	<2	<2	<2	--	<2	-	<2	<2	<2	<2	<2	<2	-	<2	<2	-
Sum of BTEX	µg/L	1	<1	<1	<1	--	<1	-	<1	<1	<1	<1	<1	<1	-	<1	<1	-

ANALYSIS	UNITS	LOR	BH20D				BH21S		BH21D		BH23S				BH23D		
			Dec-18	Jan-19 (re-sample)	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jan-19 (re-sample)	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Jul-19 (re-sample)
Sample Number			121810481A028	011910481018	061910481A081	-	121810481A029	061910481A082	121810481A030	061910481A083	121810481A031	011910481a017	061910481A084	-	121810481A032	061910481A085	-
Date Sampled			18-12-18	30-01-19	20-06-19	25-07-19	18-12-18	20-06-19	18-12-18	20-06-19	18-12-18	30-01-19	19-06-19	25-07-19	18-12-18	19-06-19	25-07-19
Sampled By			CR/LS	KH/LS	CR	CR	CR/LS	CR	CR/LS	CR	CR/LS	KH/LS	CR	CR	CR/LS	CR	CR
Time Sampled			14:40	12:37	10:00	10:05	12:25	12:35	12:09	11:45	12:53	11:25	14:30	12:00	13:30	15:03	11:30
pH Value	pH unit		6.07	6.06	6.11	-	11.09	11.15	7.64	8.95	8.5	--	8.01	-	6.73	6.45	7.36

ANALYSIS	UNITS	LOR	BH20D				BH21S		BH21D		BH23S				BH23D		
			Dec-18	Jan-19 (re-sample)	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jan-19 (re-sample)	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Jul-19 (re-sample)
Conductivity	µS/cm		53600	--	46000	-	1260	1200	10400	5240	724	--	711	-	23200	19900	-
Temperature	°C		20.8	--	20	-	21.1	21.7	21.8	21.3	20.1	--	19.8	-	20.9	19.1	-
Bromide	mg/L	0.01	55.4	--	45.6		0.789	0.765	8.24	4.08	0.254	--	16.5	0.201	23	0.264	-
Dissolved Metals																	
Aluminium	mg/L	0.01	<0.10	--	<0.10	-	0.58	1.2	0.08	0.1	0.12	<0.005	<0.01	-	<0.01	0.07	-
Arsenic	mg/L	0.001	<0.010	--	<0.010	-	0.006	0.005	0.002	0.003	0.002	--	0.003	-	<0.001	0.006	0.002
Cadmium	mg/L	0.00001	<0.0010	--	<0.0010	-	<0.0001	0.0002	<0.0001	0.0003	<0.0001	--	<0.0001	-	<0.0001	<0.0001	-
Copper	mg/L	0.001	<0.010	--	<0.010	-	<0.001	<0.001	<0.001	<0.001	<0.001	--	<0.001	-	<0.001	<0.001	-
Manganese	mg/L	0.001	10.6	--	12.3	4.61	<0.001	0.099	0.4	0.151	0.288	--	0.939	-	1.05	0.419	-
Nickel	mg/L	0.001	0.035	0.0473	0.043	-	0.002	0.005	0.002	0.004	<0.001	--	0.006	-	<0.001	0.005	-
Zinc	mg/L	0.005	<0.050	--	<0.050	-	<0.005	0.011	<0.005	<0.005	<0.005	--	0.012	-	<0.005	<0.005	-
Iron	mg/L	0.05	38.3	--	49	-	0.09	0.73	1.91	0.17	1.66	--	13.5	2.84	8.51	2.49	-
Cyanide																	
Free Cyanide	mg/L	0.004	<0.004	--	<0.004	-	0.005	0.005	0.006	0.008	0.004	--	<0.004	-	<0.004	0.007	<0.004
Total Cyanide	mg/L	0.004	<0.004	--	<0.004	-	0.276	0.264	0.198	0.368	0.067	--	0.044	-	0.01	0.095	0.014
Polynuclear Aromatic Hydrocarbons																	
Naphthalene	µg/L	1	<1.0	--	<1.0	-	37.4	219	92.6	234	<1.0	--	<1.0	-	<1.0	<1.0	-
Acenaphthylene	µg/L	1	<1.0	--	<1.0	-	1.8	5.6	1.2	1.7	<1.0	--	<1.0	-	<1.0	<1.0	-
Acenaphthene	µg/L	1	<1.0	--	<1.0	-	3.5	4.1	1.6	1.6	<1.0	--	<1.0	-	<1.0	<1.0	-
Fluorene	µg/L	1	<1.0	--	<1.0	-	4.6	5.8	1.3	1.5	<1.0	--	<1.0	-	<1.0	<1.0	-
Phenanthrene	µg/L	1	<1.0	--	<1.0	-	10.2	17.6	3	2.6	1.6	--	<1.0	-	<1.0	<1.0	-
Anthracene	µg/L	1	<1.0	--	<1.0	-	<1.0	6.1	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Fluoranthene	µg/L	1	<1.0	--	<1.0	-	5.8	12.3	1.5	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Pyrene	µg/L	1	<1.0	--	<1.0	-	3.9	10.9	1.1	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Benz(a)anthracene	µg/L	1	<1.0	--	<1.0	-	<1.0	4.7	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Chrysene	µg/L	1	<1.0	--	<1.0	-	<1.0	3.6	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Benzo(b+j)fluoranthene	µg/L	1	<1.0	--	<1.0	-	<1.0	4	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Benzo(k)fluoranthene	µg/L	1	<1.0	--	<1.0	-	<1.0	2.6	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Benzo(a)pyrene	µg/L	0.5	<0.5	--	<0.5	-	<0.5	3.9	<0.5	<0.5	<0.5	--	<0.5	-	<0.5	<0.5	-
Indeno(1.2.3.cd)pyrene	µg/L	1	<1.0	--	<1.0	-	<1.0	2.9	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-

ANALYSIS	UNITS	LOR	BH20D				BH21S		BH21D		BH23S				BH23D		
			Dec-18	Jan-19 (re-sample)	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Dec-18	Jun-19	Dec-18	Jan-19 (re-sample)	Jun-19	Jul-19 (re-sample)	Dec-18	Jun-19	Jul-19 (re-sample)
Dibenz(a.h)anthracene	µg/L	1	<1.0	--	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Benzo(g.h.i)perylene	µg/L	1	<1.0	--	<1.0	-	<1.0	3.7	<1.0	<1.0	<1.0	--	<1.0	-	<1.0	<1.0	-
Sum of PAHs	µg/L	0.5	<0.5	--	<0.5	-	67.2	307	102	241	1.6	--	<0.5	-	<0.5	<0.5	-
Total Petroleum Hydrocarbons																	
C6 - C9 Fraction	µg/L	20	<20	--	<20	-	<100	30	<100	30	<20	--	<20	-	<20	<20	-
C10 - C14 Fraction	µg/L	50	<50	--	<50	-	190	380	190	360	<50	--	<50	-	<50	<50	-
C15 - C28 Fraction	µg/L	100	<100	--	<100	-	<100	470	<100	130	<100	--	<100	-	<100	<100	-
C29 - C36 Fraction	µg/L	50	<50	--	<50	-	<50	200	<50	<50	<50	--	<50	-	<50	<50	-
C10 - C36 Fraction (sum)	µg/L	50	<50	--	<50	-	190	1050	190	490	<50	--	<50	-	<50	<50	-
BTEX																	
Benzene	µg/L	1	<1	--	<1	-	<5	3	<5	3	<1	--	<1	-	<1	<1	-
Toluene	µg/L	2	<2	--	<2	-	<5	<2	<5	<2	<2	--	<2	-	<2	<2	-
Ethylbenzene	µg/L	2	<2	--	<2	-	<5	<2	<5	<2	<2	--	<2	-	<2	<2	-
meta- & para-Xylene	µg/L	2	<2	--	<2	-	<5	3	<5	2	<2	--	<2	-	<2	<2	-
ortho-Xylene	µg/L	2	<2	--	<2	-	<5	4	<5	3	<2	--	<2	-	<2	<2	-
Total Xylenes	µg/L	2	<2	--	<2	-	<5	7	<5	5	<2	--	<2	-	<2	<2	-
Sum of BTEX	µg/L	1	<1	--	<1	-	<5	10	<5	8	<1	--	<1	-	<1	<1	-

APPENDIX 5

ANNUAL REPORT (2018/19) 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 (2018-2019)

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.

Draft prepared July 2019. Report finalised August 2019

Executive Summary

***Note**: An extended discussion of this summary is provided in the Discussion (Section 4), using the structure below for subheadings etc.*

Conservation biology of *Litoria aurea* on Kooragang Island

1. **Population size**: Comparing estimates of robust modelling-derived population size with counts from visual encounter surveys (VES) at sample wetlands indicates that the ratio of 'frogs present' to 'frogs detected during VES' is approximately 5:1. Extrapolating VES data from the island-wide survey gives a population estimate of approximately 4,000-5,000 individual *Litoria aurea* (adults and >40 mm SVL juveniles on Kooragang Island) in early summer. This represents an increase estimated on estimated population size in recent years (Figure 3.8.1).

   Multi-year occupancy trends of count data from the Island-wide surveys also suggest some increase in the population, although not to the same degree (Figure 3.9.2). Both forms of data indicate that the population has been at least stable since 2016. The current population is most likely larger than it was between 2011-2014.

2. **Demography**

   a. Age/sex class structure: The proportion of adult males to females is similar to recent years, with two males detected for every adult female. Slightly less than half of the *L. aurea* detected across the season were juveniles (Figure 3.4.1). Demographic analysis identifies at least two distinct cohorts of juveniles; one set that were spawned in autumn rains of the 2017-18 season, and another that spawned in spring rains of the 2018-19 season (Figure 3.4.5). The latter cohort may have three sub-components, corresponding to rainfall events in early September, early October, and early December respectively (Figure 3.6.3).

   b. Recruitment: Thirteen wetlands within the Industrial Zone held either tadpoles and/or metamorphs at some point during the 2018-19 breeding season, the largest number recorded in the last five seasons. Breeding was also recorded in many of the BHP CHEMP wetlands. There was a very large breeding event at K105A (Figures 3.3.5, 3.3.6) in the spring following significant rain in September and especially early October 2018 (Figure 3.6.3), apparently linked to the almost complete removal of *Gambusia* from that wetland at the end of the previous summer. In that event, *L. aurea* exhibited many of the traits of an explosive breeder, and selection of the breeding site was apparently linked to the behaviour of conspecifics. Adult *L. aurea* appear to be able to select breeding sites that lack high densities of predatory fish; a strong link between *L. aurea* breeding and low/zero density of *Gambusia* is evident, although that pattern is not as clear if only binary data on presence/absence (of both breeding behaviour and *Gambusia*) are analysed (Figures 3.2.9, 3.6.5 and accompanying discussion).

   c. Gravid females: Data from candling (Figure 2.6.3) adult female *L. aurea* indicates that females may achieve sexual maturity (i.e. the production and storage of eggs in the ovaries) at sizes above 54 mm snout-vent length (SVL), although the proportion of gravid females at that size is low (Figure 3.6.4). Approximately 50% of examined 60 mm SVL females were gravid; for animals of 65 mm or greater, that figure was greater than 70%.

      Using a threshold of 58 mm SVL for female maturity, 272 individual adult females (identified by PIT tags) were captured during the 2018-19 Island-wide surveys (Table 3.1.3). This number is similar to the corresponding data from the two previous seasons and indicates that the effective population size of *L. aurea* on Kooragang Island is sufficient for at least the immediate

persistence of the population. However, the low survival rates (Table 3.5.2) of adult *L. aurea* on Kooragang Island mean that the population remains vulnerable; consecutive seasons of low recruitment will likely result in severe decline of this population.

3. Longitudinal data

a. Persistence: Less than 10% of the tagged *L. aurea* that are recaptured are recaptured more than one year after their first capture, and less than 2% are recaptured after more than 2 years (Table 3.5.2). This indicates a low rate of survivorship. Note that only individuals larger than 40 mm SVL are tagged, so this survivorship rate cannot be attributed to the high mortality of eggs, tadpoles, metamorphs and small juveniles typical of many frogs. In contrast, adult survivorship of *L. aurea* on Kooragang Island is low – much lower than the rates seen in populations not affected by chytrid. This feature of the population means that it remains vulnerable (see point 2c above)

b. Movement: Although most recaptures of marked individuals find them in the same wetland, *L. aurea* who persist for more than 12 months after initial capture have a 34% probability of being recaptured in a different wetland (Table 3.5.8). That figure rises to 67% for the (few) animals that persist for more than 3 years after initial capture. Our longitudinal dataset shows that, for 3,168 recaptures of 8,914 marked individuals, 514 movements into different wetlands were detected (Table 3.5.3). While many of these are small movements into neighbouring wetlands, more than 70 are movements of more than 100 metres and fourteen movements exceeded 1 km (Table 3.5.6). More than twice as many movements were detected by males compared to females (Table 3.5.7); note, however, that detection is biased towards males so this may not represent a true different in movement between males and females.

   A large number of movements detected in 2018-19 involve dispersal towards K105A from surrounding large and small refuge wetlands (K29, K106C, C1) as part of the large breeding event at K105A in the spring and early summer (Figures 3.5.1, 3.5.2). Several individuals were recaptured again at their original wetlands later in the season, demonstrating the capacity of *L. aurea* to visit breeding sites and then return to refuge wetlands (Tables 3.5.4, 3.5.5).

   Other recorded movements show high connectivity between the BHP CHEMP wetlands, and increasing connectivity among the NCIG CHEMP wetlands in the Northern Zone. Within the Industrial Zone, K29 is a locus for a large number of movements (Figure 4.3.1). Recorded movements in the Southern part of the Industrial Zone increased markedly in 2018-19, indicating improved connectivity in that region (Figures 3.5.1, 3.5.2). Connectivity between the Northern Zone and the rest of the island is poor (Figure 4.3.1).

c. Growth: Longitudinal data from two cohorts of *L. aurea*, for whom spawning dates can be estimated with confidence, indicates rapid early growth. Males reach a maximum size, between 50 and 60 mm SVL, in their second year, whilst females have a maximum size greater than 60 mm which is approached in their third year (Figure 3.5.5).

4. Landscape use

a. Distribution: The highest abundance of *Litoria aurea* on Kooragang Island continues to be in the Industrial Zone, although the population in the Central Zone in 2017-18 and 2018-19 remains higher than in prior seasons due to increased numbers at the BHP CHEMP wetlands (Figure 4.4.1, Table 3.9.2). In the Northern Zone, abundance was higher in 2018-19 than in any previous seasons, due principally to increased occupancy at the NCIG CHEMP wetlands.

Most of *the L. aurea* in the Northern Zone were detected in the Millam's Pond subregion (NCIG Stages 4, 5, and 7).

Within the Industrial Zone, the southern part holds much greater abundance of *L. aurea* than in the years prior to the construction of the HDC wetlands, and the number of adults occupying that region in 2018-19 was the highest yet detected (Table 3.9.2). Nonetheless, the greatest numbers continue to be found in the northern part of the Industrial Zone (Figure 4.4.1). As noted above (point 3b), a notable feature of *L. aurea* distribution in the 2018-19 season was the dispersal of adults to K105A during a large breeding event in spring and early summer from nearby refuge wetlands, with the result that the occupancy of the Deep Pond subregion (K105A, K105AS, K105B) was the highest yet recorded (Table 3.9.4, Figure 4.4.1).

A very dry middle and late summer saw most wetlands across the island dry out completely by early March 2019. Deep Pond may also have provided refuge for *L. aurea* during this period, although its proximity to an active fire zone between January and May prevented late season surveys of that area (see point 8a below). In the southern part of the Industrial Zone, K115, K100A, and C2 provided refuge habitat and access to permanent water during this dry period (Figure 3.3.7).

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

i. Habitat: Wetland habitat types required for the long-term persistence of local *L. aurea* populations on Kooragang Island have previously been identified as (i) large, permanent ('refuge'), wetlands and (ii) wetlands used for breeding. Data from recent Island-wide surveys suggests that small, permanent well-vegetated wetlands ('stepping stone' or 'small refuge' wetlands) are also an important habitat type, and in the very dry summer of 2018-19 these evidently played an important role in providing aquatic habitat as the system dried out, especially after grass fires damaged certain areas

The physiognomy of well occupied large refuge wetlands suggests that these should have large areas of open water, at least some areas of deep water, and extensive banks of emergent reeds providing cover around the edge of the wetland (Figure 3.7.1). Whilst there has been some debate as to the required hydroperiod for breeding wetlands, it is becoming clear that *L. aurea* will undertake explosive breeding in ephemeral, semi-permanent, or permanent wetlands as long as *Gambusia* density is low or zero. The other microhabitat features of breeding wetlands are open water and shallow sloped edges that can provided flooded ground vegetation after heavy rain. Extensive banks of reeds around the wetland edge seem to be advantageous, but are not essential as long as there are refuge habitats close by.

The wetlands that appear to provide small refuge habitats are all deep, permanent wetlands with extensive aquatic vegetation and some access to open water (K106C, C1, C2, K100A, K36, K115). During the driest part of the summer, the largest numbers of *L. aurea* were in those wetlands that are well shaded by trees (C2, K100A) (Figure 3.3.7). These small refuge provided habitat for juveniles that are thought to have been spawned in nearby wetlands (Figures 3.4.12, 3.4.13, 3.6.1).

ii. *Gambusia*: Although adult *L. aurea* can coexist with even high densities of *Gambusia*, it is clear that successful breeding requires access to wetlands that are largely free of *Gambusia*. Three consecutive dry years have substantially reduced the distribution of *Gambusia* across the island from a peak in 2015-16 (Figures 3.2.8, 3.2.9), and the increase in the number of

wetlands used for breeding in this period is thought to be directly linked to the drought-driven removal of *Gambusia* from large parts of the system.

iii. **Chytrid**: Infection by the pathogenic fungus *Batrachochytrium dendrobatidis* can result in the disease chytridiomycosis (commonly known as chytrid), which affects amphibians and has caused population declines and extinction worldwide. Average chytrid load across Kooragang can be assessed via swabbing of *L. aurea* during late winter and early spring; we collected 120 samples in the 2018-19, and the analysis of those is pending.

Tracking the variation in chytrid load across different wetlands, or even regions within Kooragang Island, is more complex and requires an order of magnitude greater sampling effort and analysis. Other research (laboratory work on *L. aurea*, and field work on the closely related *L. raniformis*) shows that chytrid load is lessened in conditions of elevated salinity and temperature. Available evidence shows that the persistence of *L. aurea* depends upon access to wetlands that have salinity and/or temperature linked protection against chytrid somewhere within the frogs' local neighbourhood of habitats (c.f. the concept of the 'habitat mosaic', outlined below).

Warm temperatures, drying of wetlands, and saline conditions are all expected to reduce chytrid load, and these conditions have certainly applied over the last three seasons; it is therefore possible that chytrid load across the island is presently lower than has been the case in wetter, cooler periods, but more data is required to investigate this.

iii. **The habitat mosaic**: It is clear that heterogeneity of the wetlands within a local area is a key ingredient of population persistence with *L. aurea*. A single large wetland, or an array of smaller very similar wetlands, is much less suitable than an array of different wetlands. This concept of multiple heterogeneous wetlands within a small area has been termed the 'habitat mosaic'**.**

Although the underlying concept of wetland heterogeneity is understood, the specific features of wetland physiognomy which should vary remains an open question. Connectivity between neighbouring wetlands is logically a key trait; it is difficult to have a habitat mosaic of habitats that are not spatially connected. Variation in hydroperiod seems to be a fundamental aspect; hydroperiod is connected to temperature, salinity, abundance of *Gambusia*, and vegetation cover and thus links with many aspects of *L. aurea* ecology. Variation in wetland size has not been demonstrated to be a key feature but qualitative examination of the successful mosaics in the Industrial Zone suggests that it may be (Figures 4.4.2, 4.4.3). Other potential features of effective habitat mosaics for *L. aurea* include vegetation structure, depth and bottom profile, but the relative importance of all these requires further investigation.

iv. **Northern Zone of the island**: This has long been the zone with the lowest abundance of *L. aurea*, but numbers improved markedly in the 2018-19 season, due mainly to increased occupancy at the NCIG CHEMP wetlands (Table 3.9.2, Figure 4.4.1).

As to why the *L. aurea* population in this Zone has historically been so low, insights generated by the current island-wide survey research program suggest a number of factors that may be at play:

- Its position in the catchment is linked with low levels of salinity, which increases *L.* aurea mortality due to chytridiomycosis.
- The history of land use (a long period of farming followed by gazetting as national park), with consequent long-term dynamics in the vegetation community that do not favour *L. aurea*.
- A low quality habitat mosaic for *L. aurea*, with a lack of large permanent wetlands, low variation in wetland hydroperiod and size, and poor connectivity.

Whilst these are potential factors only, and more research is required to identify the causative factors with confidence, they can all at least be potentially addressed through management actions similar to those undertaken in the Central and Industrial Zones of Kooragang Island.

Specific management issues relevant to research partners

5. **Habitat corridor mitigation strategy**: Compared with the situation prior to 2015, the abundance of *L. aurea* in the southern habitat corridor (i.e. the southern region of Industrial Zone) has been markedly higher from 2016-19, especially in terms of adults (Table 3.9.4). The increased population in the southern corridor is linked to the increased extent and connectivity of habitat provided by the constructed wetlands in this region, which have improved the quality of the habitat mosaic for *L. aurea*. In particular, there is now a larger number of wetlands used for breeding in the southern corridor than the northern. However, the southern corridor still lacks large permanent wetlands that provide suitable refuge habitat for large numbers of adult *L. aurea*.

6. **Rail infrastructure mitigation strategy**: Longitudinal data from marked *L. aurea* shows that they frequently cross railways and associated infrastructure; 26 out of 110 'significant' movements from 2014-19 involved movements over or under rail lines (Tables 3.5.4, 3.5.5; Figures 3.5.1, 3.5.2, 4.3.1). It appears that the railway infrastructure does not constitute an impassable obstacle for *L. aurea* and the rail infrastructure on Kooragang is not expected to lead to fragmentation of the population, especially where connectivity across the landscape is maintained or improved through well-designed constructed wetlands.

   The construction of the NCIG rail-line directly affected a wetland to the east of K102, and the southern part of Deep Pond (Figure 4.6.1). The former wetland was completely infilled in order to construct the dump station, whilst Deep Pond was split into K105A and K105B through the construction of a large embankment through the southern part of the wetland. The impact of the loss of the wetland at the dump station is not well understood, but appears to have been partially compensated by the creation of K115 (an artificial, managed sediment control pond) which often contains high densities of *L. aurea* in a stand of *Typha* reeds at its western end. The provision of new wetland habitat within the Rail loop *K10 North* subregion (K111-114) seems also have at least partially offset the loss of that original wetland. In the case of Deep Pond, the increase in the area of well vegetated banks and the shallowing of the slope of the wetland edge on either side of the new embankment, combined with a change in hydroperiod of K105B to semi-permanent, appears to have markedly improve the quality of habitat for *L. aurea* in this area. Both abundance of adult frogs and frequency and intensity of breeding behaviour is much greater than previously recorded.

   Indirect effects of the NCIG rail-line construction may include the change in hydroperiod and thus habitat characteristics of the K108 wetland. This question is currently being addressed as part of a separate research by UoN and HDC.

7. **Constructed wetland strategy**: Of the four phases of constructed wetland design deployed on Kooragang Island over the last decade, three have been highly successful in providing habitat that is occupied by *L. aurea*: the 'cluster ponds', the HDC wetlands, and the BHP CHEMP. These continued to be successful in 2018-19, with high levels of *L. aurea* abundance at the BHP CHEMP wetlands, and widespread breeding behaviour at both the HDC and the BHP CHEMP wetlands. The improvement in extent, connectivity, and heterogeneity of wetland provided by both the HDC and BHP CHEMP designs is understood to have markedly improved the quality of the habitat mosaic and is directly linked to the increased abundance of *L. aurea* in those respective subregions (Table 3.9.4).

Although the NCIG CHEMP wetland design has not been as initially successful as the others, there are other factors at play in the region where they are located (see point 4b.iv above) and the abundance of *L. aurea* at these wetlands does not necessarily reflect problems with their design and execution. There is some indication in the 2018-19 data that occupancy in these is starting to increase. Consideration of the large scale habitat mosaic in the Northern Zone suggests some opportunities to improve the performance of these wetlands (see points 4b.iii and 4b.iv above).

In the context of a hot, dry summer, the capacity of the cluster ponds to provide refuge habitat as nearby wetlands dried was highlighted, and the C1 cluster even provided refuge after a grass fire despite being itself damaged in the fire. On the basis of these benefits, a further three sets of smaller clusters were installed in the southern part of the Industrial during 2018-19 (Figure 3.4.14): the performance of these will be monitored in future years.

8. **Other issues**

   a. Fire: For the second consecutive year *Litoria aurea* habitat was impacted by a grass fire during the latter part of the summer. The grass fire in the 2018-19 was more severe than the previous one, burning out several wetlands that usually support large numbers of adult *L. aurea*, including the BHP CHEMP wetlands, K22, K23, and K29. The C1 cluster ponds were also heavily damaged. The grass fire in turn ignited a ground fire in Area 2 of the Industrial Zone. That ground fire burnt for several months; it posed a significant environmental hazard and health and safety risk before being brought under control in April-May 2019.

      A series of consecutive dry summers, as experienced over the three most recent seasons, can be expected to increase the risk of summer grass fires on Kooragang. Increased frequency and severity of fire can in turn be expected to impact *L. aurea* habitat and the safety of personnel. The risks posed by grass fires seem to be increasing and this is an issue that needs a coordinated response from all stakeholders on Kooragang Island.

   b. Drought & Climate change: The recent pattern of long, hot, dry summers is consistent with predicted patterns of changing climate, and for the last three seasons a large number of wetlands used by *L. aurea* have dried up by the start of the autumn. In two of those years significant autumn rains have enabled a late season breeding event, but that did not occur in the 2018-19 season.

      The summer of 2018-19 was the hottest on record and much of NSW was in drought for most of it. Even though the wetland system on Kooragang Island was fully charged at the start of summer as a result of good spring rainfall, by the end of the summer almost every wetland on the island was dry. The small number of wetlands that did hold water through the summer are understood to have provided important refuge habitat; many of these were constructed wetlands, pointing to an important role for those.

      In addition to the increased risks from fires (see above), the severe drying of wetland habitat clearly has the potential to impact the Kooragang population of *L. aurea*. However, there are some potential benefits to a warmer, drier system; the incremental sequence of drying and recharging over the last three years have removed *Gambusia* from most wetlands on the island, and warm temperatures combined with drier (and possibly more saline) conditions are expected to decrease chytrid loads.

      The potential risks and benefits of the expected changes to wetland hydroperiod, temperature, average rainfall, salinity, vegetation and sea level, combined with the

likely increases in extreme weather events, are complex. The fact that many of these interact in ways that will affect *L. aurea* habitat and ecology make the task of predicting the likely effects of climate change on the *L. aurea* Kooragang population especially difficult. However, recent experience of environmental management of the island, combined with the information gained from the island-wide survey research program, suggests that various aspects of these can be mitigated or improved with targeted management actions. Assessment of the climate change related risks to the Kooragang *L. aurea* population should be a focus in the near future so that medium and long-term actions can be planned.

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Cover photo: A small *Litoria aurea* holds onto a *Typha* stem in the K117 wetland after release from data processing, early December 2018. Colin McHenry

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1. Introduction

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

The Conservation Biology Research Group (formerly the Amphibian Research Group) at the University of Newcastle (UoN) has been conducting annual surveys of the green and golden bell frog (*Litoria aurea*) on Kooragang Island since 2010. The research aims to provide insight into the biology and ecology of this endangered species; these insights are intended to inform effective habitat management and creation by the partner organisations. Those partner organisations – Port Waratah Coal Services (PWCS), Newcastle Coal Infrastructure Group (NCIG) and the Hunter and Central Coast Development Corporation (HCCDC; formally HDC) – are involved with 'on ground' management and landscape works across Kooragang; by providing high quality data from population monitoring, this project aims to inform those activities and hence ecological outcomes for the Kooragang population of *L. aurea*.

Over the course of these surveys more than four thousand *L. aurea* have been captured (with another five thousand animals captured as part of different PhD projects at UoN; 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, and yet is essential 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 prioritized. With respect to population monitoring, these are:

1. Gaining general insights into the biology and ecology of *L. aurea*.
2. Meeting population monitoring requirements for operation on Kooragang Island by:
    a. Providing a population size estimate for *L. aurea* on Kooragang Island;
    b. 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.
    c. Defining the spatial distribution of the *L. aurea* across Kooragang Island, considering movement patterns and aggregations.
3. Informing 'on the ground' management plans with to major works on the Terminal 4 and adjacent industrial sites.

1.2 Context of the green and golden bell frog decline; bell frogs in SE Australia

The general background to the decline of *Litoria aurea* – a once common and widespread species along Australia's East Coast and inland tablelands from northern New South Wales to southern Victoria – has been described in detail in our previous annual reports (see, for example, McHenry et al. 2019) and various published papers (Mahony et al., 2013, Pyke and White, 1996, Pyke et al., 2002). The current population is understood to be much smaller than it was 50 years ago and persists in less than 10% of its historical range, occupying fewer than forty sites in a highly fragmented set of small refuge habitats (White and Pyke, 1996, Mahony et al., 2013). A similar situation – although possibly not quite as acute – faces the closely related southern bell frog *L. raniformis* (Heard et al. 2015), whilst the third species of SE Australian bell frog – *L. castanea* – is now known from only a single locality.

The pattern of decline in SE Australian bell frogs is unusual in the context of severe declines and even extinctions amongst other Australian frogs. In the Australian context, the amphibian extinction crisis has been most severe in montane, wet forest dwelling species, and bell frogs do not fall into this category; they are not a montane species and they do not inhabit wet forest, nor indeed any other kind of forest. As a consequence, there has been some argument about the causes of decline in this species, with attention focused upon three primary threats; (i) habitat loss/degradation, (ii) the invasive fish species *Gambusia holbrooki*, and (iii) the fungal disease known as 'chytrid'.

Habitat: the former range of all three SE Australian bell frog species (hereafter, 'bell frogs') largely encompasses regions that have been highly modified for agriculture, urban development, and industry since European occupation. In NSW, bell frogs were distributed across the Eastern coastal plains and slopes, the coastal hinterland highlands on the east side of the Great Dividing Range, the tablelands that make up the upper parts of the Murray-Darling catchment on the west side of the Great Dividing Range, and the slopes and plains of the Murray river catchment. In Victoria, they were found on the inland tablelands, the slopes and plains of the Murray, the coastal slopes and plains, and the coastal highlands of East Gippsland. Most of these areas have been profoundly altered in the last 200 years, and hence the loss and degradation of habitat is a clear potential factor in the decline of these species in the last 50 (Mahony 1999, Clemann & Gillespie 2012, Mahony et al. 2013).

The clearing of native habitat for agricultural development across the Murray-Darling Basin is understood to be a highly significant factor in the general (and severe) environmental degradation of this catchment, and has negatively impacted large numbers of species. The general sequence of impacts on bell frogs is likely exemplified by the processes that have been described for other species in the Murray valley (*Litoria booroolongenesis* and *Crinia sloanei*); removal of riparian vegetation and river access by sheep and cattle causes severe bank erosion and sedimentary infill of deeper holes in the river bed, resulting in the loss of basking, foraging, and refuge microhabitats for frogs such as bell frogs that require access to standing water all year around (David Hunter, pers. comm.). Regulation of the rivers by large dams alters the timing and extent of flooding events, with likely further consequences upon breeding habitat.

Arguments against habitat degradation being the primary cause of bell frog decline point to the persistence of *L. aurea* in highly modified post-industrial landscapes, and to the rather sudden decline of

all species in the last 50 years in a manner that does not obviously match the steady degradation of habitat in over the last 200 years. For this reason, early attempts to explain the bell frog decline also emphasised the impact of the invasive fish, the plague minnow *Gambusia*.

The eastern plague minnow, *Gambusia holbrooki*: these were introduced to many countries including Australia through the 20th Century as a putative control measure against mosquitos (hence their other vernacular name, 'mosquitofish'; ironically, their control of mosquito populations was less than was hoped for). *Gambusia* have been described as voracious predators and possess a combination of life-history that make them highly successful invaders of aquatic ecosystems. They have had significant effects on numerous native species, including various frogs, and have been demonstrated to significantly reduce survivorship of *L. aurea* tadpoles in laboratory experiments (Morgan & Buttemer 1996, Pyke and White 2000). Their current range in NSW and Victoria has strong overlap with the locations from which bell frogs have declined; as a result, ecologists seeking to understand the decline of bell frogs in the 1990s drew attention to the potential impact of *Gambusia* on these frogs (Gillespie 1996, Mahony 1999).

As with the explanations focusing on habitat degradation, the case for *Gambusia* being a primary agent of bell frog decline has some complications. Bell frogs have declined markedly from the highland and tablelands where *Gambusia* are rare or absent; in NSW, *L. aurea* persists in landscapes infested by *Gambusia*; and few of the other frog species that co-occur with *Gambusia* have shown such marked declines.

Chytrid: Over the course of the 1990s, ecologists suspected that the pattern of amphibian declines and extinctions most closely fitted that of a disease epidemic, rather than the effects of habitat degradation or predation by an invasive species. This was confirmed in 1996 by the description of chytrid; more correctly known as chytridiomycosis, this is a disease caused by the pathogenic fungus *Batrachochytrium dendrobatidis* which can be fatal to a range of amphibian species (see summaries in Berger et al. 2007, Skerratt et al. 2018, Scheele et al. 2019).

Some aspects of the decline of bell frogs, especially *L. aurea*, match the general pattern of chytrid-mediated decline of frog species. *Batrachochytrium dendrobatidis* is more active in cooler temperatures, and its greatest impacts have been upon frogs living at higher altitudes (Puschendorf et al. 2009, Puschendorf et al. 2013, Geoff Heard pers. comm.); *L. aurea* has largely disappeared from the high elevated parts of its former range, and persists mainly in warmer coastal zones. More recently, *B. dendrobatidis* has been shown to have a low tolerance to saline environments, again consistent with the coastal distribution of surviving populations of *L. aurea*.

Combined effects: as much as chytrid appears to be the smoking gun behind bell frog declines, there are some aspects that suggest that chytrid on its own may not be the whole story. In particular, the population of *L. aurea* in eastern Victoria seems to have suffered minimal decline and continues to persist in good numbers. While eastern Victoria has some lower lying areas – the Gippsland lakes, Snowy River estuary, and Genoa River estuary – that presumably experience saline influences some way inland, a large part of East Gippsland is relatively high country that directly contacts the coast. Although systematic surveys are lacking, the available data suggests that *L. aurea* populations are in good shape in this region (Gillespie 1996). Importantly, there is no reason to suppose that this area is any less susceptible to chytrid than the rest of SE Australia.

Area	Species	Status	Habitat	Chytrid	*Gambusia*
Coastal slopes & plains NSW	*L. aurea*	present, but severe decline, persists only in refuges	Highly modified for residential, industrial, and agriculture *L. aurea* refugia are industrial/saline environments	present but limited in places by salt and temperature?	very high numbers
	L. castanea	never present			
	L. raniformis	never present			
Coastal highlands NSW	*L. aurea*	disappeared	medium to low modification	present	absent or rare
	L. castanea	never present			
	L. raniformis	never present			
Inland tablelands NSW	*L. aurea*	severe decline but low persistence in Monaro	modified for grazing and cropping	present	absent or rare
	L. castanea	present but severe decline			
	L. raniformis	severe decline			
Inland slopes & plains NSW	*L. aurea*	never present	highly modified for grazing and cropping (Lachlan and north), and grazing, cropping and irrigation (Murrumbidgee and Murray)	may be limited by summer temps and drought?	abundant
	L. castanea	never present			
	L. raniformis	disappeared from Lachlan and Macquarie, present in Murrumbidgee and Murray			
Coastal slopes &plains VIC	*L. aurea*	present around East Gippsland lakes, river valleys, and morasses - persisting	Highly modified for residential, industrial, and agriculture, although less so in East Gippsland. Part of zone of *L. aurea* persistence is around saline coastal lakes (*L. raniformis* less salt tolerant that *L. aurea*?)	present but limited in places by salt and temperature?	abundant in south and west, but absent in East Gippsland
	L. castanea	never present			
	L. raniformis	present but declined			
Coastal highlands VIC	*L. aurea*	never present?	medium to low modification	present, with some limitation by temperature at lower altitudes?	absent
	L. castanea	never present			
	L. raniformis	never present			
Inland tablelands VIC	*L. aurea*	never present	modified for grazing and cropping	present	absent or rare
	L. castanea	never present			
	L. raniformis	present but declined			
Inland slopes & plains VIC	*L. aurea*	never present	highly modified by grazing, cropping and irrigation	may be limited by summer temps and drought?	abundant
	L. castanea	never present			
	L. raniformis	present but declined			

(Previous page) **Table 1.2.1**: Regional overview of populations of the three species of south east Australia bell frogs (*Litoria aurea*, *L. castanea*, and *L. raniformis*) across their former range. The impacts of changes in habitat, chrytrid, and *Gambusia* distribution are summarized. Shading shows intensity of impacts or the suspected threatening processes. See text for discussion.

Tabulating the population status of bell frogs and extent of these threatening processes in SE Australia shows some interesting patterns (Table 1.2.1). At higher altitudes (coastal highlands of NSW and inland tablelands), all three species have experienced severe declines even with moderate or low habitat degradation and despite the absence of *Gambusia*. In these regions, the presence of chytrid is evidently enough to have a devasting impact on bell frogs. However, at lower altitudes and in more coastal areas, the situation becomes more complex. When *Gambusia* is present in high densities, bell frogs persist only in saline environments, irrespective of the level of habitat degradation (coastal plains of NSW). When *Gambusia* is present at lower densities and habitat modification is not extreme, bell frogs may also persist (*L. raniformis* in inland tablelands of Victoria; Mahony 1999, Gillespie & Clemann 2012). Similarly, where coastal plains have lower levels of both degradation and *Gambusia*, bell frogs persist (*L. raniformis* in most of coastal Victoria; Heard et al. 2013, Gillespie and Clemann 2012). And where habitat modification is minimal and *Gambusia* is completely absent, bell frogs show little evidence of decline (*L. aurea* in the East Gippsland region of Victoria; Graeme Gillespie, pers. comm.).

This pattern suggests that, whilst chytrid alone has likely extirpated bell frogs from the higher parts of their former range, the disease alone does not account for the pattern of decline in the lower-lying coastal and inland regions. The complexities of habitat degradation can be difficult to understand, but there appears to be a very clear signal with respect to the interaction between chytrid and *Gambusia*; in East Gippsland, **at elevations under 200m and where *Gambusia* are almost completely absent, green and golden bell frogs appear to persist in good numbers**.

An important caveat that must be noted here is that there are no systematic monitoring of either *L. aurea* or *Gambusia* in East Gippsland (Nick Clemann, pers. comm.), and the real situation may be quite different to the picture painted by what are essentially a series of anecdotal observations. For this reason, systematic monitoring of that region is urgently needed. Until that point, the pattern outlined above must be considered as putative at best.

1.3 Threats interacting at a small scale: *Litoria aurea* on Kooragang Island

In laboratory challenge experiments *L. aurea* is particularly susceptible to the chytrid fungus, (Stockwell et al., 2010), and 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.* 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). The population level effects of this mortality are significant: infected populations are predicted to decline at twice the rate of healthy ones (Stockwell et al, 2011).

The majority of extant *L. aurea* populations are found in coastal environments, consistent with the suggestion 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, Clulow et al. 2018). Indeed, salt concentrations above 2 ppt and below 5ppt were found to be beneficial (Stockwell et al., 2015b, Stockwell et al., 2015a). The potential for using salt as part of a management tool *L. aurea* conservation on Kooragang was investigated by Callan (2018), who found that an array of wetland habitats which provided wild *L. aurea* with access to at least some saline wetlands did result in improved survivorship. Note that elevated salinity and temperature have been shown to improve survival in *L. raniformis* (Heard et al. 2014).

Callen (2018) also found that variation in hydroperiod was also important for the persistence of the subpopulation that was the focus of her study; this variation in wetland characteristics between neighbouring wetlands has been dubbed the 'habitat mosaic' and is emerging as an important concept in the conservation management of *L. aurea*. Connectivity (proximity of an array of wetlands to each other, with suitable interconnecting habitat) is obviously a key attribute of an effective mosaic (Hamer et al. 2008, Wassens et al. 2008, Heard et al. 2015), but variation in hydroperiod among the wetlands is also important (Klop-Toker 2016, Callen 2018). Of particular importance is the proximity of permanent wetlands (Valdez et al. 2015), preferably through their inclusion within the mosaic. Wetland size has yet to be demonstrated as an important feature on Kooragang, but has been shown to be important for *L. raniformis* in Victoria (Heard et al. 2015).

In the context of *L. aurea* on Kooragang Island, an effective habitat mosaic should have variation in microhabitat sufficient to provide environmental protection against chytrid via access to increased salinity and temperatures (Heard et al. 2014, Heard et al. 2018). Variation in hydroperiod can also provide protection against *Gambusia*, which have a significant impact on *L. aurea* recruitment on Kooragang Island (Klop-Toker 2016). Laboratory experiments have demonstrated predation of *Gambusia* upon amphibian tadpoles and eggs (Stanback, 2010, Mahony et al., 2013) and *Litoria aurea* tadpoles do not show any avoidance or refuge seeking behaviours when introduced to *Gambusia*, further increasing their susceptibility (Hamer et al., 2002b).

Whilst the relationship between *L. aurea* declines and the expansion of *Gambusia* into NSW has been debated – numerous sites exist where *L. aurea* declined despite local water bodies being free of the predatory fish (Mahony et al. 2013), and several studies have noted the co-occurrence of *L. aurea* tadpoles and *Gambusia* in the same water body (Sanders et al., 2015, Hamer et al., 2002a) – the pattern seen from field studies on Kooragang leaves little doubt that *L. aurea* recruitment is heavily affected by the presence of *Gambusia* (Klop-Toker 2016, McHenry et al. 2017, 2019, this annual report). *Gambusia* do not affect adult *L. aurea* (Klop-Toker 2016), but their impact on tadpoles means that *L. aurea* populations subject to chytrid and coexisting with *Gambusia* will be subject to both increased adult morality and reduced recruitment. 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 et al. 2002; Pyke, White et al. 2002); this highlights the importance of designing wetland infrastructure to control for *Gambusia* infestation.

1.4 Research Objectives

Research objectives for the 2018-19 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. **Habitat corridor mitigation strategy (PWCS)**: A long-term aim is to decrease the proportion of *L. aurea* occupancy of wetlands in the north of the precinct (previously earmarked for development - see Section 2.1: 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 the Industrial Zone.

6. **Rail infrastructure mitigation strategy (NCIG)**: 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. **Constructed wetlands strategy (HDC)**: 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.

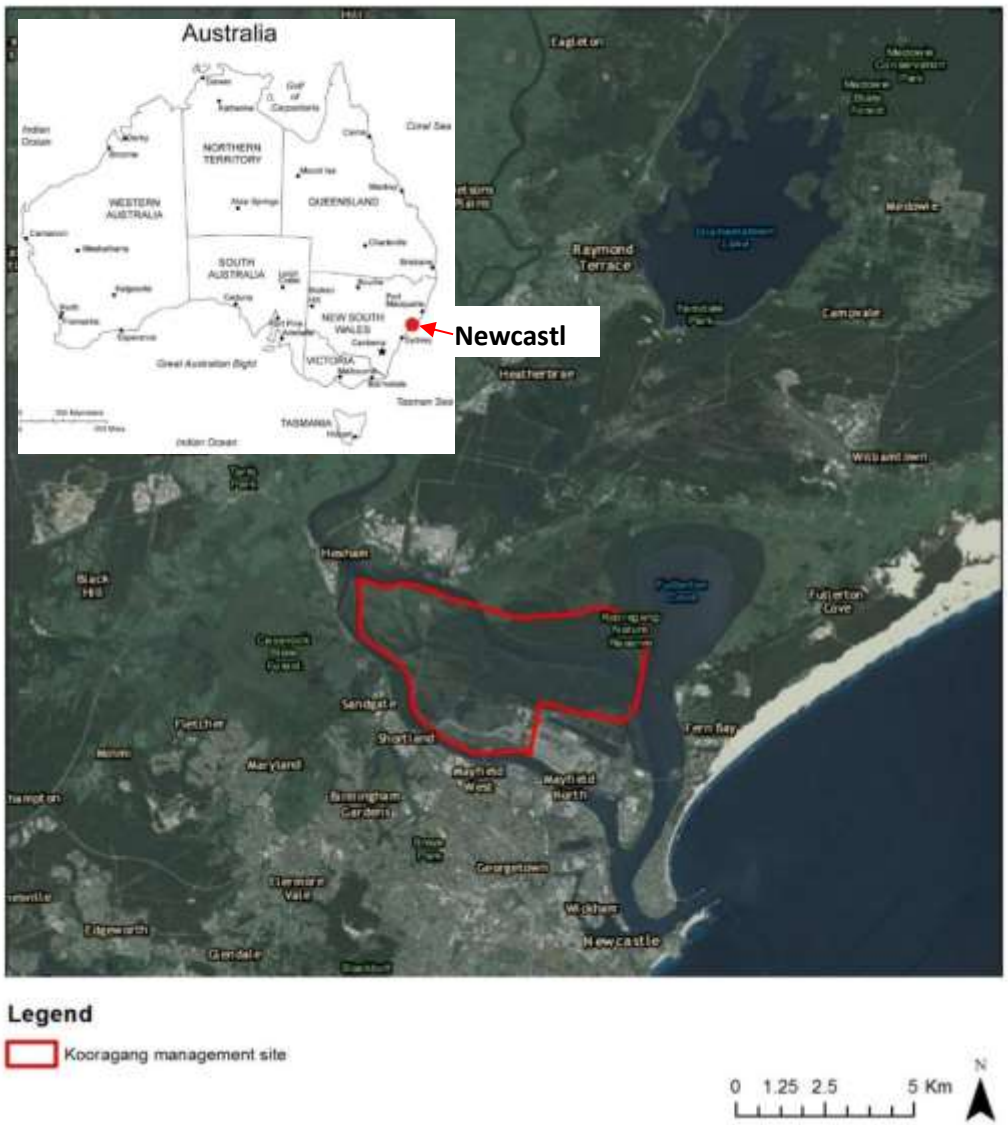

Figure 2.1.1: Contextual map depictingthe location of Kooragang Island, near Newcastle, NSW.

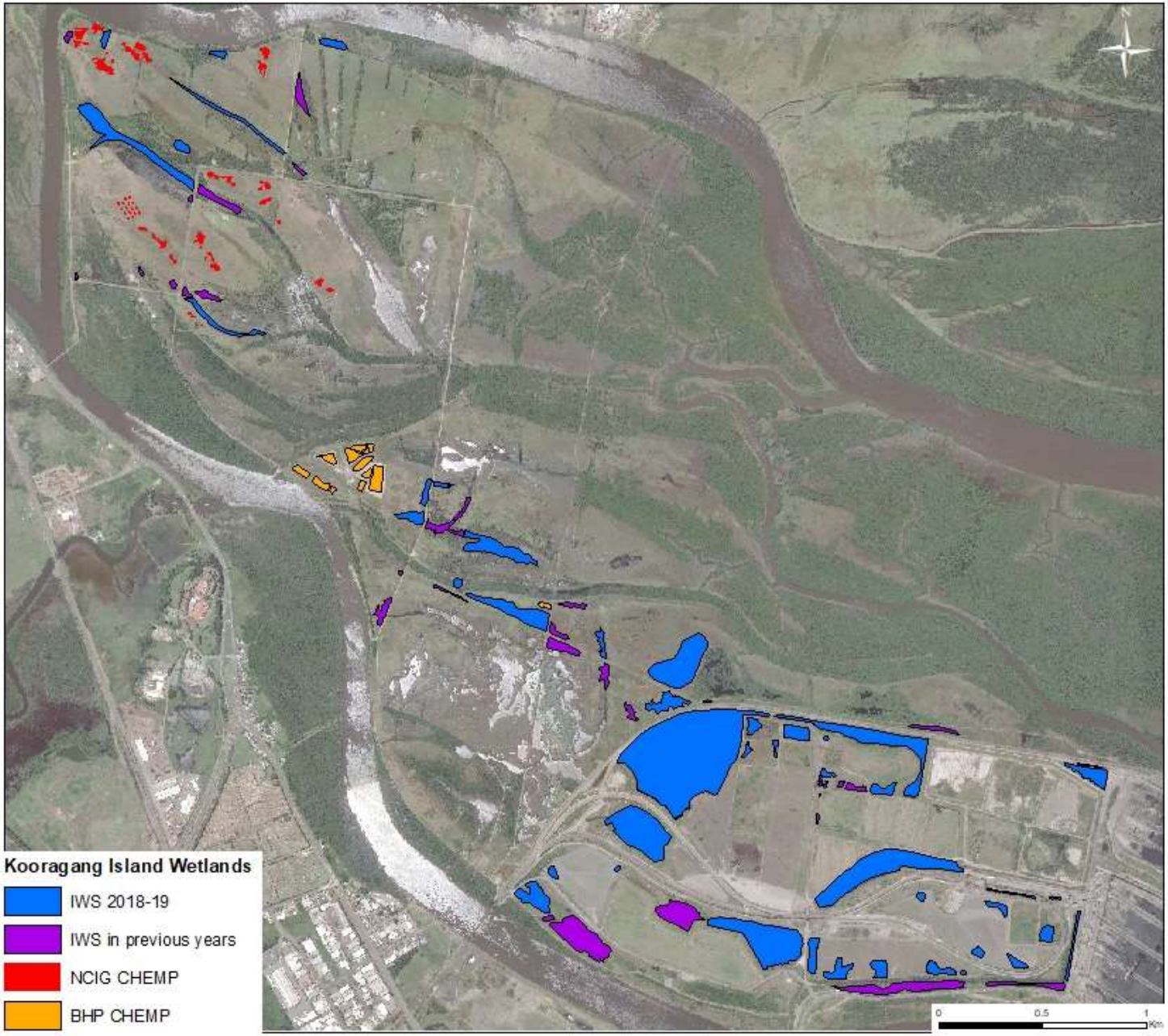

Figure 2.1.2: Wetlands of Kooragang Island - showing the 48 wetlands surveyed in each round of the 'island-wide' surveys of 2018-19. The positions of NCIG and BHP CHEMP wetlands are also shown; 16 of these wetlands were surveyed in each round of the island-wide surveys in 2018-19, making a total of 64 wetlands which make up the core of the data is presented in this report.

The location of wetlands that were surveyed in previous years is also shown. Most of these were not surveyed at all this year, but some were surveyed during one or two rounds; results from those surveys have been included into the data summaries in Section 3.4 and 3.9.

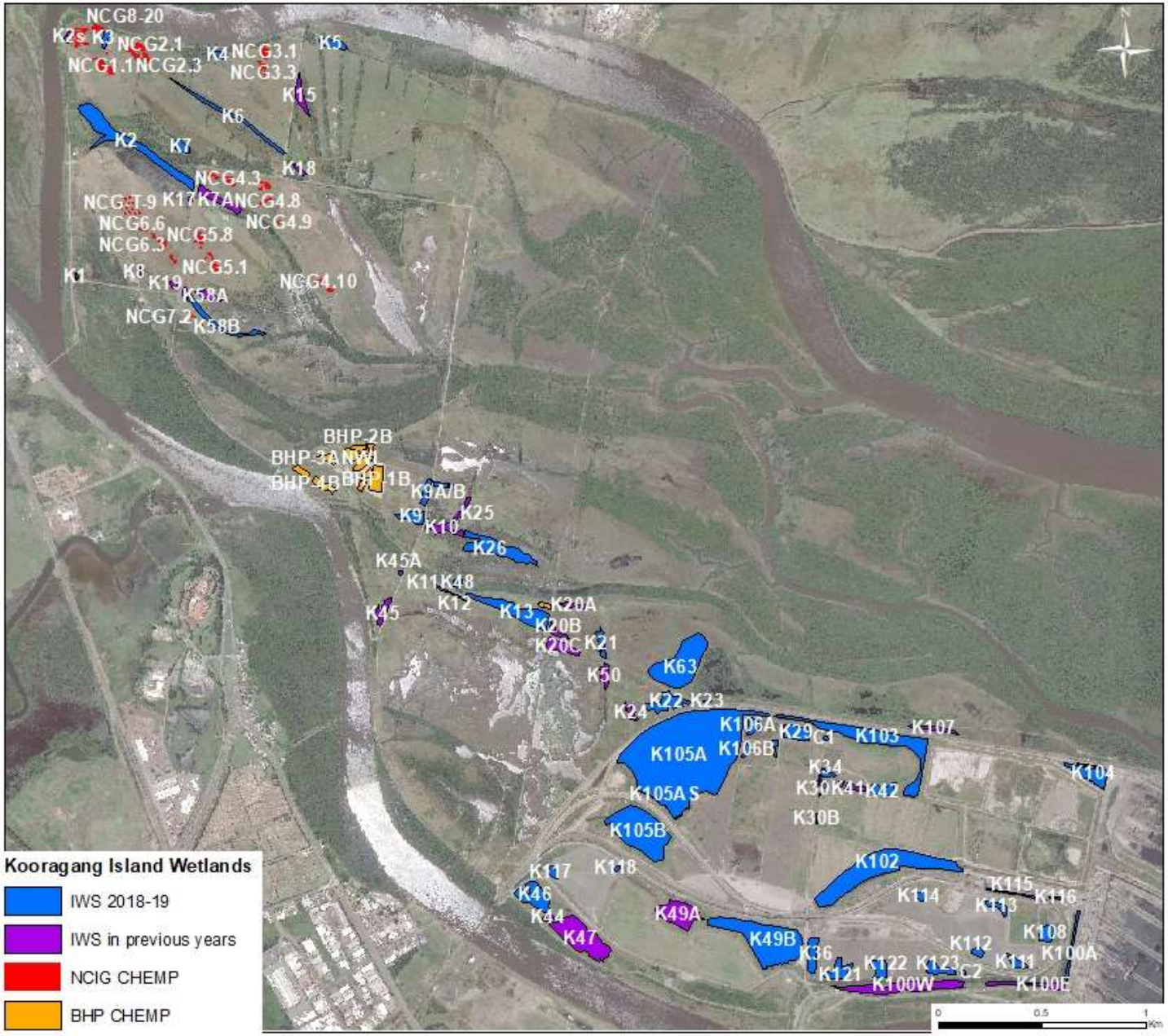

Figure 2.1.3: UoN reference labels for the wetlands shown in Figure 2.1.2.

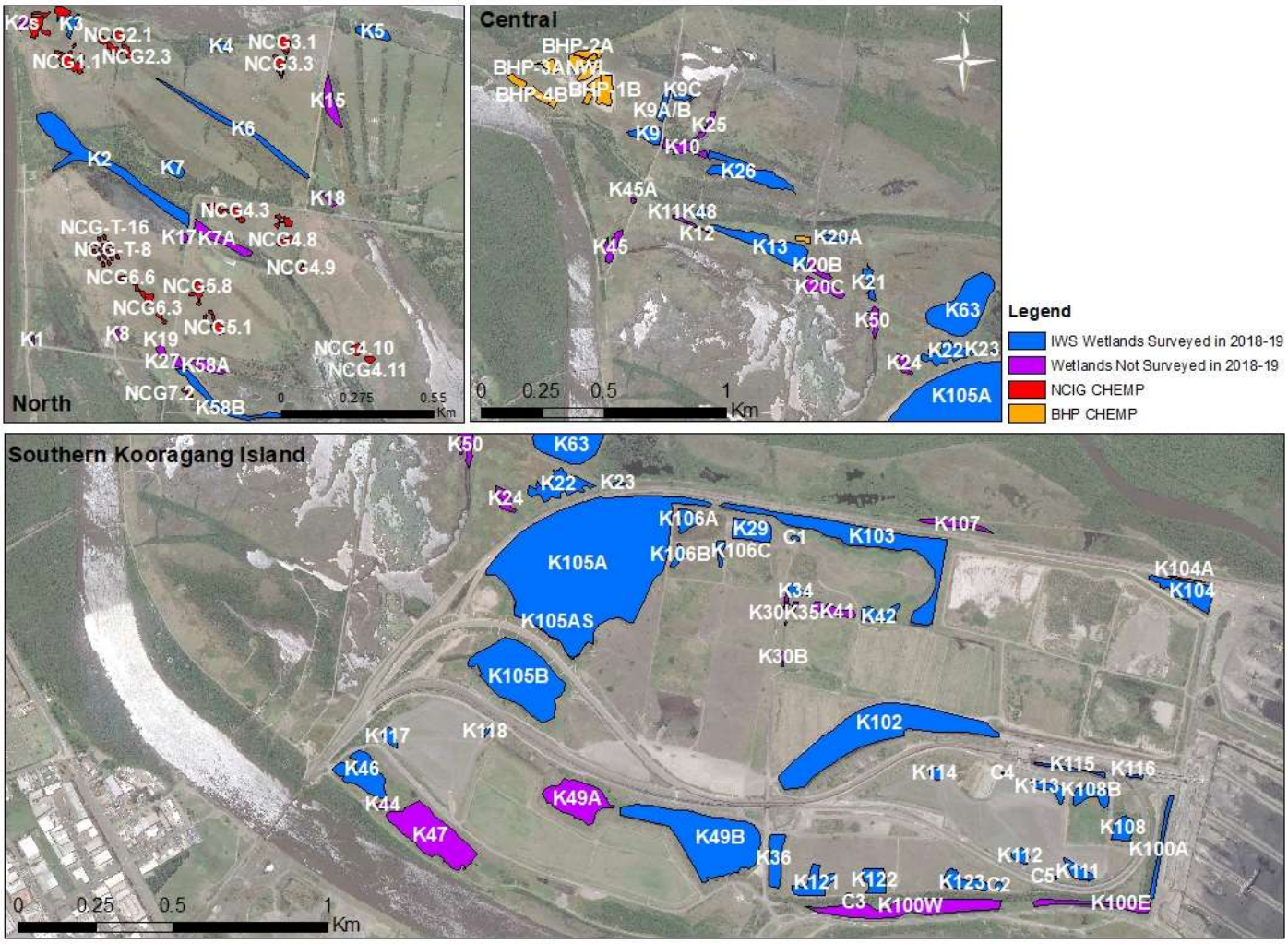

Figure 2.1.4: Close-up of wetlands (with UoN labels) in each of the three zones (North, Central, and Industrial Zones) – see Section 2.2. Note that the Industrial Zone lies on southern Kooragang Island.

In the 2018-19 breeding season, 64 wetlands across the island were surveyed (Figure 2.1.2). The list of wetlands surveyed each year is largely consistent, but with some variation between each season (see Table 2.2.1). 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 17 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 16 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 The Industrial Zone is dominated by the Kooragang Island Waste Emplacement Facility (KIWEF), a series of constructed 'cells' on top of the estuarine wetland floor that were varying filled with industrial waste from the Newcastle steelworks and other heavy industry through the 20th Century. Some of the unfilled cells now provide wetland habitat, whilst closure works on filled cells have required the construction of sediment control ponds which also provide now wetland habitats; as a result, 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 346 ha. The northern part of the Industrial was the approved site for the development of a fourth coal terminal ('T4'), but progress on that developed was halted in 2019 and is not expected to proceed. 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.

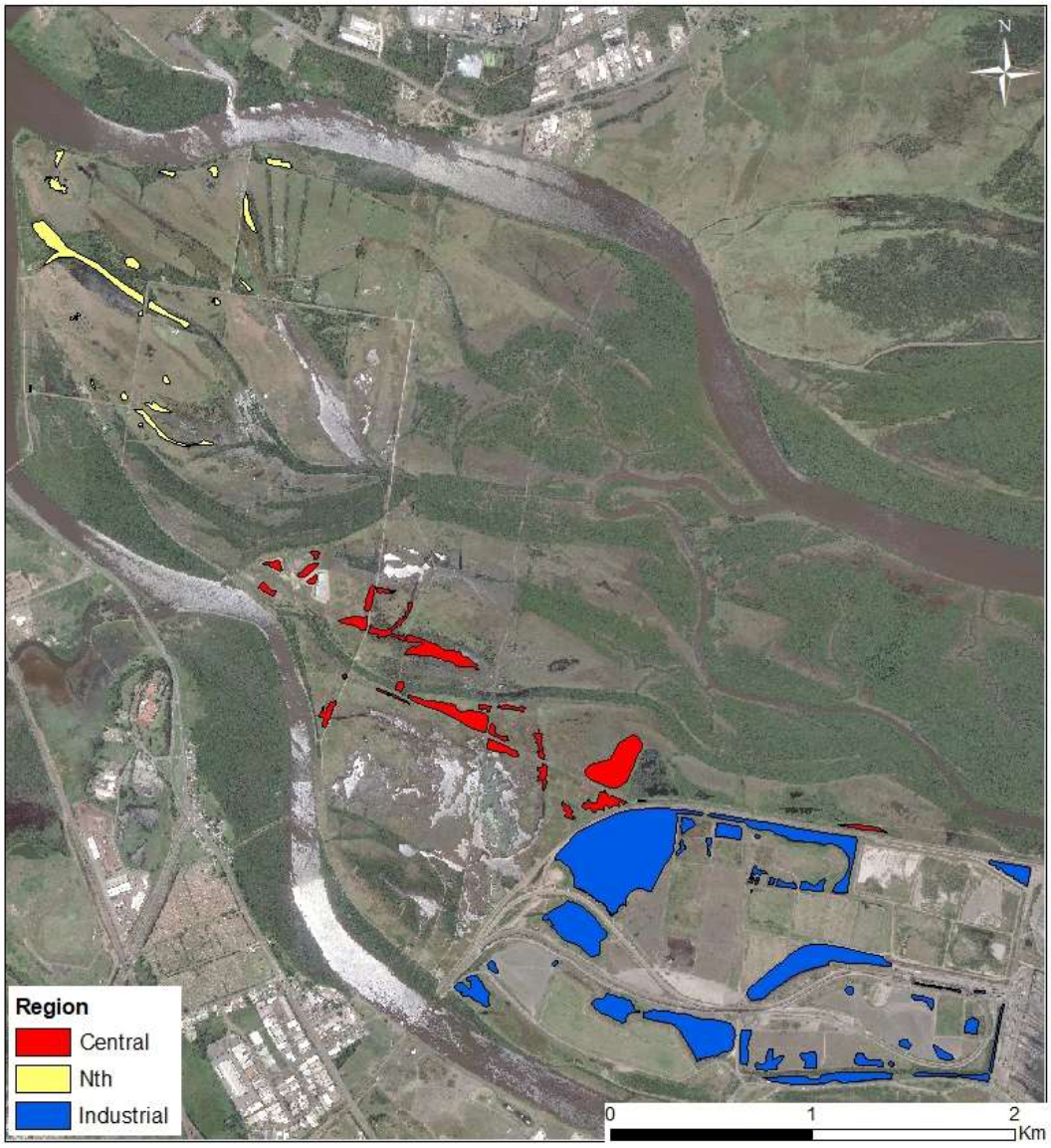

Figure 2.2.1: Allocation of surveyed wetlands on Kooragang Island to Zones; see text and Table 2.2.1 for explanation.

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 for the purposes of multi-year occupancy analysis (**Section 3.9**).

- 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

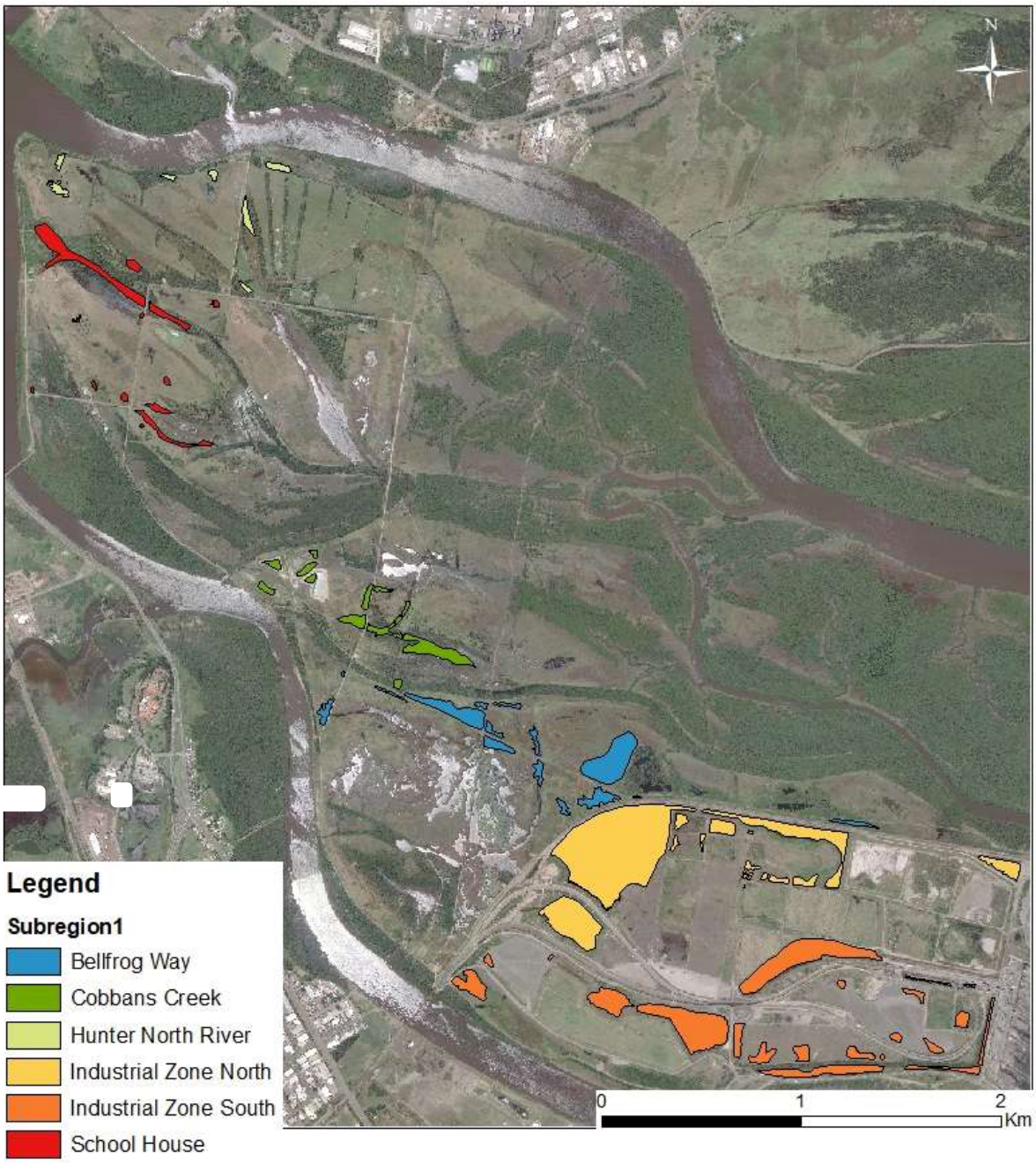

Figure 2.2.2: Allocation of surveyed wetlands to Regions. See text and **Table 2.2.1** for explanation.

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.

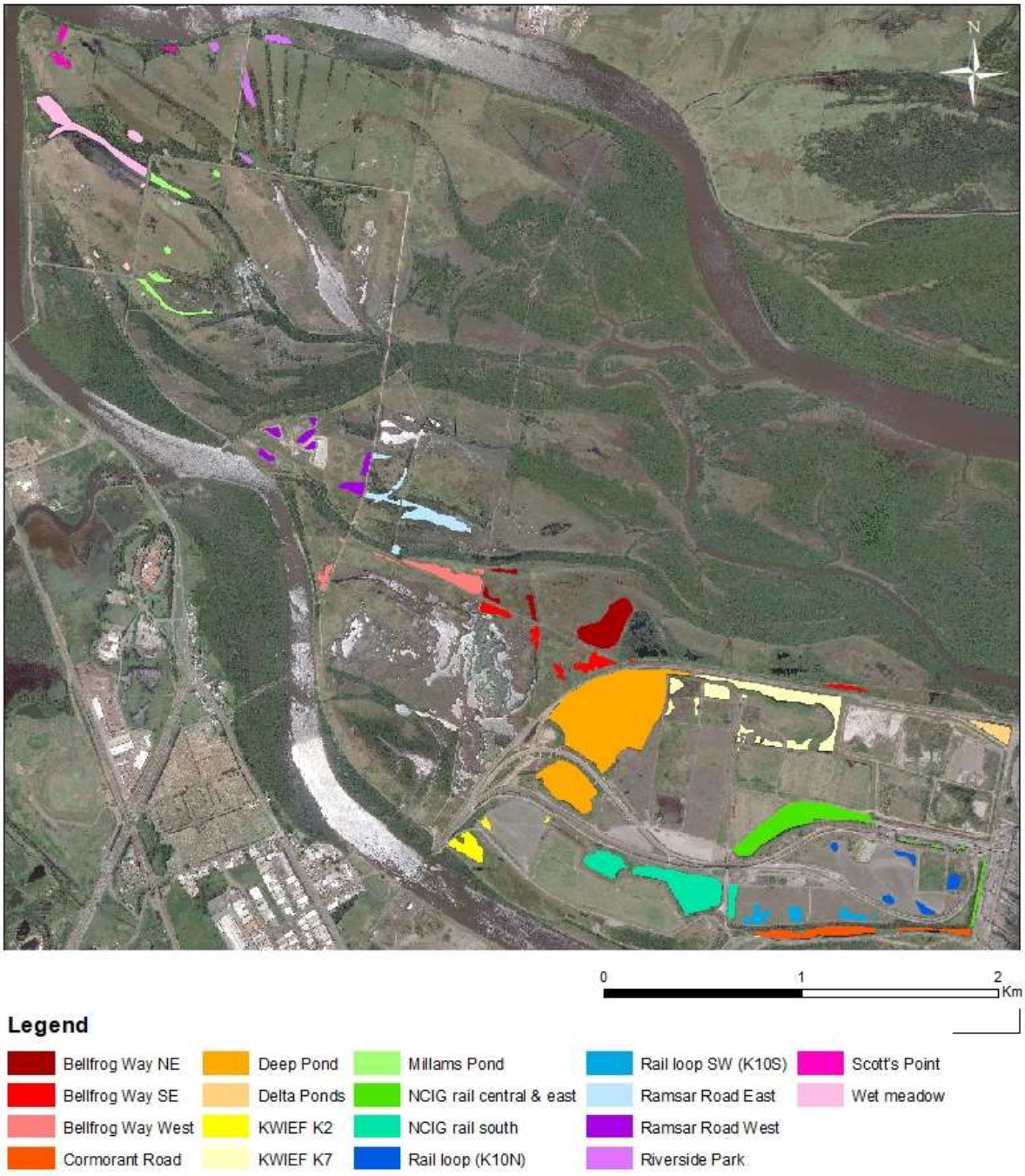

Figure 2.2.3: Allocation of surveyed wetlands to Subregions. See text and Table 2.2.1 for explanation.

Zone	Region	Subregions	Wetlands included
Nth	Hunter River North	Scott's Point	K2S, K3, K4; NCIG CHEMP Stage 1 & Stage 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, *K108B*, 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 have been surveyed in previous years but were not surveyed in 2018-19; wetlands shown in *italics* were surveyed in one or two rounds only (i.e. opportunistically); wetlands shown in red font were not surveyed in the 3rd round due to proximity to the Industrial Zone ground fire in early 2019. Underlined wetlands are those that are also surveyed in the SoS project.

A total of 64 wetlands were surveyed in the 2018-19 in each of the survey rounds (although some of these could not be surveyed in round 3 due to the Industrial Zone ground fire). A further 14 wetlands were surveyed opportunistically in one or two of the rounds.

Jurisdiction

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

- National Parks and Wildlife (NPWS): 15 wetlands (North and Central zones)
- CHEMP (NCIG and BHP): 16 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)

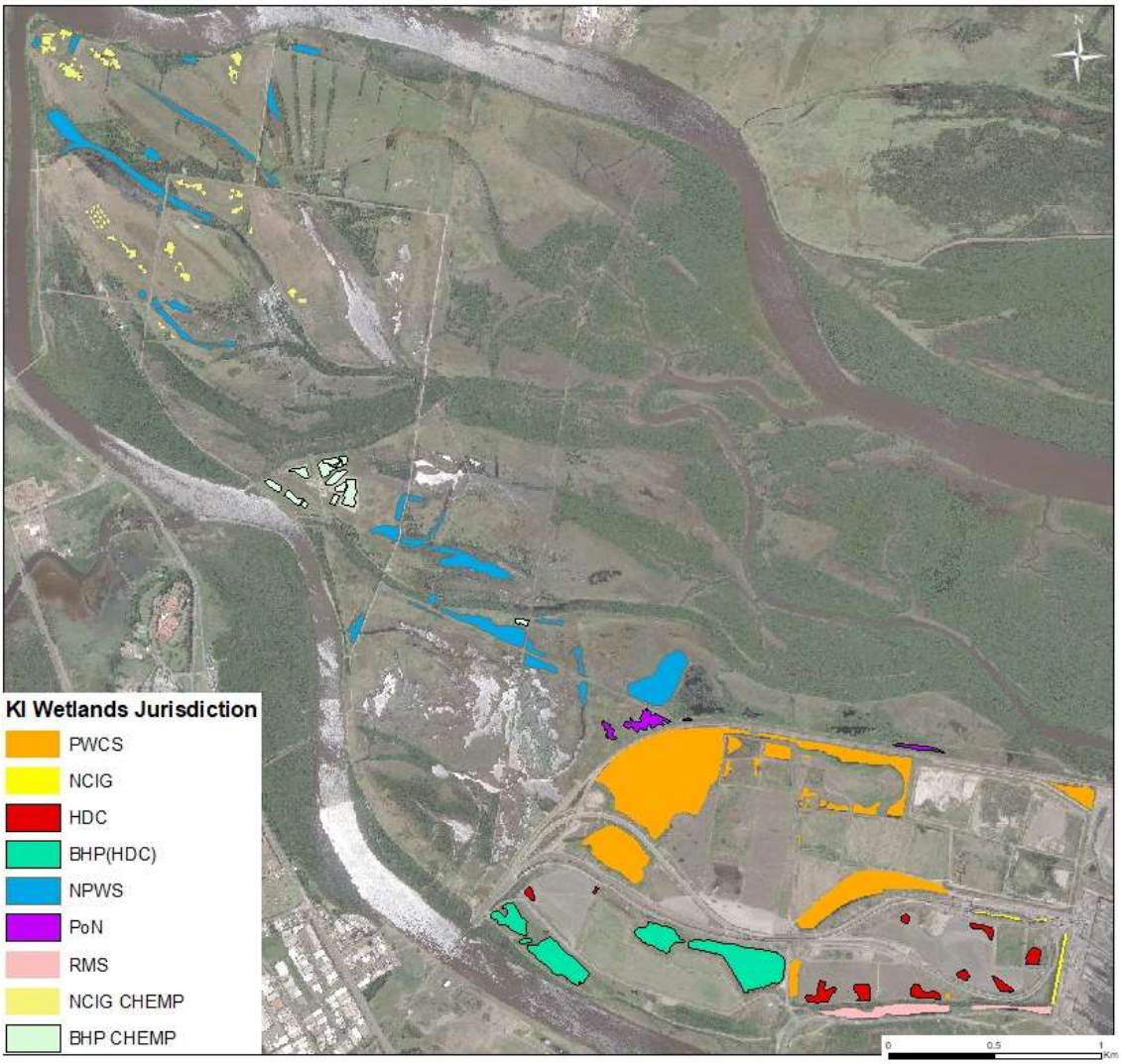

Figure 2.2.4: Named wetlands on Kooragang Island, summarized by jurisdiction. Note that not all of these were surveyed in the 2018-19 season (see text and Table 2.2.1)

Previous surveys have included two wetlands that are under the jurisdiction of Roads & Maritime Services (RMS), but these were not surveyed in the 2017-18 or 2018-19 seasons.

2.3 Long-term monitoring approach

The whole island monitoring program has followed a standard method for seven 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 and tibia length were 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). Metamorph*s* 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. Not every frog captured is weighed (the project already has hundreds of data points for length-weight relationship from this population, and take weight measurements adds to the per-frog processing time), and swabs for chytrid are not collected in the summer. Tissue samples for genetic analysis are collected from a subsample of captured frogs only. 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 up to 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	2018-19
Wetlands surveyed	55	75	71	60	**63**
Total wetland surveys	118	150	195	245	**207**
Nights of field surveys	38	37	41	48	**48**
Total search effort VES (person.minutes)	7,979	8,899	8,861	11,201	**13,375**

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 one additional round in September (Round 0) for the SOS (Save Our Species) surveys (Table 2.2.1, Figure 2.5.1). This was not as extensive as the principal rounds.

We intended to conduct CMR surveys at each of K23, K29, and K104 in each round, but numbers in K22/23 were deemed too low to complete CMR surveys in rounds 1 and 2.

The logistical problems presented by the Industrial Zone ground fire (See **Section 4.8**) in early 2019 meant that the third round was also incomplete; no CMR surveys were conducted in that round, and visual encounter surveys were not completed for a number of wetlands (see Table 2.2.1). Thus, the third round was partial only, of similar extent to the Round 0.

Round	Date	CMR
0	Sept 2018	-
1	Oct 2018	K29, K104
2	Nov-Dec 2018	K29, K104
3	Jan-Mar 2019	

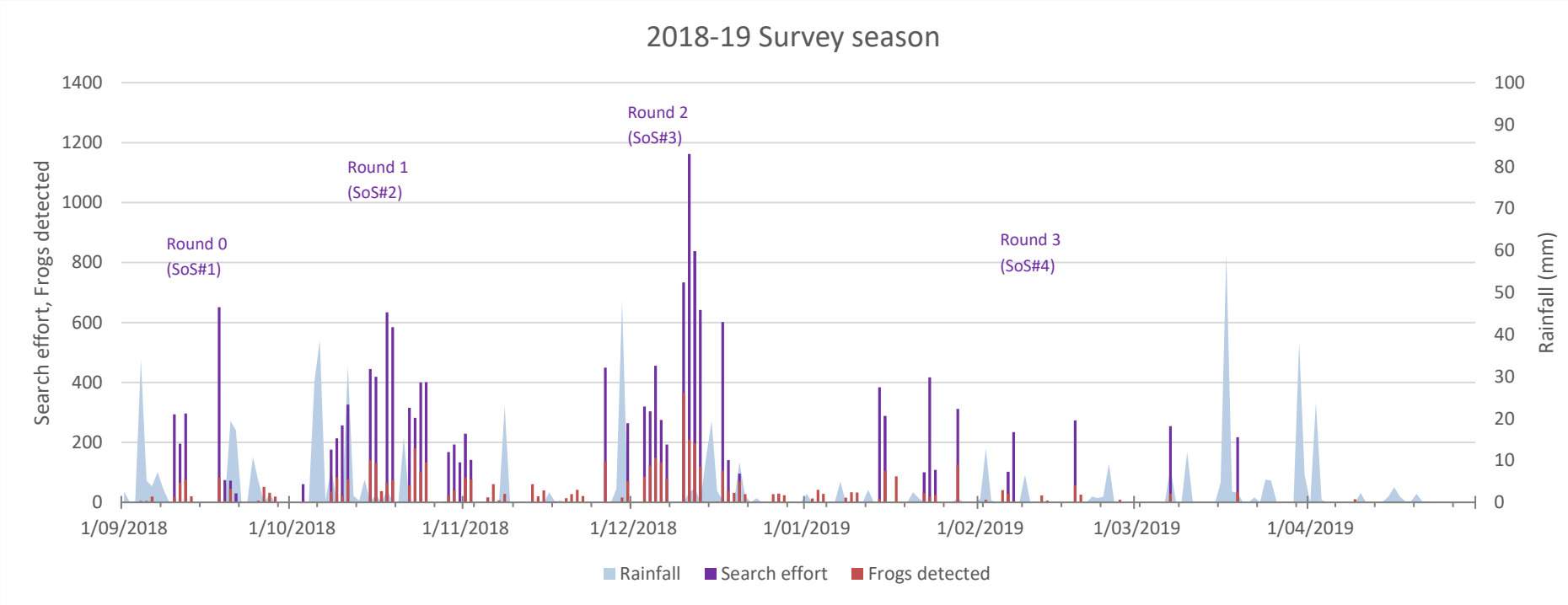

Figure 2.5.1: Search effort and *L. aurea* detections across the 2018-19 survey period, shown alongside rainfall.

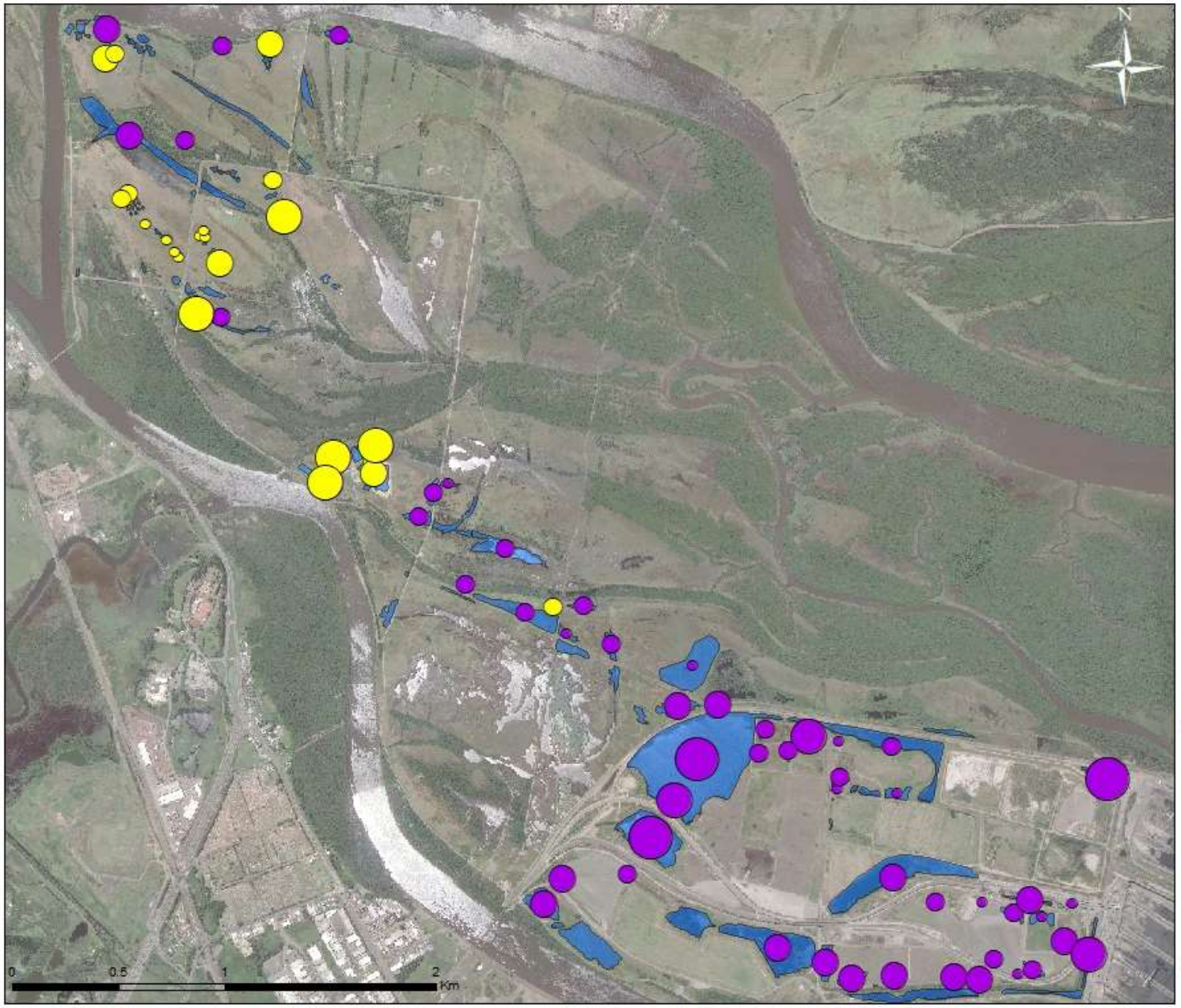

Figure 2.5.2: Search effort (person.minutes) across the 64 wetlands surveyed as part of Island-wide monitoring in 2018-9

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 2018-19 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.

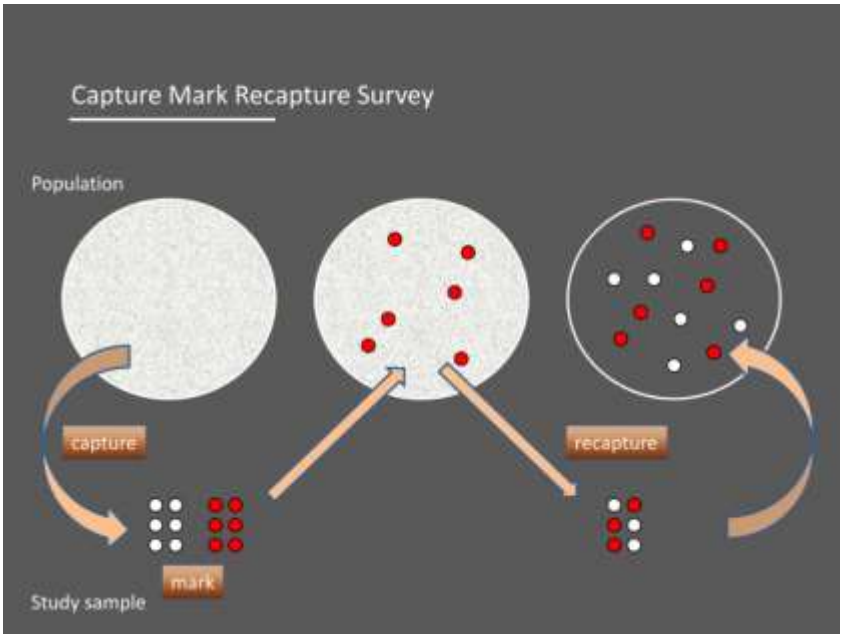

Figure 2.6.1. A simple illustration of capture-mark-recapture survey (based on two capture events only). Left circle: nothing is known about the population size, during the first capture event animals are caught, marked and released. Middle circle: the number of marked animals within the population is 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 two locations over two primary survey periods.

- K29 ('The Cell')
- K104

N.B. Historically, CMR surveys have been conducted at K22/23, but low numbers of L. aurea detected in rounds 1 and 2, and the ground fire during round 3, led to CMR surveys being abandoned for that wetland complexed in the 2018-19 season.

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 based upon 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' (= 'candling'), 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.

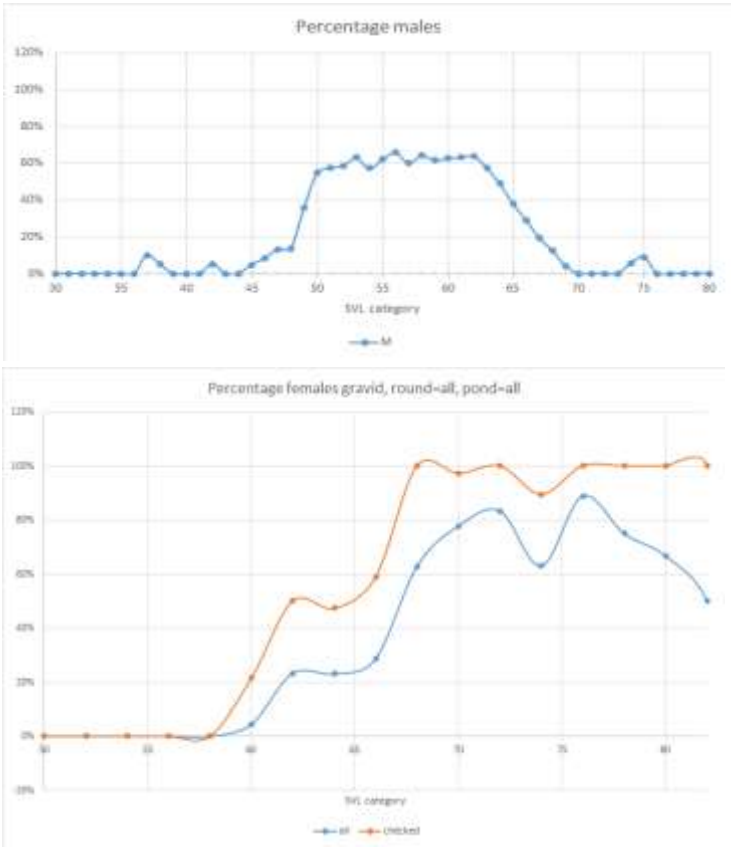

Figure 2.6.2: Proportion of animals that can be confirmed as reproductively mature (i.e. adults), plotted against SVL. Top, males; Bottom, females. In the lower chart, the red line represents the number of females found to be gravid, as a proportion of the animals inspected for gravidity, whilst the 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
	Total	**Total**	**Total**	**Total**
Search effort	1,571	4,068	5,075	2,661
VES Detections	152	558	938	302
All Detections	175	1,101	1,671	366
Captures	119	779	1,126	259
Unique	89	579	452	128

Table 3.1.1: Summary data from all surveys in 2018-19 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 Round 0 is a partial survey of 30 wetlands. Because of the ground fire that affected the 3rd round, only Rounds 1 and 2 were 'full' surveys of all 64 wetlands (see Section 2.5)

The highest number of detections were in the Round 2 (early summer) (Table 3.1.1) – a similar temporal pattern to the previous year. Detections rose steadily though spring (Rounds 0 and 1). The low numbers in Round 3 (late summer—early autumn) are likely a result of (1) a dry summer, and (2) reduced surveys as a consequence of the Industrial Zone ground fire.

Zones (detections)	**Search effort (VES)**	**VES**	**Total**	**Search Sensitivity**
Northern Zone	3,014	92	102	0.03
Central Zone	2,898	362	432	0.12
Industrial Zone	7,463	1,496	2,779	0.20

Jurisdiction (detections)	**Search effort (VES)**	**VES**	**Total**	**Search Sensitivity**
NPWS wetlands	1,592	21	21	0.01
CHEMP wetlands	3,679	383	413	0.10
PoN wetlands	641	50	100	0.08
PWCS wetlands	4,600	1,071	2,185	0.23
NCIG wetlands	680	125	136	0.18
HDC wetlands	1,677	244	397	0.15
BHP (HDC) wetlands	506	56	61	0.11

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 number of frogs detected in the CHEMP is consistent with the previous season, although the number of frogs detected in the Central Zone has decreased. The PWCS wetlands support the greatest number of *L. aurea*.

The total numbers of frogs detected and captured were higher than in previous years, despite the abbreviated final survey round (Table 3.1.3). This is likely a consequence of the significant breeding events around Deep Pond (K105A, K105AS, K106B) and the BHP_CHEMP wetlands in the spring and early summer. The total number of unique individuals encountered during the three main survey rounds was similar to the previous season (see Figure 3.4.3B).

	Primary VES	Total
Frogs detected	1,950	3,313
Frogs captured	1,229	2,283

	Captures	Unique
PIT tagged frogs	3,195	1,250

Demographic summary	Captured		PIT tagged		Unique		Recapture index
	Number	%	Number	%	Number	%	
juveniles (SVL < 49.5 mm)	796	37%	245	15%	208	17%	1.18
subadult females (49.5mm<SVL<58mm, no nups)	103	5%	103	6%	85	7%	1.21
adult males (>49.5, nups)	852	40%	852	53%	662	54%	1.29
adult females (>58mm SVL, no nups)	394	18%	394	25%	272	22%	1.45
metamorphs	114		-		-		
unknown animals (not tagged)	24		32		23		
	2,283		**1,626**		**1,250**		

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 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. The recapture index for adult females was again high (1.45); this means that the probability of recapturing an adult female was greater than for any other demographic.

As only frogs above 40 mm SVL are tagged, and smaller individuals are counted but not tagged, the actual proportion of juveniles in the population is much greater than the 15% indicated by PIT tagged animals. The proportion captured *L. aurea* that were juveniles (37%) is much higher than in the previous season (23%), indicating high levels of recruitment in the latter part of the 2017-18 season and the early part of the 2018-19 season.

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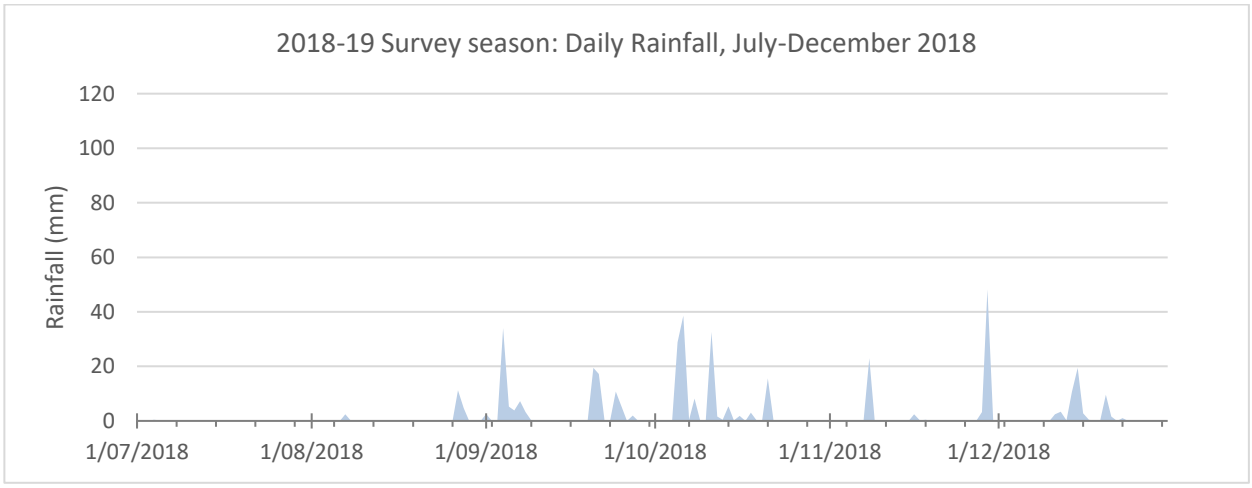
3.2. Seasonal context: environmental factors

Overview

Rain in March, April, and June 2018 meant that the system was well charged by end of August 2018. The 2018-19 survey season was characterised by large rainfall events in Spring (early September and early October), but with very low levels of summer rainfall. The system was the driest in our recent experience by early March 2019. There was a small rain event in late March but, unlike the previous season, this was evidently not sufficient to stimulate a late season breeding event and by late May 2019 many of the wetlands were dry. Heavier rain in June 2019 has at least partially recharged the system at time of writing.



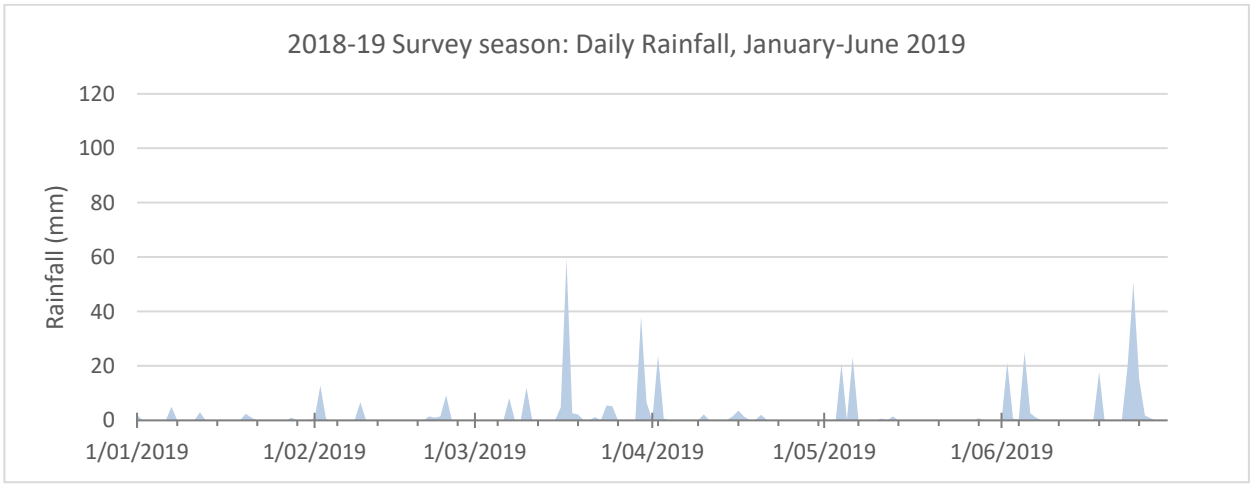


Figure 3.2.1: Weekly rainfall before, during, and after the 2018-19 survey season (October to April) on Kooragang Island, taken from BoM records for Williamtown airport.

Wetlands were well charged by the end of winter 2018 and the system was at 100% capacity by mid-October 2018. Low summer rainfall lead to almost all wetlands – including several that have been characterised as 'deep permanent', such as K36 – being dry by the end of February.

Conditions were so dry by early January that, for the second consecutive year, a number of wetlands and a large part of the island were affected by a grass fire, This season, the fire started in the central part of the island and which spread southwards, burning out a large number of wetlands and resulting in some mortality of adult *L. aurea*.

Following two previous dry seasons 2016-17 and 2017-18, the latter part of the 2018-19 was the driest experienced by the current survey team. Almost all wetlands had dried by the end of February, although some were partially filled again following rain in mid-March. The lack of rain over summer is exemplified by K36, which appears to have dried out by early March; this is characterised as a deep permanent wetland and has not been seen dry previously.

Table 3.2.1: Summary of water presence at each wetland per round, along with presence of *Gambusia* and observed breeding. High levels of early spring rain meant that only one wetlands was dry at the start of the survey period, but low levels of summer rainfall led to 35 being dry by the end of summer. This drying, following a similar drying event in the previous two years, has resulted in the removal of *Gambusia* from many wetlands.

	Hydrology			Gambusia	Breeding
Pond	Early Summer	Late summer	Early Autumn	Mar 2019	
K2	1	1	0	-2	
K3	1	1	1	2	
K4	1	1	0	-2	
K5	1	1	0	-2	
K7	1	0	0	-2	
K58B	1	1	0	-1	
NCIG_1.1	1	1	1	2	
NCIG_1.3	1	1	1	-2	
NCIG_3.1	1	1	0	-2	
NCIG_4.7	1	1	1	2	
NCIG_4.9	1	1	1	-2	
NCIG_5.1	1	1	0	-2	
NCIG_7.1	1	1	1	2	
NCIG_7.2	1	1	1	-2	
NCIG_T13	1	1	1	-1	
NCIG_T14	1	1	0	-2	
NCIG_T15	1	1	1	-1	
BHP-1A	1	1	1	-1	mets
BHP-2C	1	1	1	-2	mets
BHP-3A	1	1	1	-2	mets
BHP-4B	1	1	0	-2	
BHP-14A	1	1	1	2	
K9A/B	1	1	0	-1	
K9C	0	1	1	-2	
K9	1	1	0	-1	
K26	1	1	0	-2	
K48	1	1	0	-1	
K13	1	1	0	-2	
K20A	1	0	0	-1	
K21	1	1	0	-1	
K63	1	1	0	-1	
K22	1	1	0	-1	tads mets
K23	1	1	0	-2	

Pond	Hydrology			Gambusia	Breeding
	Early Summer	Late summer	Early Autumn	Mar 2019	
K104	1	1	1	2	tads mets
K103	1	1	1	2	
K105A	1	1	1	-2	tads mets
K105AS	1	1	1	1	tads mets
K105B	1	1	0	-2	tads mets
K106A	1	0	0	-2	
K106B	1	0	0	-2	
K106C	1	1	0	-2	
K29	1	1	0	-2	tads mets
C1	1	1	0	-2	
K31	1	1	0	-2	
K34	1	1	0	-2	
K42	1	1	0	2	
K102	1	1	1	2	tads mets
K36	1	1	1	-1	
C2	1	1	1	-2	
K115	1	1	1	-2	
K116	1	1	1	-2	
K100A	1	1	1	2	
K108	1	1	0	-2	
K111	1	1	0	-2	mets
K112	1	1	0	-2	tads
K113	1	1	0	-2	
K114	1	1	0	-2	mets
K121	1	1	0	-2	
K122	1	1	1	-2	tads mets
K123	1	1	1	-2	tads mets
K46	1	1	0	-2	
K49B	1	1	1	-1	tads mets
K117	1	1	1	-2	
K118	1	1	1	-2	tads

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

The repeated years of dry summers have incrementally excluded *Gambusia* from a large number of the surveyed wetlands, and this year appear to have removed the fish from K36 and K49B for the first time in recent years. As of March 2019, only 13 wetlands are believed to contain *Gambusia*, compared with 16 in March 2018, 24 in February 2017, and 65 in March 2016 (see subsection below for details). The detection of breeding in 17 wetlands is nearly double the number in the previous season and is the largest number in the last five seasons.

Hydrology

Figures 3.2.2 to 3.2.4 show the changing hydrology of the wetlands across the 2018-19 breeding season; during Spring and into early Summer, most of the wetlands in the Industrial Zone held good levels of water following high levels of Spring rainfall. (Figure 3.2.1, 3.2.2, 3.2.3).

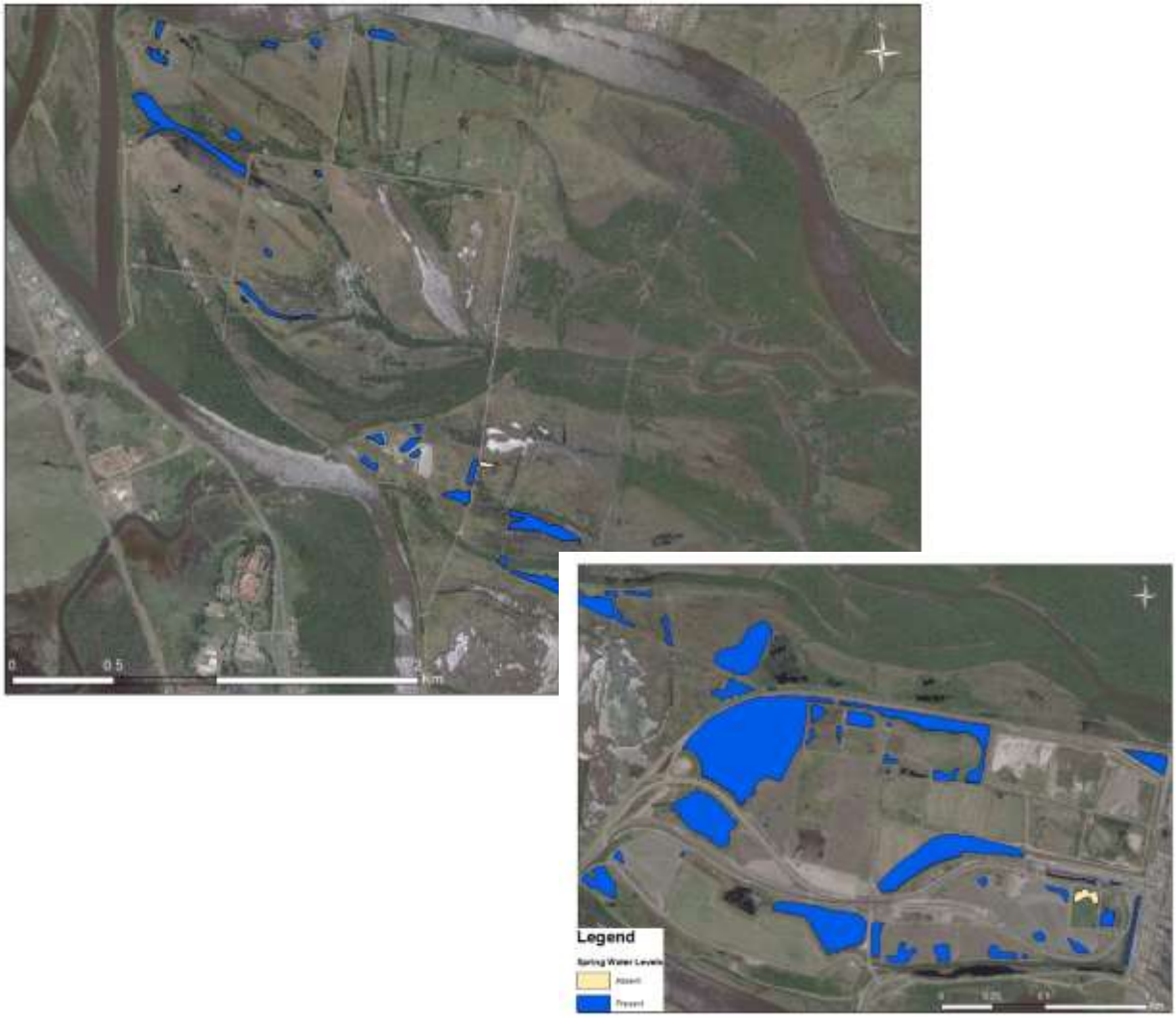


Figure 3.2.2: Water presence/absence across southern Kooragang Island wetlands in October 2018 (Round 1)

Figure 3.2.3: Water presence/absence across surveyed wetlands in December 2018 (Round 2).

Figure 3.2.4: Water presence/absence across Kooragang Island in late February to early March 2019 (Round 3).

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 large permanent wetlands such as K105A (Deep Pond), K103, and K102 were nearly dry (Figure 3.2.2). Even K36 and K49B dried out by early March, although they were slightly refilled by the time they were surveyed in Round 3. In the Northern and Central zones of the island, the only wetlands to hold water were some of the CHEMP wetlands, and K3 and K9C. The latter is understood to be inundated by king tides during dry periods.

Salinity

The maximum salinity levels recorded across the breeding season are shown in Figure 3.2.5. As with the previous season, high salinity levels were seen in the wetlands immediately north of Bellfrog Way, indicating connectivity with estuarine water especially during dry conditions when they can be inundated by estuarine water during king tides.

The wetland K5, in Riverside Park, was constantly saline; it appears to be tidal.

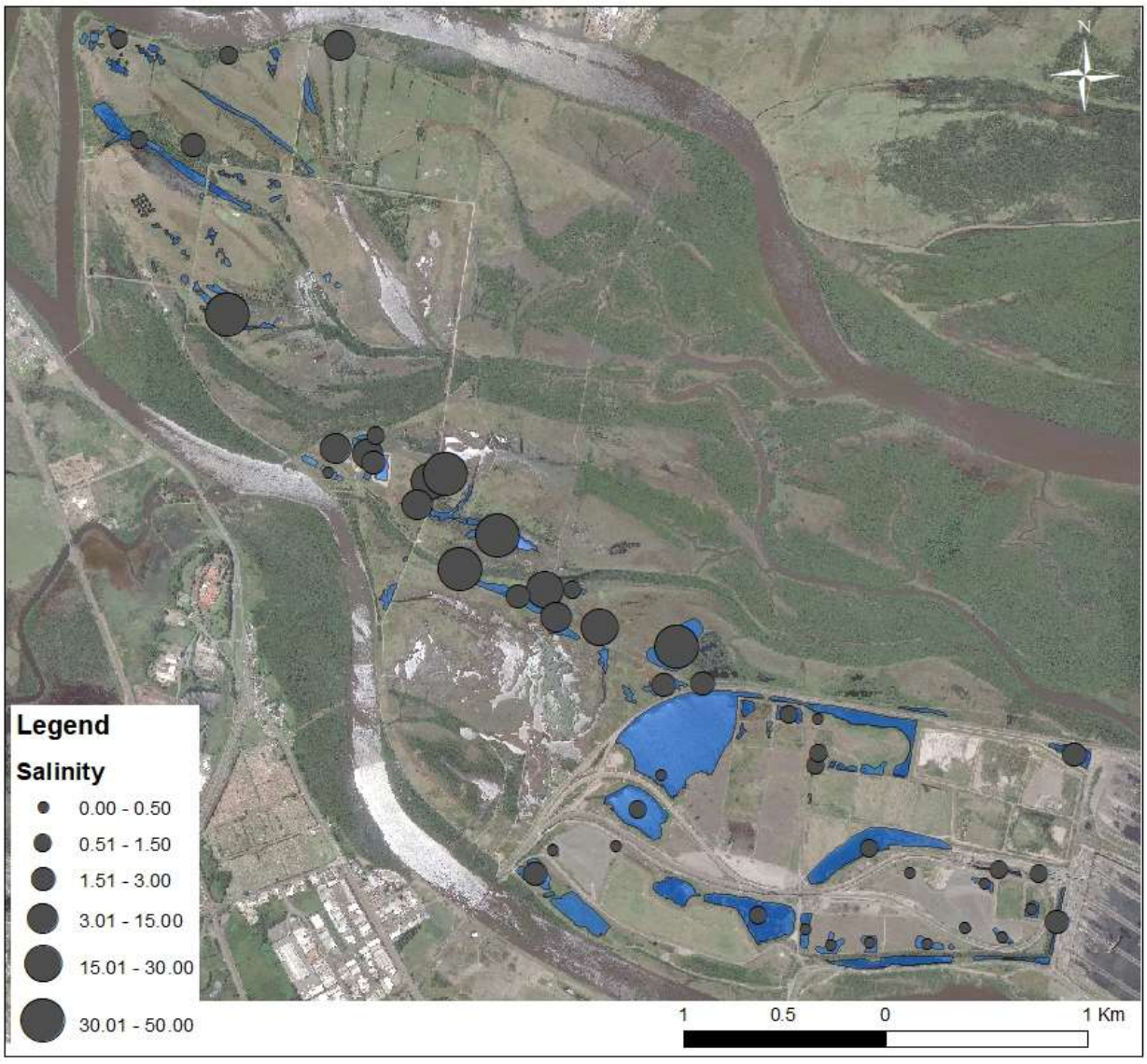


Figure 3.2.5: Maximum salinity levels (ppt) recorded across the 2018-19 survey season.

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, and hydroperiod is a key factor of that mosaic.

The scheme used here is based upon that used last year; the number and schema of categories is consistent, but the nomenclature of category '0' has been adjusted (Table 3.2.2). The number of categories reflects the aim of categorising wetland hydroperiod in a way that is relevant to understanding *L. aurea* ecology; a more 'coarse-grained' system (with e.g. three categories: ephemeral, semi-permanent, and permanent) does not appear to capture the complexities of habitat that we perceive in the course of field work. The 'finer-grained' categorisation used here has the advantages that:

- 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*.

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	2	Seasonal
K3	3	Semi-permanent
K4	2	Seasonal
K5	7	Saline (regular tidal)
K7	1	Temporary
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	5	Deep permanent
NCIG_T14	2	Seasonal
NCIG_T15	5	Deep permanent
BHP-1A	5	Deep 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	8	Saline (irregular)
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	5	Deep permanent
K103	5	Deep permanent
K105A	5	Deep permanent
K105AS	5	Deep 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	5	Deep permanent
K36	5	Deep permanent
C2	9	Managed
K115	9	Managed
K116	9	Managed
K100A	5	Deep permanent
K108	1	Temporary
K111	3	Semi-permanent
K112	2	Seasonal
K113	2	Seasonal
K114	3	Semi-permanent
K121	3	Semi-permanent
K122	3	Semi-permanent
K123	3	Semi-permanent
K46	3	Semi-permanent
K49B	4	Nearly permanent
K117	5	Deep permanent
K118	4	Nearly 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 and 2018-19 (drought years) (Table 3.2.3, Figure 3.2.6, Figure 3.2.7).

Figure 3.2.6: Hydroperiod scores for wetlands across the Northern and Central zones of Kooragang Island, updated using information from the 2017-18 survey season. See text for explanation of categories

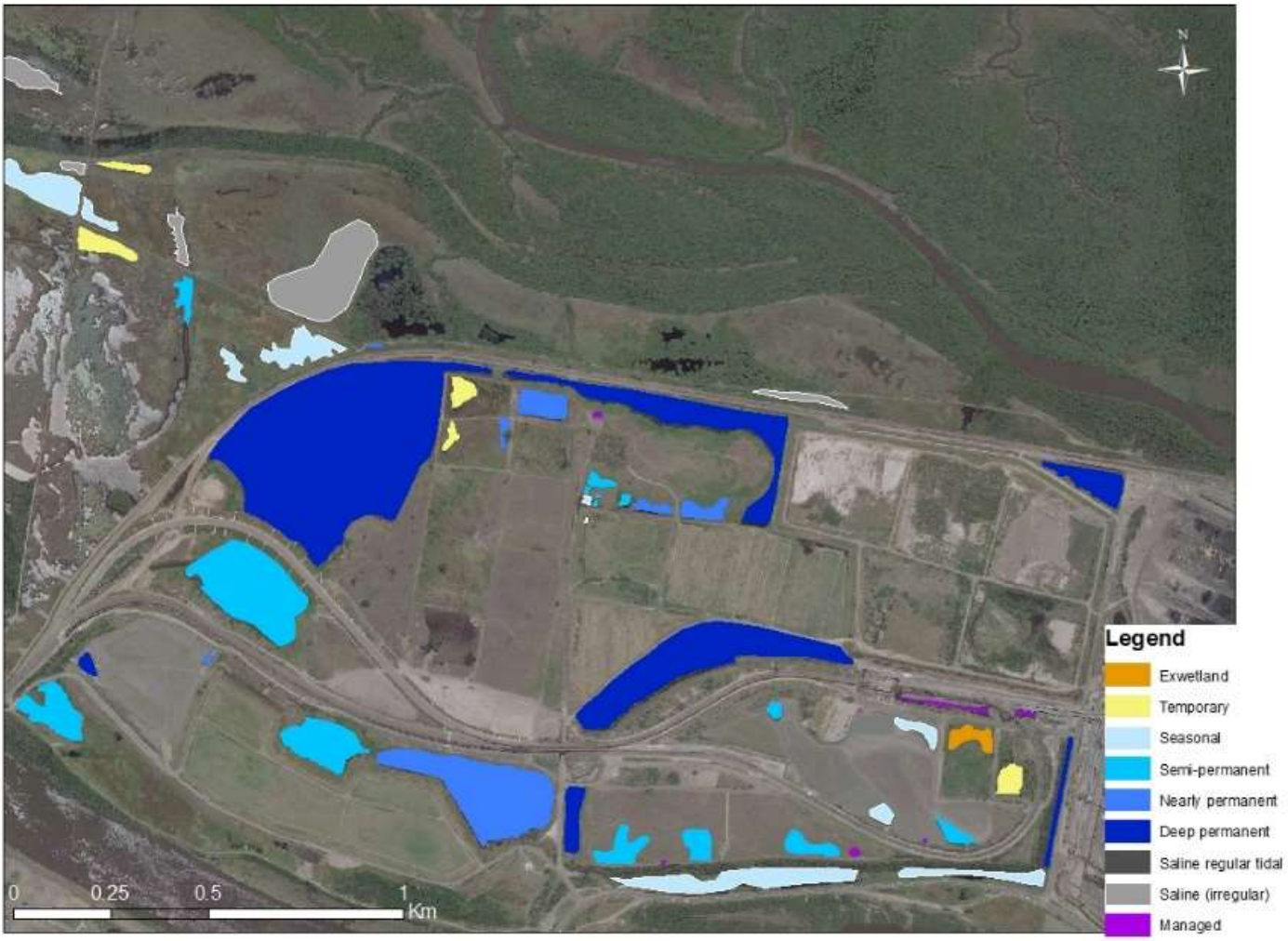
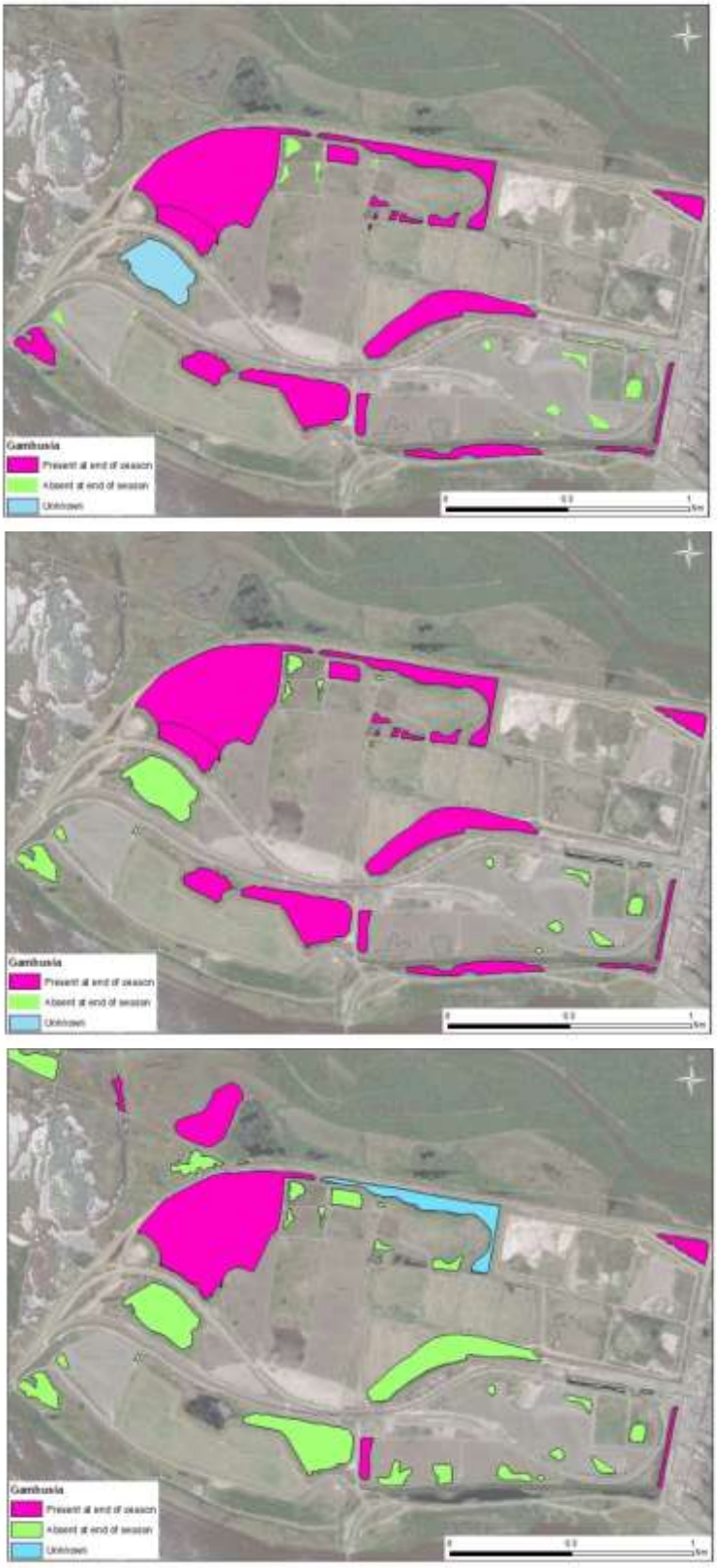


Figure 3.2.7: Wetland hydroperiod in the Southern part of Kooragang Island. See text for explanation of categories. Note the diversity of hydroperiod categories for wetlands around K29 and the Rail-loop (c.f. habitat mosaic)

Gambusia



The 2018-19 season was the third year of lower than average summer rainfall. The repeated and incremental cycles drying and recharging of wetlands has gradually removed *Gambusia* from much of the system. Across Kooragang Island, the number of wetlands with *Gambusia* present has declined from 65 in March 2016 to 13 in March 2019 (Table 3.2.1). Within the Industrial Zone, only 13 wetlands were free of *Gambusia*; by March 2019 that number had increased to 25 and *Gambusia* was detected in only 6 wetlands within that zone (K104, K105A, K103, K42, K102, and K100A).

Although *Gambusia* was present, its numbers were very low at K105. This low density of the fish seems to have been a factor in the breeding event detected there in the first half of the 2018-19 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 of 2016 (top), 2017 (middle), and 2018 (bottom). After extensive infestation in 2015 following heavy summer rains, two consecutive dry summers eliminated *Gambusia* from most wetlands.

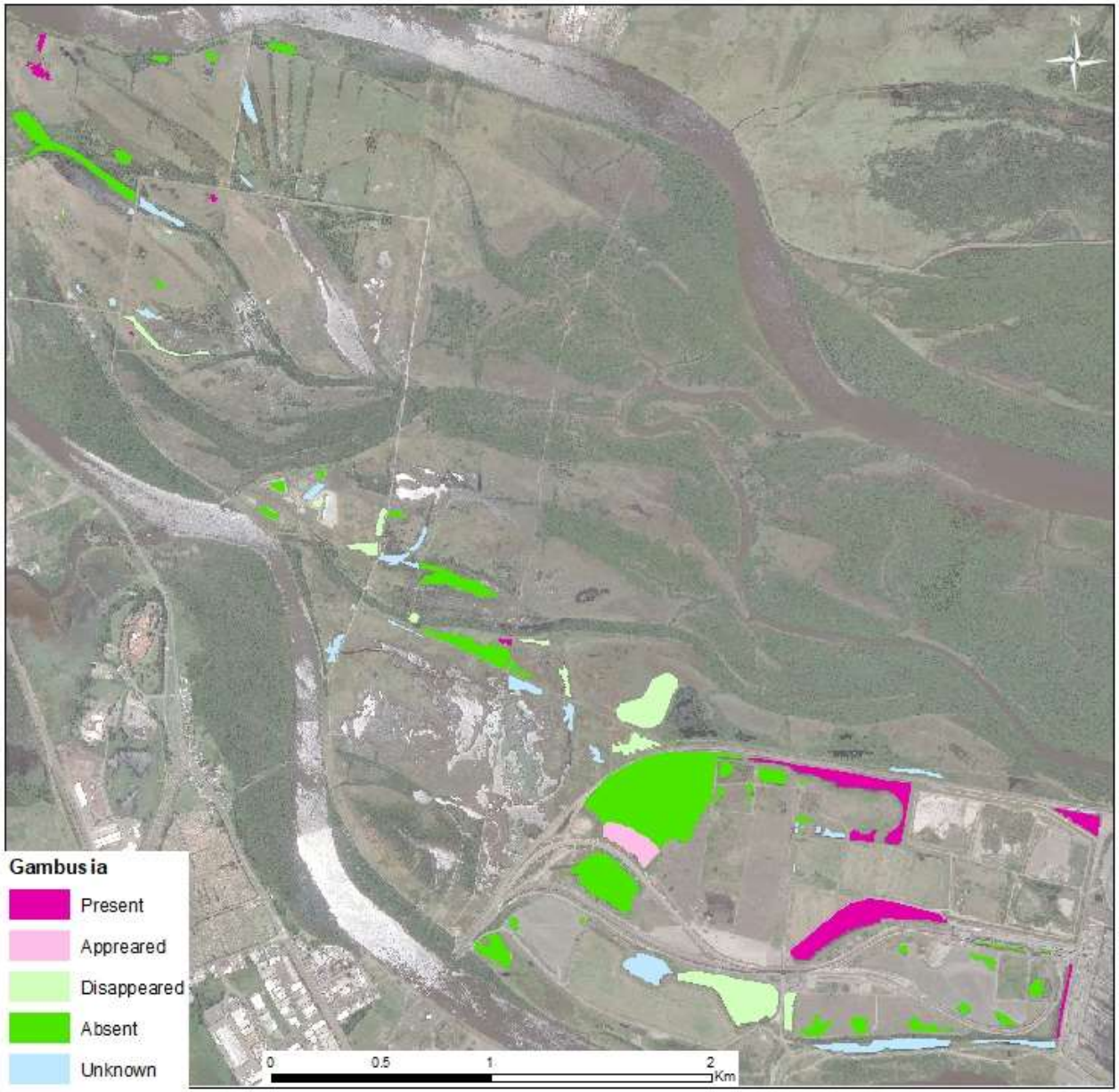


Figure 3.2.9: *Gambusia* distribution across the southern wetlands. Wetland scored as 'disappeared' are mostly those that dried during the season.

Note that the data for K105A shows very low densities of *Gambusia* in the southern part; *Gambusia* was not detected in the northern part but these parts are connected and *Gambusia* must have been present at very low densities across all of K105A in the early part of the season. K105A dried out during May 2019 so *Gambusia* may have been completely eliminated from that wetland.

For those wetlands that could not be surveyed in Round 3 (due to the Industrial Zone ground fire), Gambusia distribution is inferred based upon (1) status in Round 2, (2)

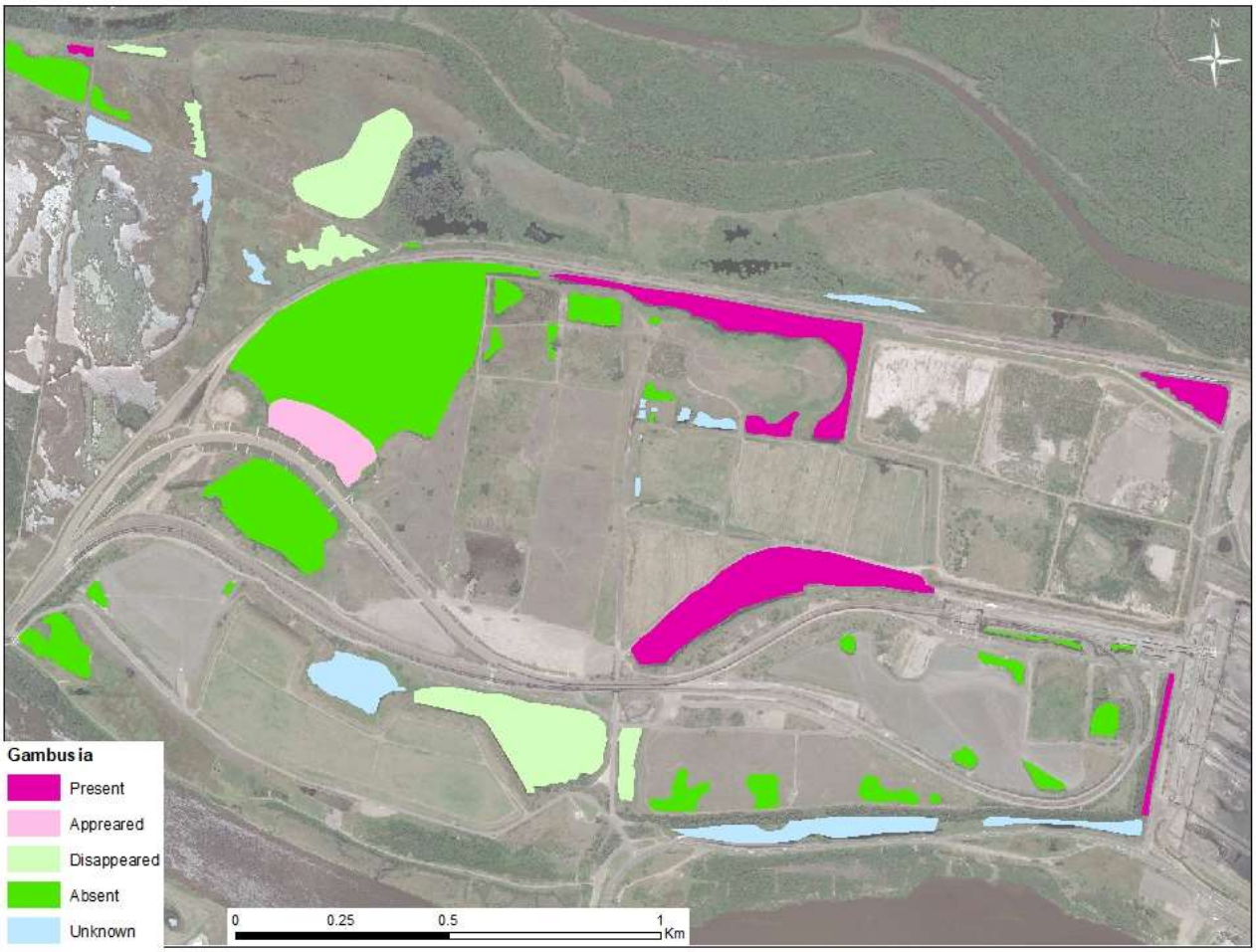
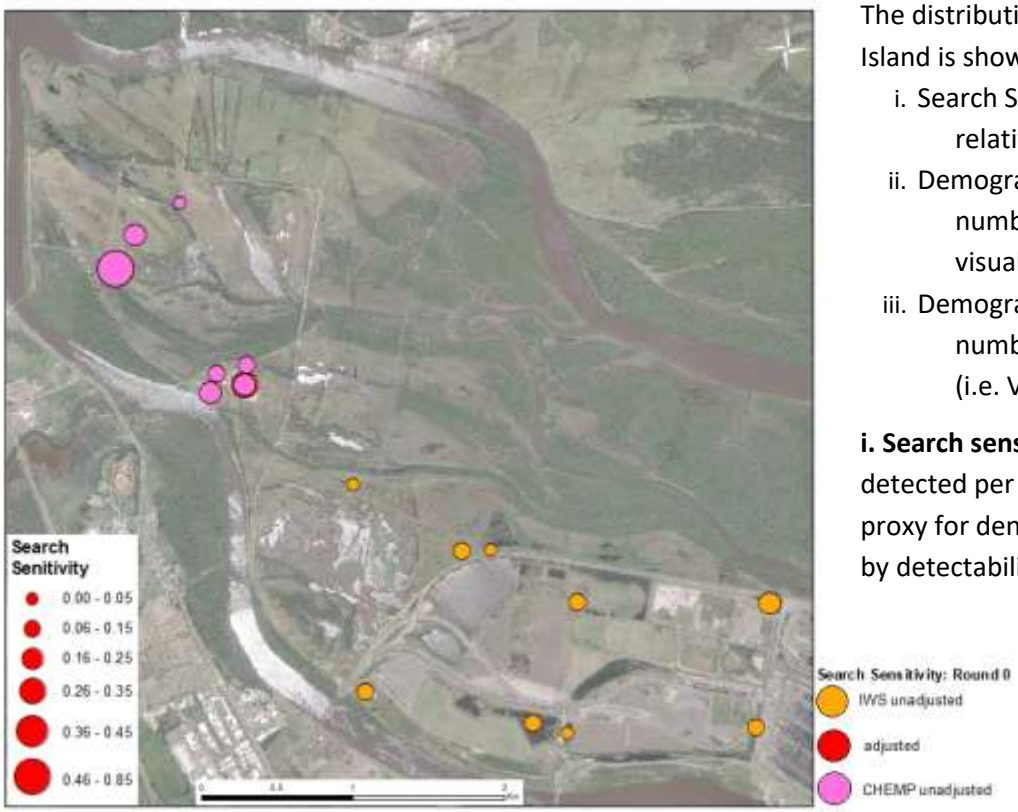


Figure 3.2.10: Gambusia distribution for the wetlands around the Industrial Zone; see Figure 3.2.9 for explanation.

3.3. Distribution of *Litoria aurea* across Kooragang Island



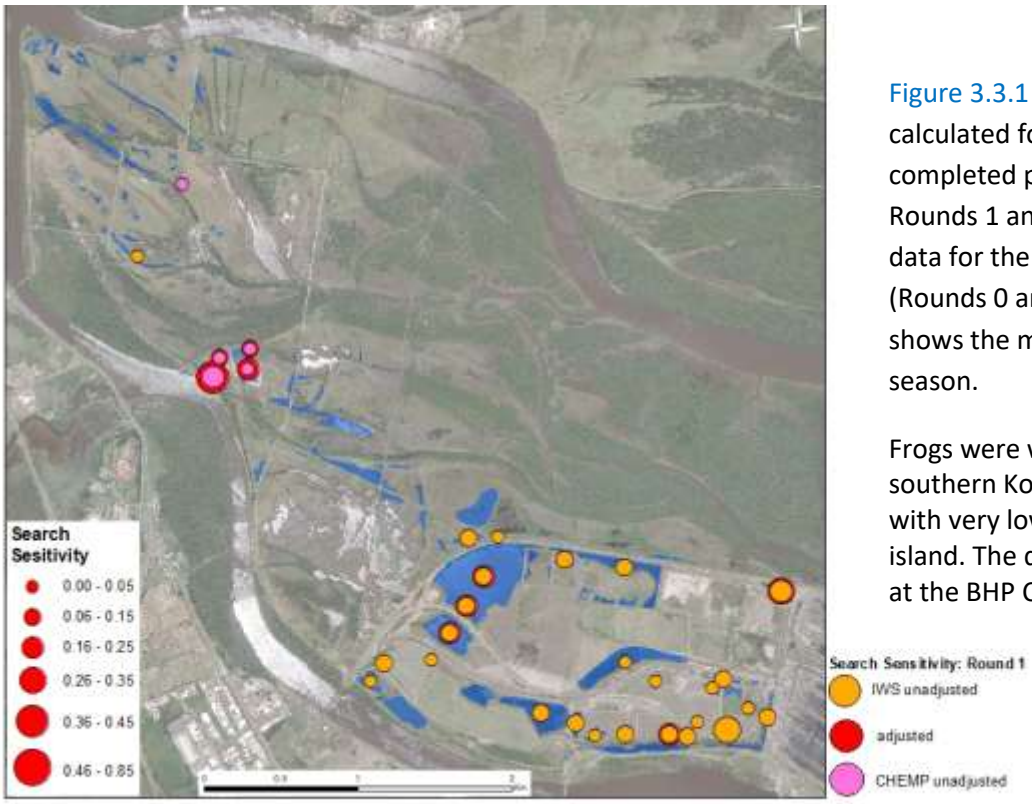


Figure 3.3.1: Search sensitivity (frogs detected per person.minute) across the 64 wetlands surveyed as part of 'whole island' monitoring in 2018-19, for Round 0 (September 2018) and Round 1(October 2018). Data is for **primary** VES surveys only. See caption of Figure 3.3.3 for explanation.

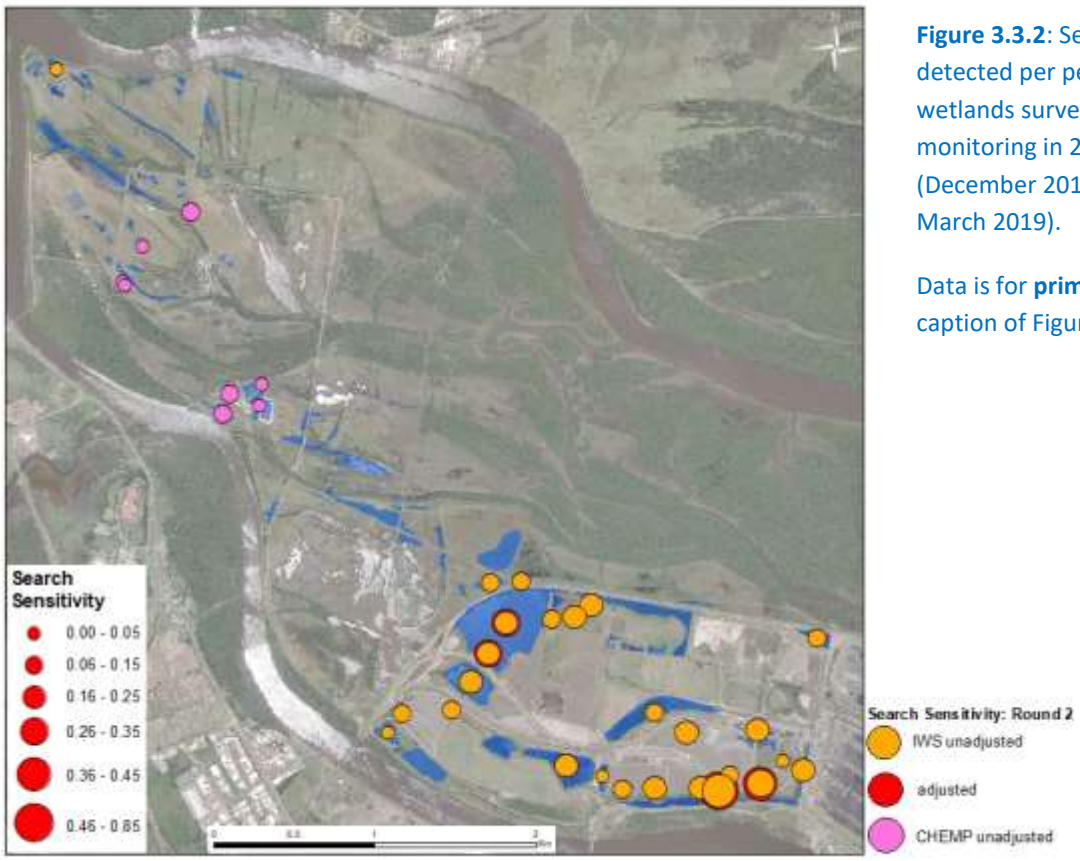
The distribution of *L. aurea* across Kooragang Island is shown using:

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 2 completed principal survey rounds (i.e. Rounds 1 and 2). Figure 3.3.2 shows the data for the two 'incomplete' rounds (Rounds 0 and 3), whilst Figure 3.3.23 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.



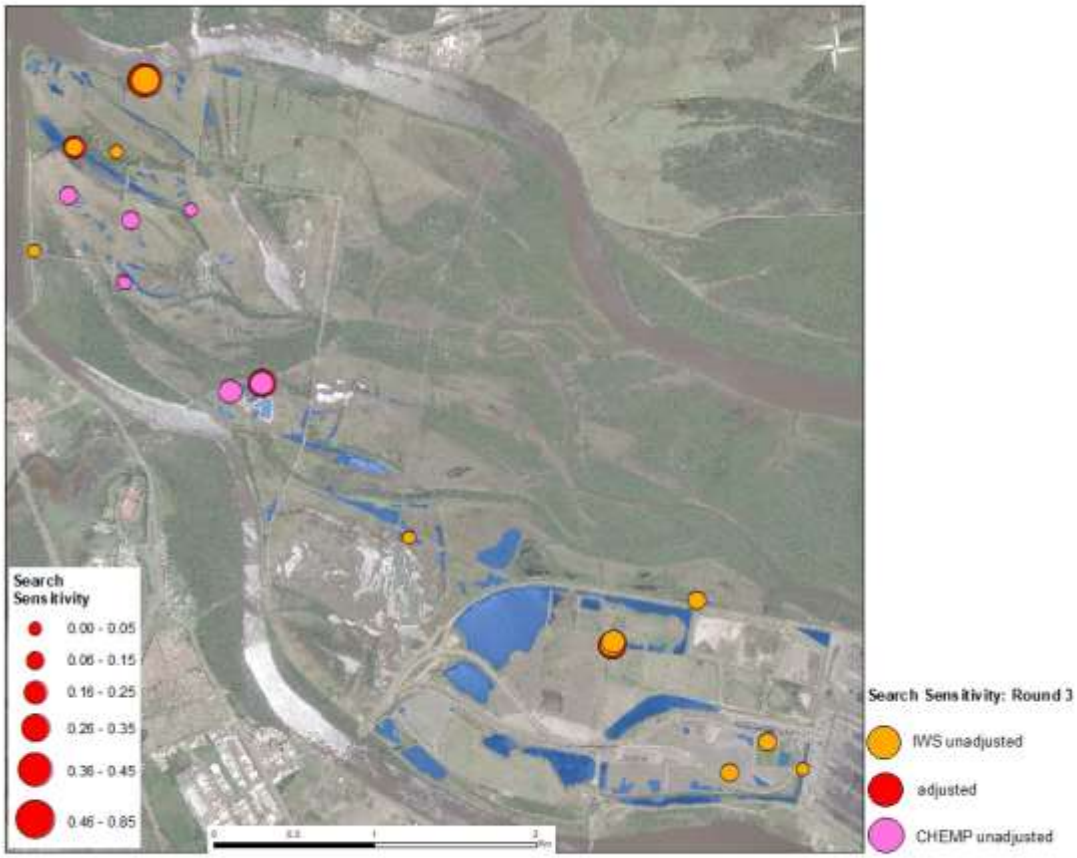


Figure 3.3.2: Search sensitivity (frogs detected per person.minute) across the 64 wetlands surveyed as part of 'whole island' monitoring in 2018-19, for Round 2 (December 2018) and Round 3 (January-March 2019).

Data is for **primary** VES surveys only. See caption of Figure 3.3.3 for explanation.

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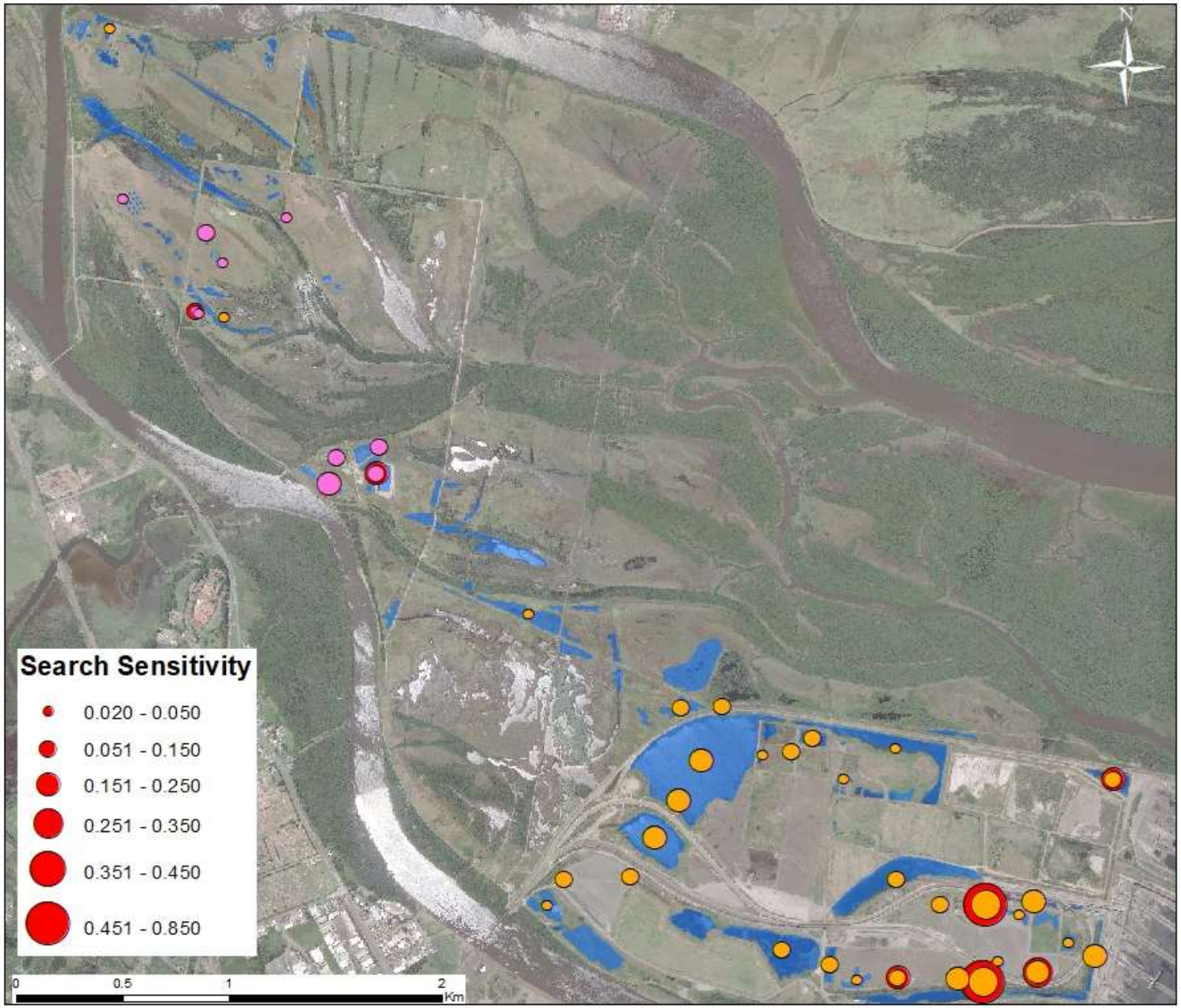


Figure 3.3.3: Search sensitivity (frogs detected per person.minute) across the 64 wetlands surveyed as part of 'whole island' monitoring in 2018-19, pooled across the principal survey rounds.

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

Note that the CHEMP wetlands shown here are only those included in the Save Our Species (SOS) and Island-Wide 2018-19 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).

ii. Demographic plots (Figures 3.3.4-3.3.8) 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. VES surveys are standardised, timed surveys of each wetland, but 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, and those detections are also shown in these figures.

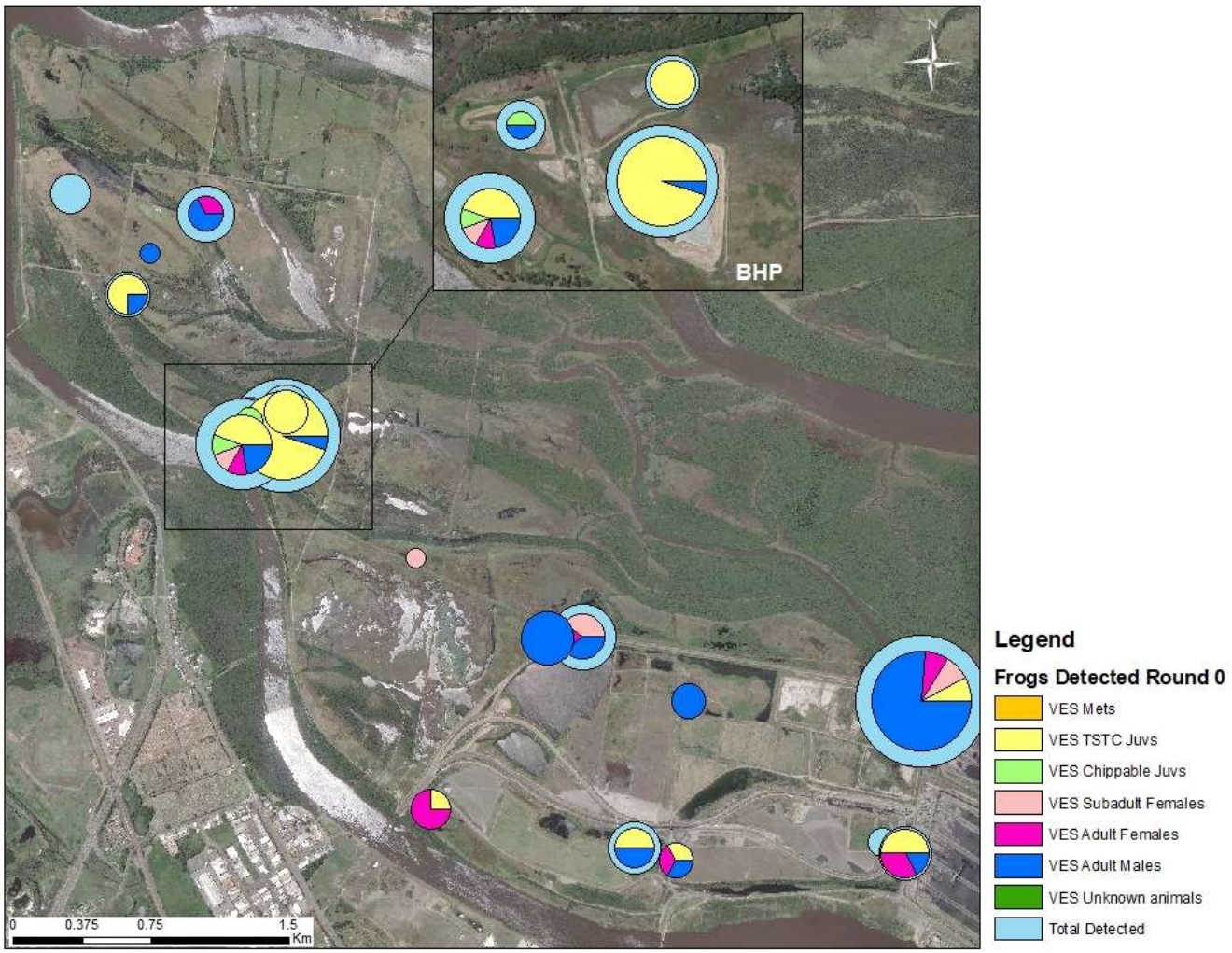


Figure 3.3.4: Demographic breakdown of frogs detected during Round 0 in September 2018. **Total Detected** is shown but only VES were conducted during this round (at a subset of at 30 wetlands across the island). Note that where surveys are primarily visual (rather than capture), it is difficult to distinguish between subadult and adult females and so these categories are grouped together. See Figure 3.3.5 caption for explanation of demographic categories.

Round 0 (early September): This was a 'partial' survey of 30 wetlands. Immediately before the start of this round there was early spring rainfall (~70 mm in 14 days) which almost fully recharged the system. Across the Industrial Zone, calling was heard from K105A, K105B, and K104 (note that K105A and K105B were not directly surveyed in this round), but no large chorusing was detected. Adults detected were predominantly males in K22, K23, K34, K104, and K49B; K100A and K46 had higher proportions of females. We found juveniles in K104, K100A, K36, K49B, NCIG_7.1 and especially BHP-1A; these were presumably *L. aurea* that were spawned during the autumn rain event in autumn 2018, having overwintered as tadpoles.

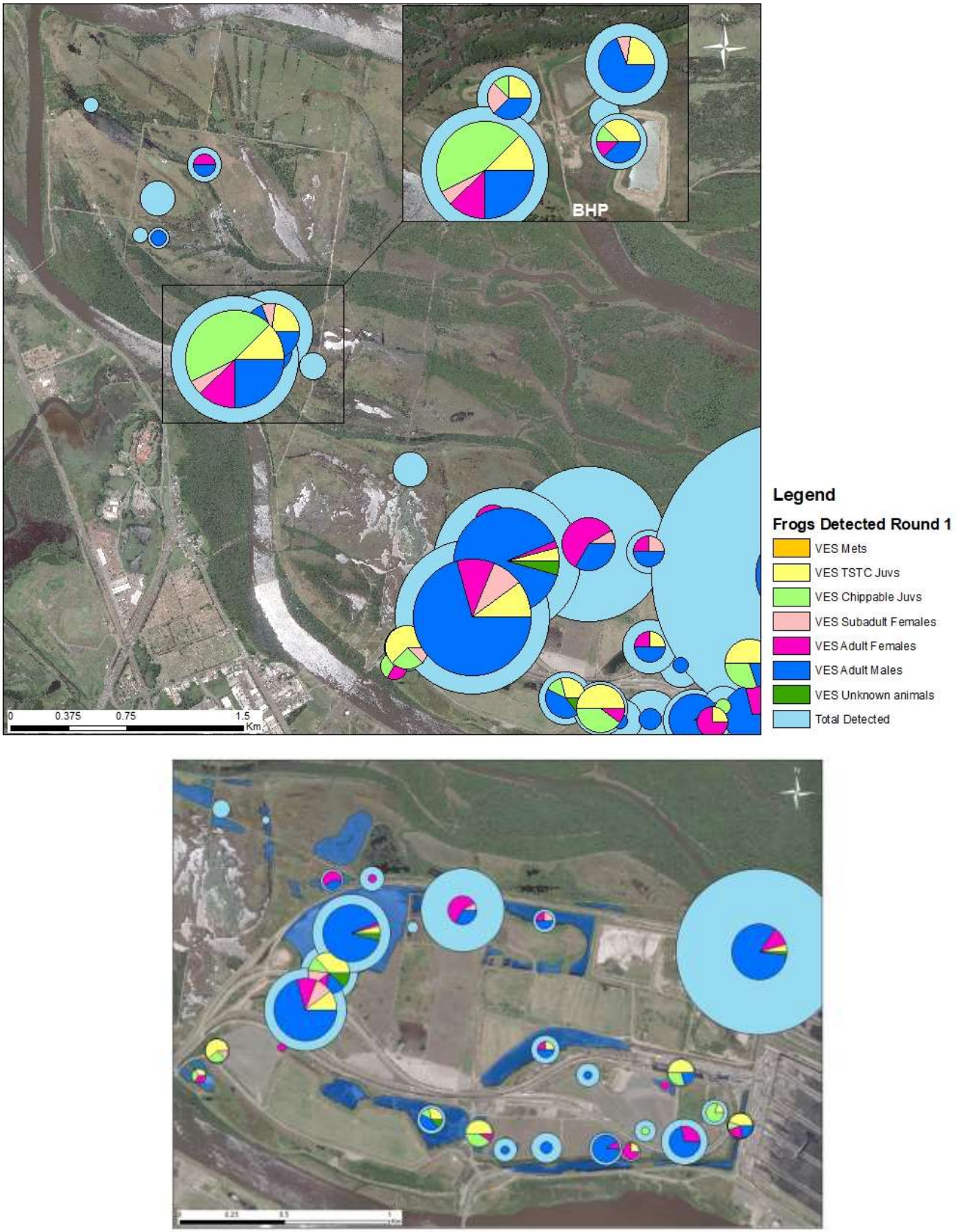


Figure 3.3.5: Demographic GIS plots for Round 1. 'Total detected' denotes animals that were detected during CMR and non-primary VES surveys. Breakdown into demographic groups is based upon data taken from frogs captured during VES surveys only. TSTC = 'Too Small to Chip', i.e. juveniles <40 mm SVL; 'Chippable Juvs' are juveniles that are >= 40 mm SVL. 'VES unknown' are animals detected during VES but not captured or readily identifiable as juveniles/adults. Upper map shows whole island, lower shows Industrial Zone.

Round 1 (Early October – early November 2018) commenced immediately during a large rainfall event (>100 mm in 7 days, from the 5th-11th October). Large numbers of males were detected, with widespread calling at multiple wetlands and very large chorusing at K105A, K105AS, and K105B in particular.

Within the Industrial Zone, small juveniles (indicated by 'TSTC'- too small to chip – in Fig. 3.3.5) were detected in K105A, K105AS, K105B, K117, K46, K49B, K36, K115, K108, K100A, and K104; these may have been spawned during the rainfall event in early September or may have overwintered as tadpoles. As juvenile *L. aurea* move readily across the landscape (unpublished data), their presence of does not necessarily indicate breeding at those wetlands but it does indicate suitable habitat for young animals. The presence of juveniles at K36, K115, K108, and K100A is of interest as these wetlands are not thought to be used for breeding by *L. aurea* in recent years; if that is the case, then they evidently provide suitable habitat for frogs spawned elsewhere (in the case of K115, K108, and K100A, it is presumed that the juveniles encountered include animals spawned in K111 and K114, which have consistently had breeding events over the previous three seasons).

The very large numbers of males detected at K105A contrasts with the high proportion of adult females detected at K29 nearby. This may indicate different spatial use of breeding vs refuge wetlands immediately following spring rains. The other wetlands with a high proportion ≥50% of all adults) of adult females were C2, K118, K46, K22, K23, K100A and K113.

Round 2 (late November 2018 – early January 2019): This round also started with a rainfall event (50 mm in 3 days); calling was widespread for the following two weeks, although chorusing to the level heard in the October round was not detected. Wetlands were well charged, and appreciable numbers of both small juveniles and metamorphs were detected across the Industrial Zone, particularly in K105A but also in K105AS, K105B, K29, K104, K102, K49A, K122, K123, K111, and K114. The presence of both metamorphs and small juveniles in large numbers strongly suggests successful breeding at these wetlands, although both small juveniles and metamorphs can move from their natal ponds to nearby wetlands and so small numbers of these at a wetland do not necessarily indicate that breeding took place at that wetland. In the case of K105A, the numbers of each were so large that there can be little doubt that a very large breeding event took place in Deep Pond in spring 2018. Given the timing of the Round 2 surveys, it is possible that the metamorphs detected where spawned in the early October rain event, whilst larger juveniles may have been spawned in early September.

Small juveniles, but no metamorphs, were detected at K36, K121 and C2. Of these, only K121 has previously had a confirmed breeding event; K36 at that time (December 2018) was infested with *Gambusia*, and in the case of C2 there was no indication of breeding during October. The large number of small juveniles detected at C2 were likely *L. aurea* who were spawned in the nearby wetlands, K123, and also K121, K122, and K112. Unlike K121-123, C2 is well vegetated and may provide important microhabitat for newly metamorphosed frogs. Note that this wetland has also held consistent numbers of large adults through the previous season and this pattern continued into the 2018-2019 season.

Unless present in very high numbers, it is not possible to interpret the presence the of medium and large juveniles as indication of breeding at a wetland but their presence does indicate suitable habitat for young *L. +aurea*. The presence of medium and large juveniles at K105B, K49A, K36, K21, C2, K29, K104, K10, K108, K115, and K100A in Round 2 nevertheless indicates successful recruitment within the Industrial Zone prior to the early October rain event; either in the early September rain, or even in late autumn of the previous season. Within the rail loop (*K10 North*), K115, K100A and K108 appear to provide suitable habitat for juvenile *L. aurea* spawned elsewhere, as there has been no evidence of breeding in those wetlands for several years; presumably the juveniles encountered include animals spawned in K111 and K114, which had breeding events in Sspring 2018.

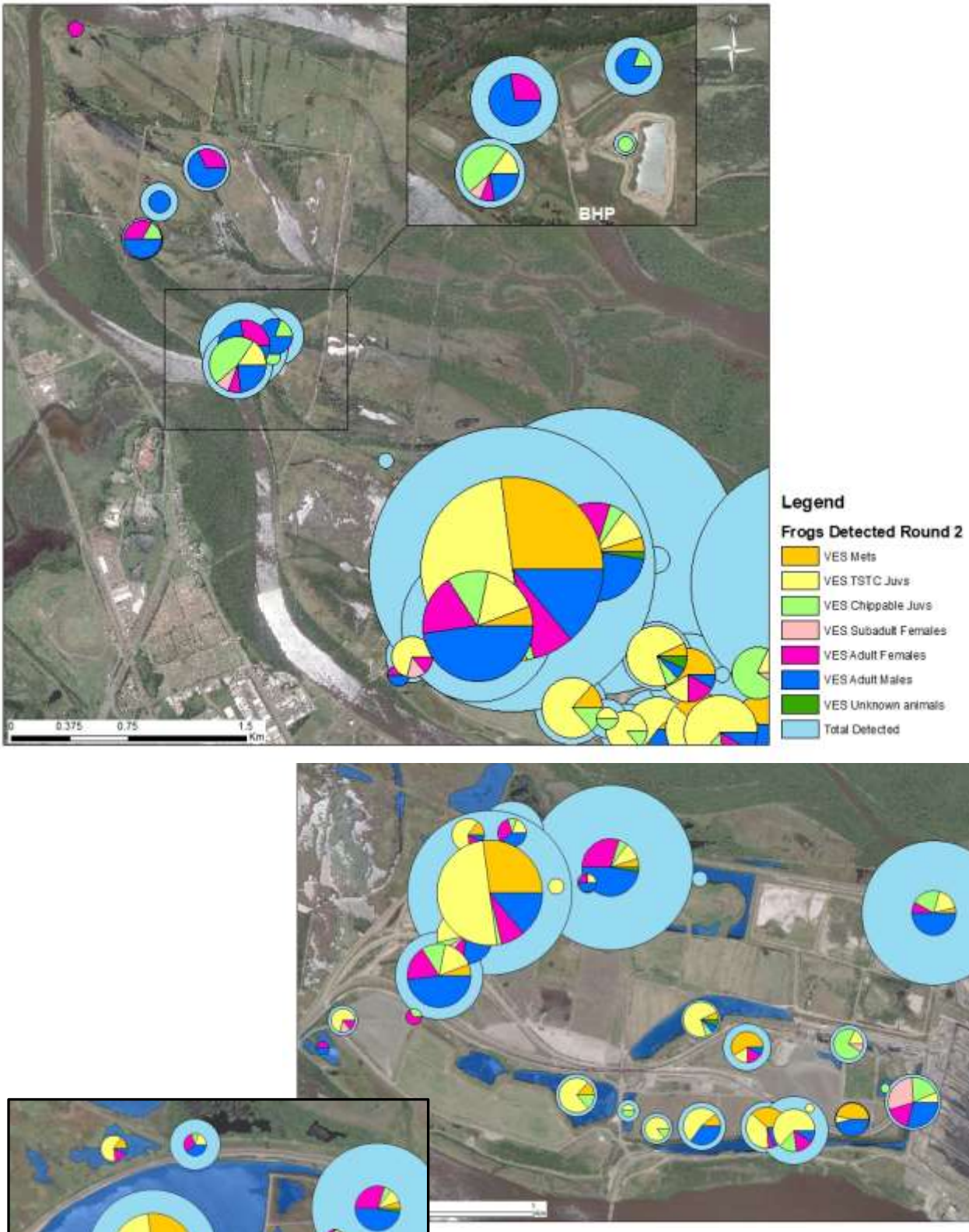


Figure 3.3.6: Demographic GIS plots for Round 2. Upper map shows northern part of island, island, lower-mid shows Industrial Zone, lower left shows close up of wetlands around Deep Pond (K105A, K105AS, K105B, K106A-C, K29). See Figure 3.3.4 for legend.

Within the Central Zone, K22 and K23 also contained small juveniles and metamorphs, and breeding apparently occurred within or close to these wetlands (note that K105A is very close). Along Bellfrog Way, only one *L. aurea* (a juvenile) was detected on the road at K13. In contrast, the BHP_CHEMP wetlands had a very large number of *L. aurea*, including large numbers of juveniles (note that the study from which the BHP_CHEMP data are taken has ethics clearance to tag even small juveniles, so these are not distinguished in Figures 3.3.4 - 3.3.8), and there was clearly a large breeding event in those wetlands during the spring.

In the Northern Zone of the island, juveniles were also detected at NCIG_7.1 during this round, whilst adults were present at K3, NCIG_5.1, and NCIG_4.9.

Round 3 (late January – mid March 2019): This survey round was significantly disrupted by a grass fire that burnt through the Central and Industrial zones in early January 2019, with a subsequent ground fire that burnt within the Industrial Zone through until May. Very high summer temperatures combined with low rainfall between mid-December to mid-March resulted in many wetlands drying out completely, and by early March only a handful of wetlands in the Industrial Zone (K105A, K117, C1, C2, K100A) contained any water. This was the most pronounced dry spell in the experience of the current survey team, even though it followed two previous seasons that had lower than average rainfall; even K36, which has always held water in previous season, appears to have dried out complete during early March 2019.

Due to the ongoing ground fire we were not able to survey K105, K106, K29, C1, K31, K34, K42, K102, K22, or K23, although some *L. aurea* were detected at some of those wetlands during inspections for fire damage (Figure 3.3.7).

Adults and juveniles were detected at K46, K118, K49B, K36, K121, K122, and K123, although in low to moderate numbers. Larger numbers were detected at K115, K100A, K104, and especially C2. The C2 clusters in particular were one of the few wetlands containing deep water; they were designed to be managed during extending dry periods and can be topped up without too much difficulty and this, combined with good vegetation structure (*Acacia* and *Lomandra*) around the ponds appears to have made them an effective habitat during this dry summer. The C1 clusters were extensively damaged during the January fire; all the terrestrial vegetation was burnt, as well as large parts of the aquatic vegetation, but *L. aurea* was present even after that damage.

In the Central Zone, large numbers of frogs were detected at the BHP_CHEMP wetlands during CMR surveys, despite the fire damage to terrestrial vegetation through that region. In the Northern Zone, NCIG_4.9 and NCIG_7.2 still contained water in late February and more frogs were detected at these wetlands in this round than in any of the previous rounds.

Total Detected: Figure 3.3.7 shows all detections of *L. aurea* detected, pooled across all surveys; another version of this is shown in Figure 4.4.1). It highlights the large numbers detected during CMR surveys at K29, K104, and the BHP_CHEMP wetlands (shown as the difference between the 'Total Detected' and the demographic pie plots). Within the Industrial Zone, it also highlights the breeding events (as large values for metamorphs and small juveniles detected), particularly at K105A, K105AS, K105B, K111, K114, and K123. The numbers of small juveniles at C2 is also apparent.

Within the Central Zone, large numbers of *L. aurea* were detected across the season in the BHP_CHEMP wetlands, but numbers along Bellfrog Way were low. In the Northern Zone, the number of detections was greater than in recent seasons.

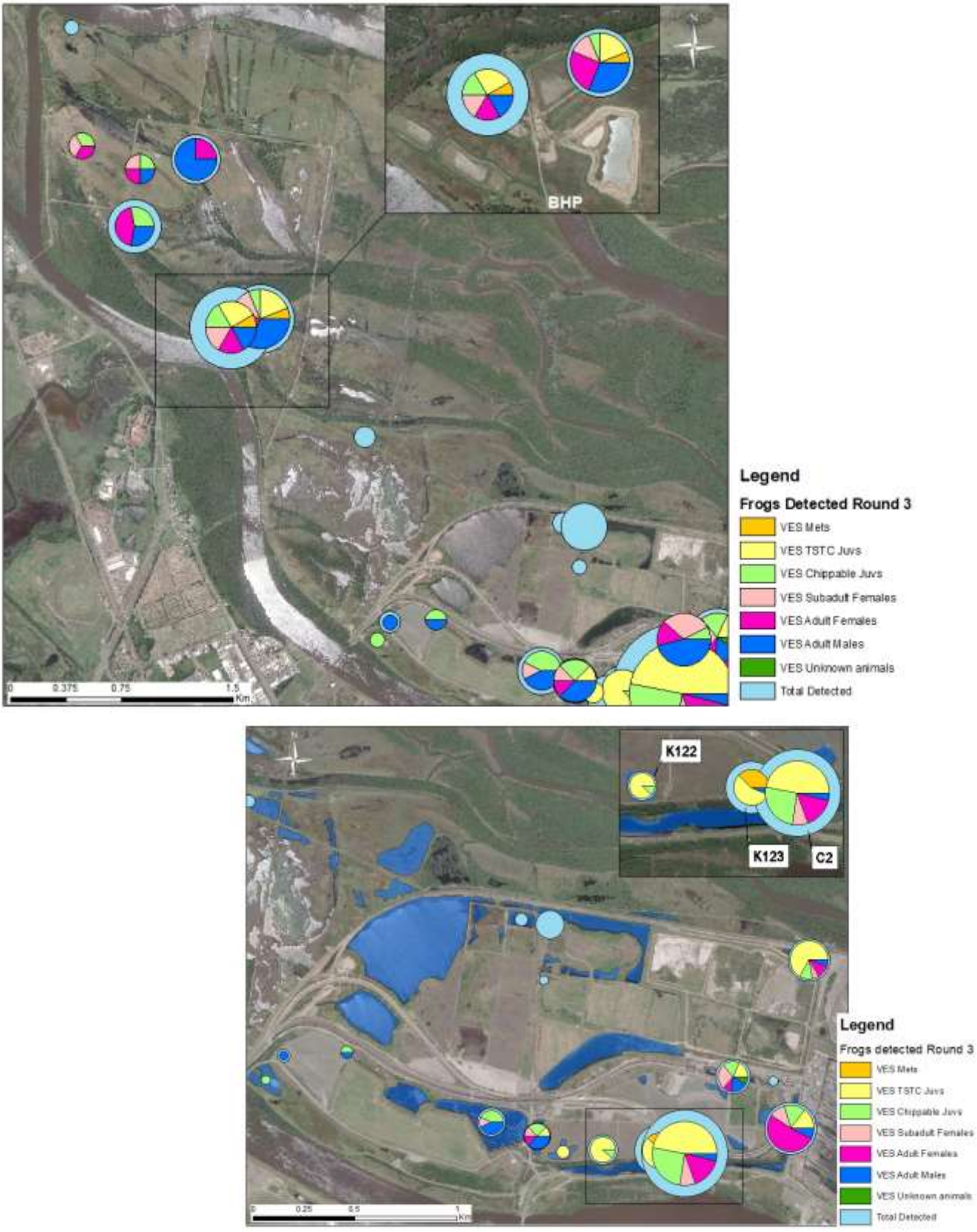


Figure 3.3.7: Demographic GIS plots for round 3. Upper map shows northern part of island, lower shows southern part. See Figure 3.2.4 for explanation of demographic categories.

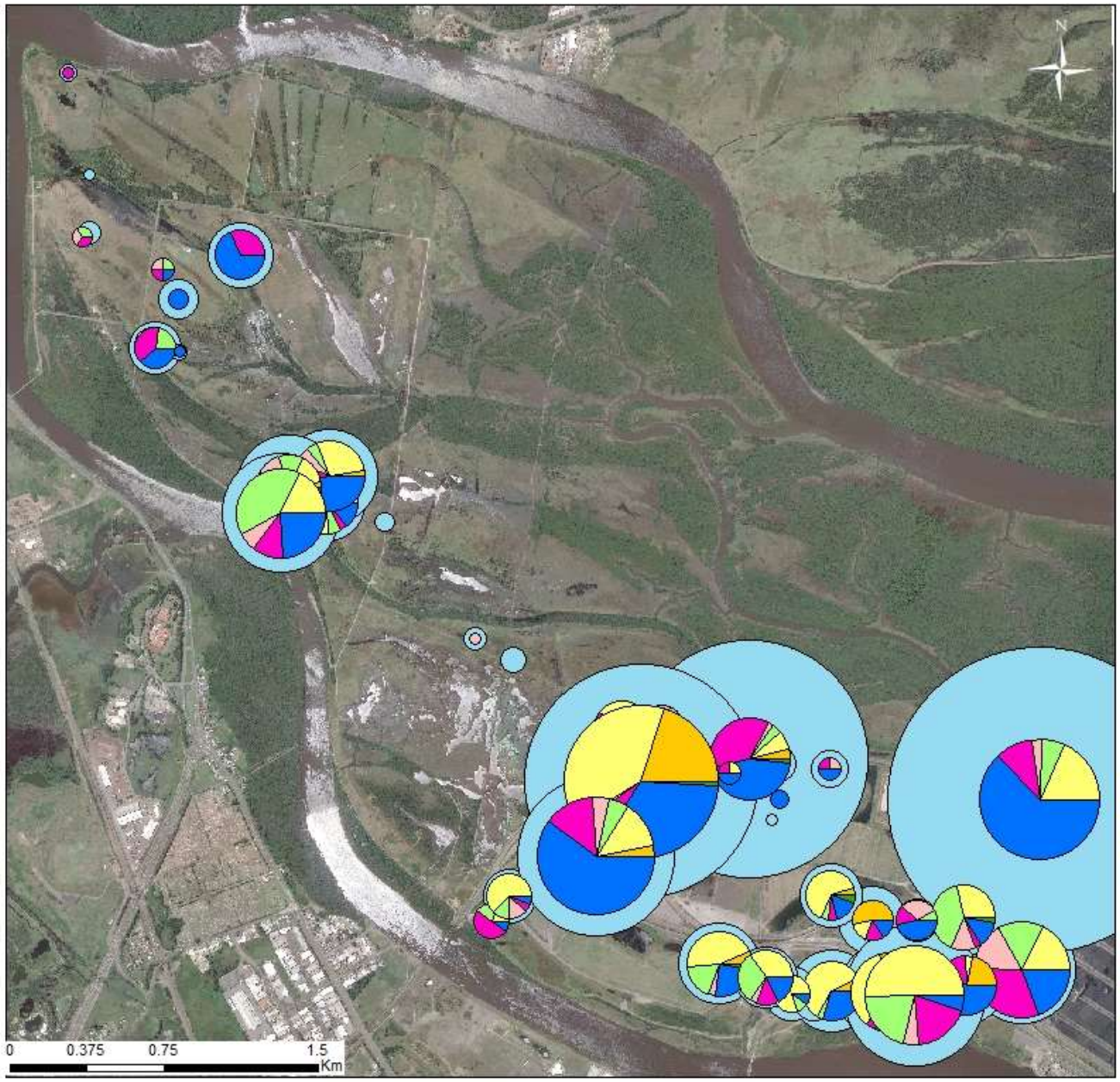
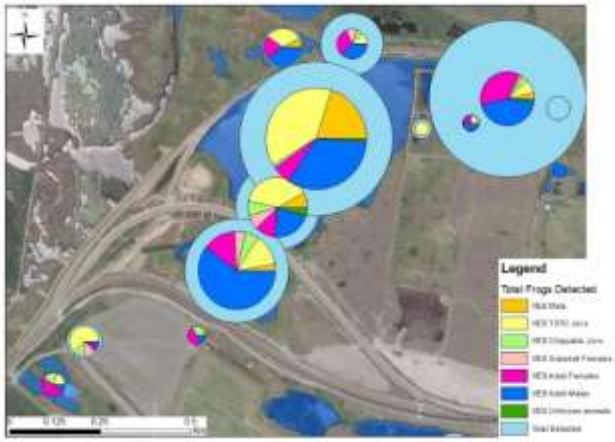


Figure 3.3.8: Demography of all detected frogs during the 2018-19 surveys, summed across all survey rounds. Close-ups on the right show (from top) the Deep Pond/K29 area (NW Industrial Zone), K104 (NE Industrial Zone), and the Rail Loop (SE Industrial Zone).



Legend

Total Frogs Detected

- VES Mets
- VES TSTC Juvs
- VES Chippable Juvs
- VES Subadult Females
- VES Adult Females
- VES Adult Males
- VES Unknown animals
- Total Detected

3.4. Demographics

Proportions of juveniles, adult males, and adult females

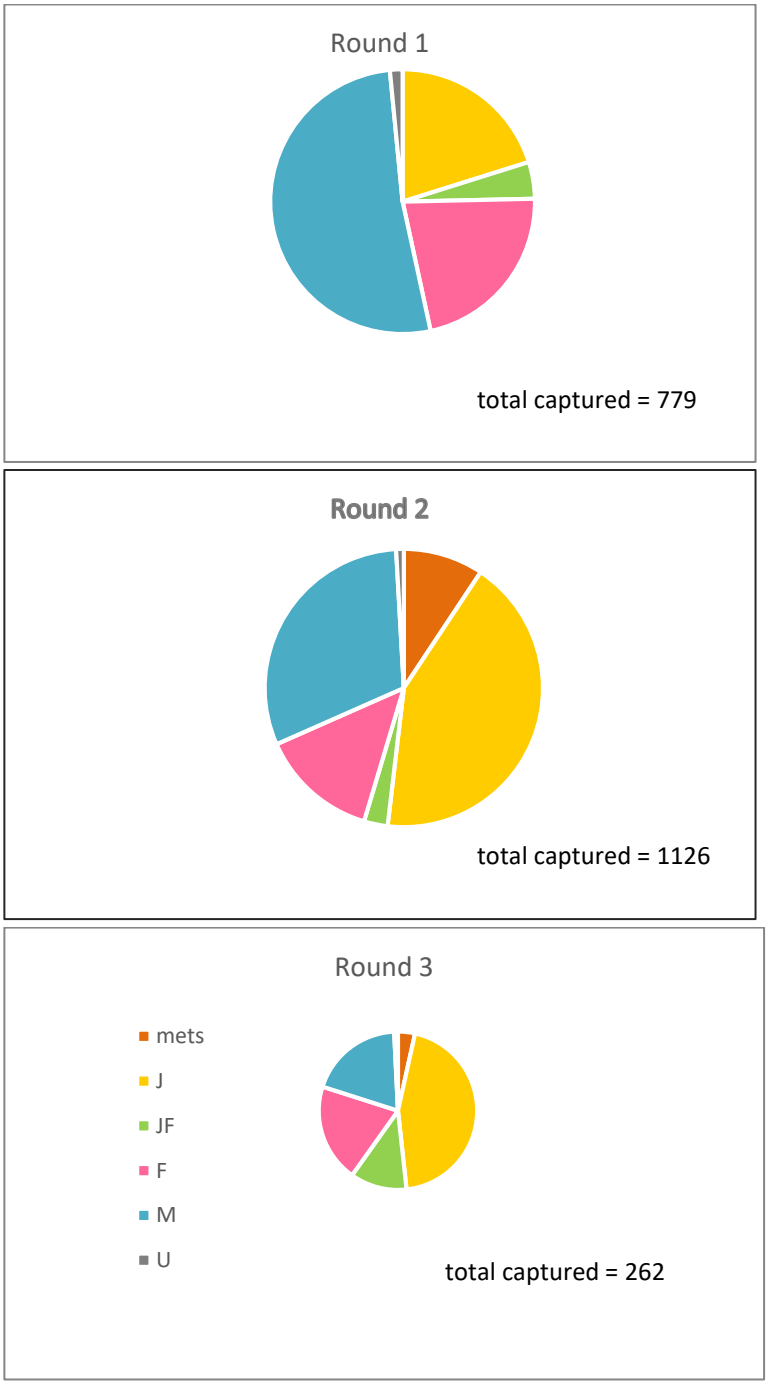
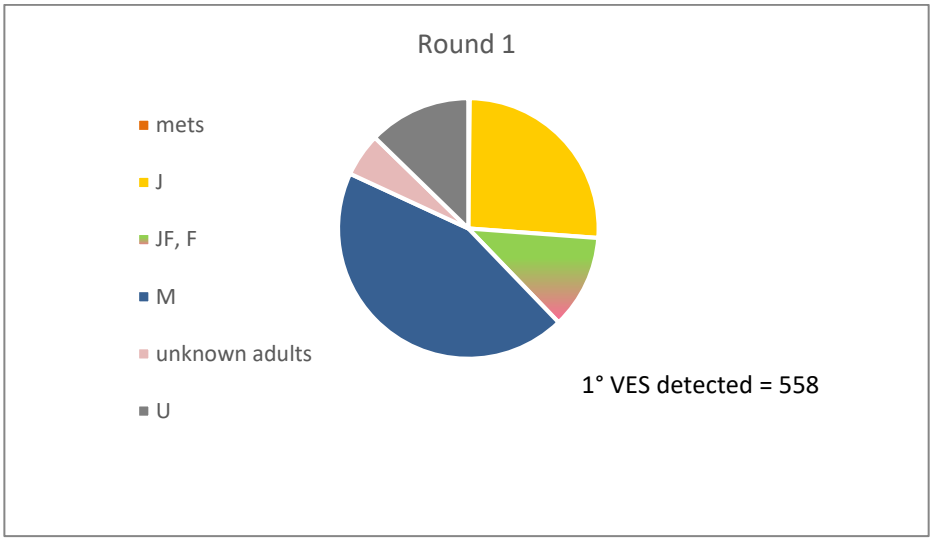
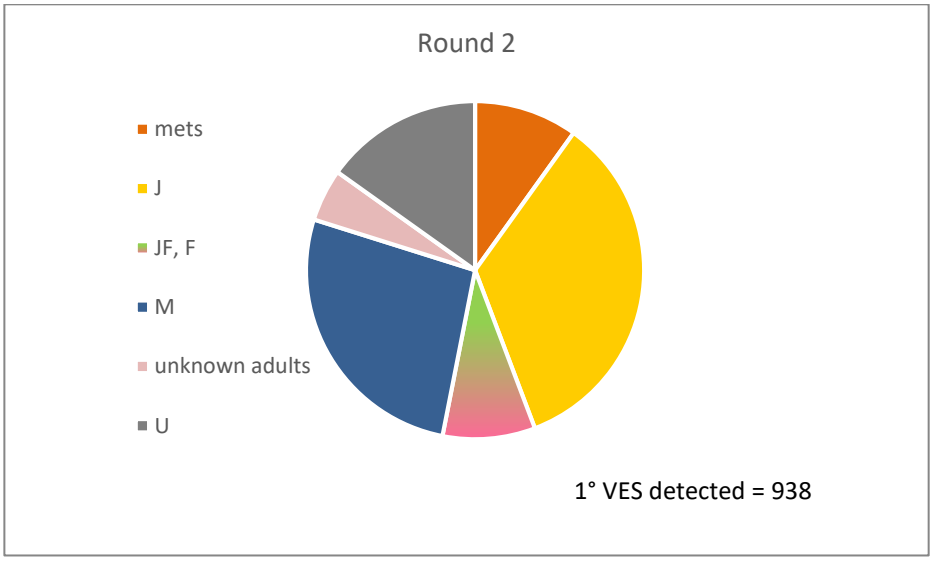


Figure 3.4.1: Summary demographics of all captured *L. aurea* (i.e. VES and CMR, including recaptures and non-tagged individuals), by round. Mets, metamorphs; M, adult males; J, juveniles; JF, subadult females; F, adult females; U, animals of unknown demography.

Figure 3.4.1 presents the demographic data in the preceding section, summarised for **captured** *L. aurea* across all wetlands, whilst Figure 3.4.2 shows the data for VES **detections**. Overall, the highest numbers of *L. aurea* were captured in round 2; the large numbers of juveniles and metamorphs (together, more than half of all captures) highlights the significant breeding event in the early part of the season.

VES Demographics





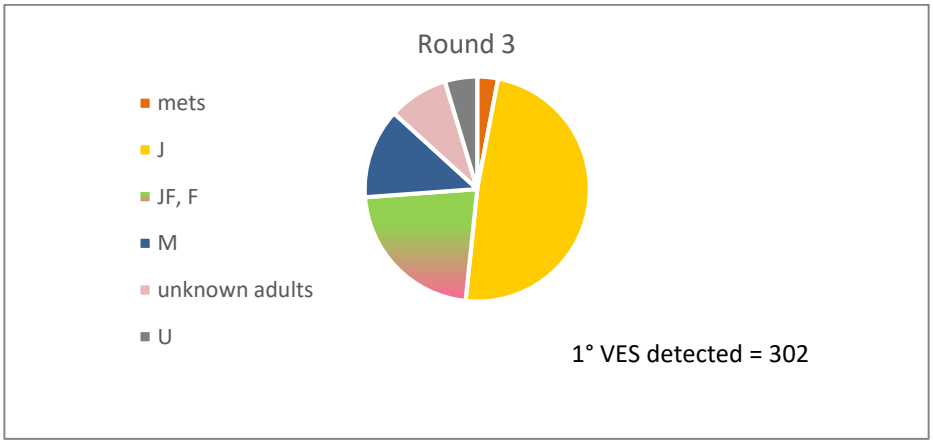


Figure 3.4.2: *L. aurea* detected during primary VES only, by round. M, adult males; F, adult females; JF, subadult females; J, juveniles; mets, metamorphs; unknown adults, *L. aurea* for whom demographic data was not collected. (note that for these counts, subadult females and adult females are counted together).

Unique individuals

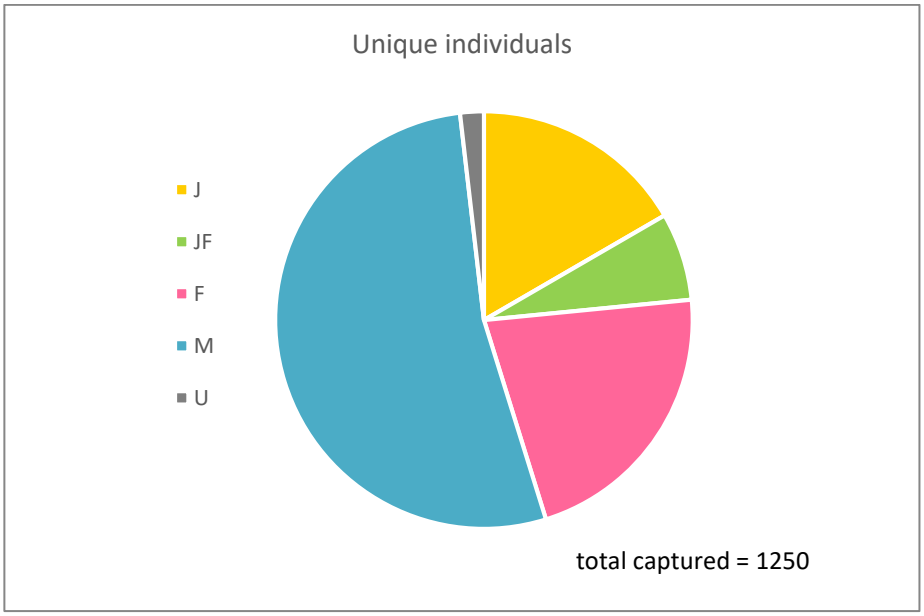


Figure 3.4.3A: Proportions and numbers of PIT-marked individuals captured during 2018-19 VES and CMR surveys. See Fig 3.4.1 for legend.

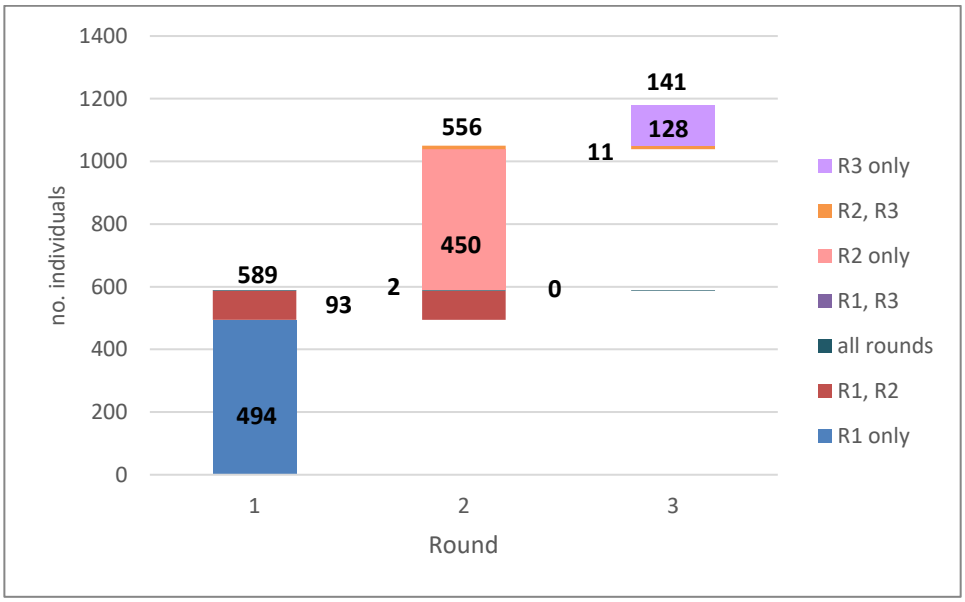


Figure 3.4.3B: Unique PIT-marked individuals captured in each of the three principal rounds, showing those animals caught in multiple rounds versus only one round.

Unique individuals are identified on the basis of PIT tags, and can only be ascertained from captured frogs. Figure 3.4.3A shows that, similar to the previous season, 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. The lack of a full set of surveys in round 3 means that very few (2) animals were detected across in all three rounds, but an additional 104 were captured in at least two of them. These 106 animals caught in more than one round were out of a total 1,176 unique animals detected across these three rounds. A further 74 animals were captured outside of the three main survey rounds.

Size classes and cohorts of captured frogs

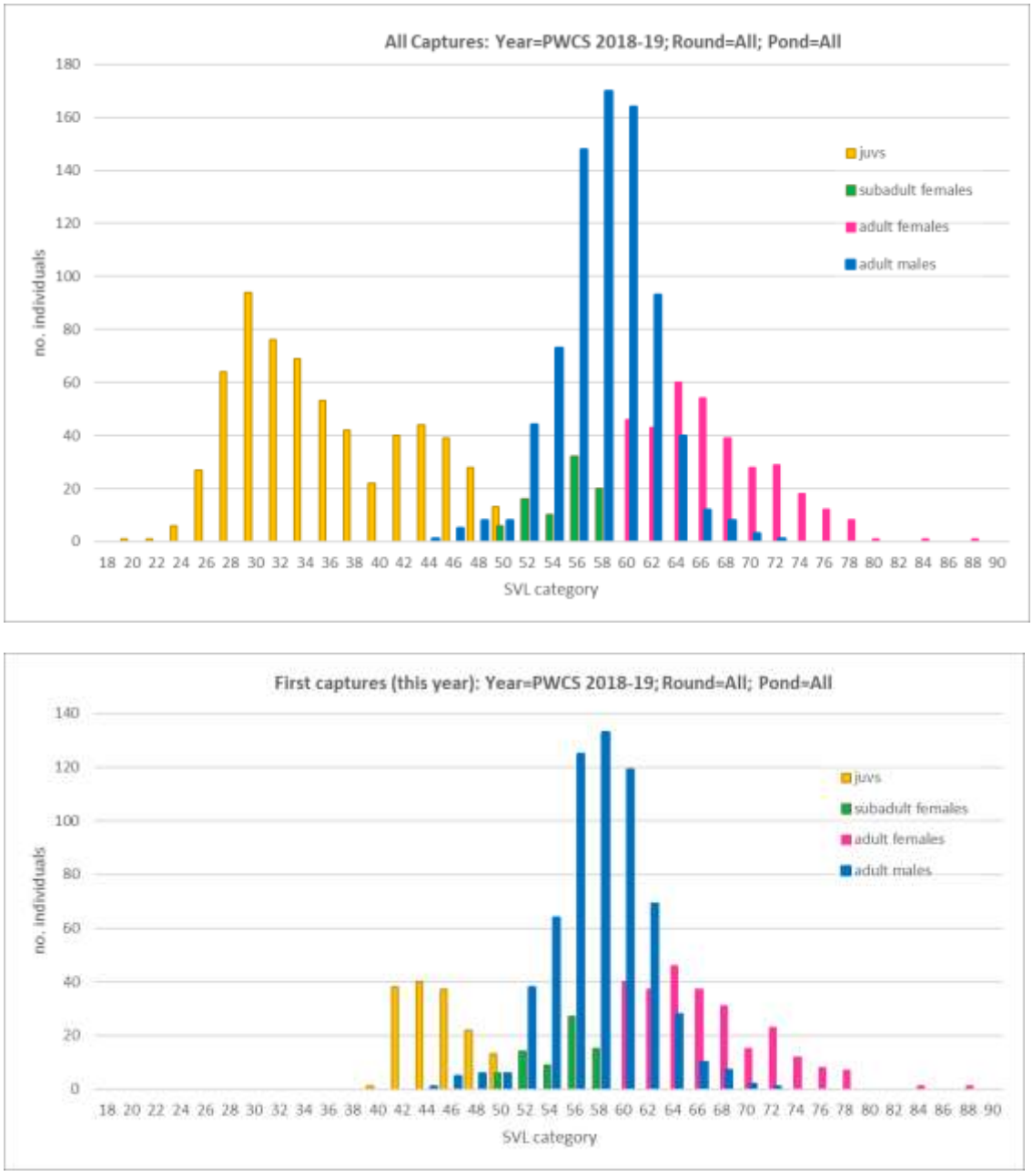


Figure 3.4.4: Frequency distribution of different sized animals captured, for VES and CMR surveys. Size is measured by snout-vent length (SVL), and size categories are measurements 'binned' into 2 mm groups, i.e. the frequency of animals 56 mm > SVL >= 58 mm is shown in the column labelled '58'. **Top**; 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.

As with the previous season, the numbers of subadult females captured were low and most adult males were between 52 and 62 mm SVL.

All captures, by round

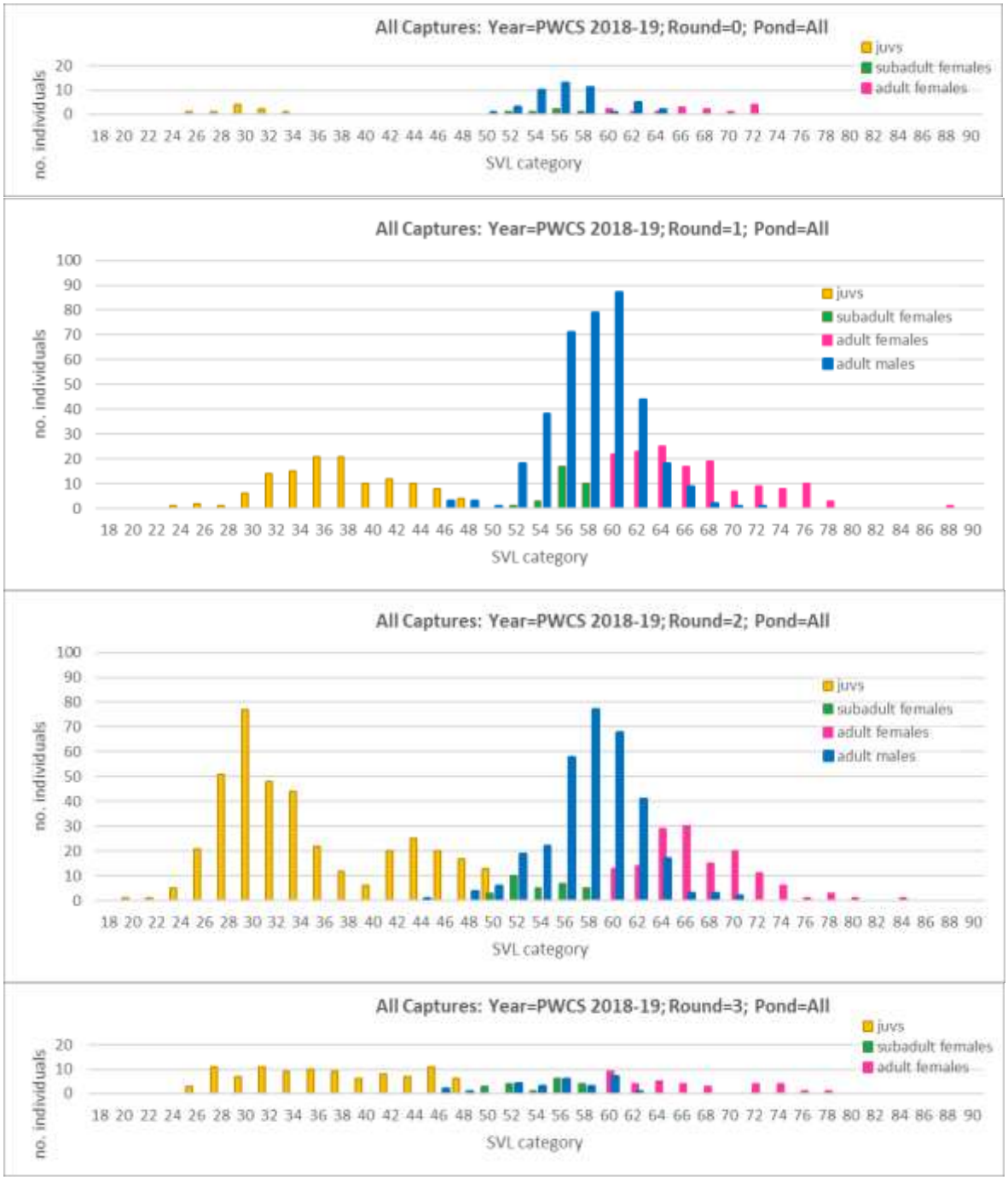


Figure 3.4.5: Frequency distribution of size classes, showing all captures for each survey round (VES and CMR). See Fig 3.4.1 for legend and Fig. 3.4.4. for explanation of size classes. Note that the smaller overall values for frequency in rounds 0 and 3 reflect the smaller search effort in those rounds (Table 3.1.1)

Plots of size/frequency distribution over the different rounds (Figure 3.4.5) show a cohort of small to mid-sized juveniles in round 0 (September); these have a modal SVL of ~30 mm and are likely the animals that were spawned in late autumn of the previous season following significant rain in March and April 2018. By round 1 (October), that cohort has increased in size, with a modal SVL of ~36-38 mm, and by round 2 (late November to late December) had grown to become large juveniles/small adults.

Round 2 also shows a second cohort of small juvenile *L. aurea* (modal SVL 30 mm); these are animals that were spawned in the spring of 2018. Both of these cohorts are also visible in round 3.

Captures by wetland – K29

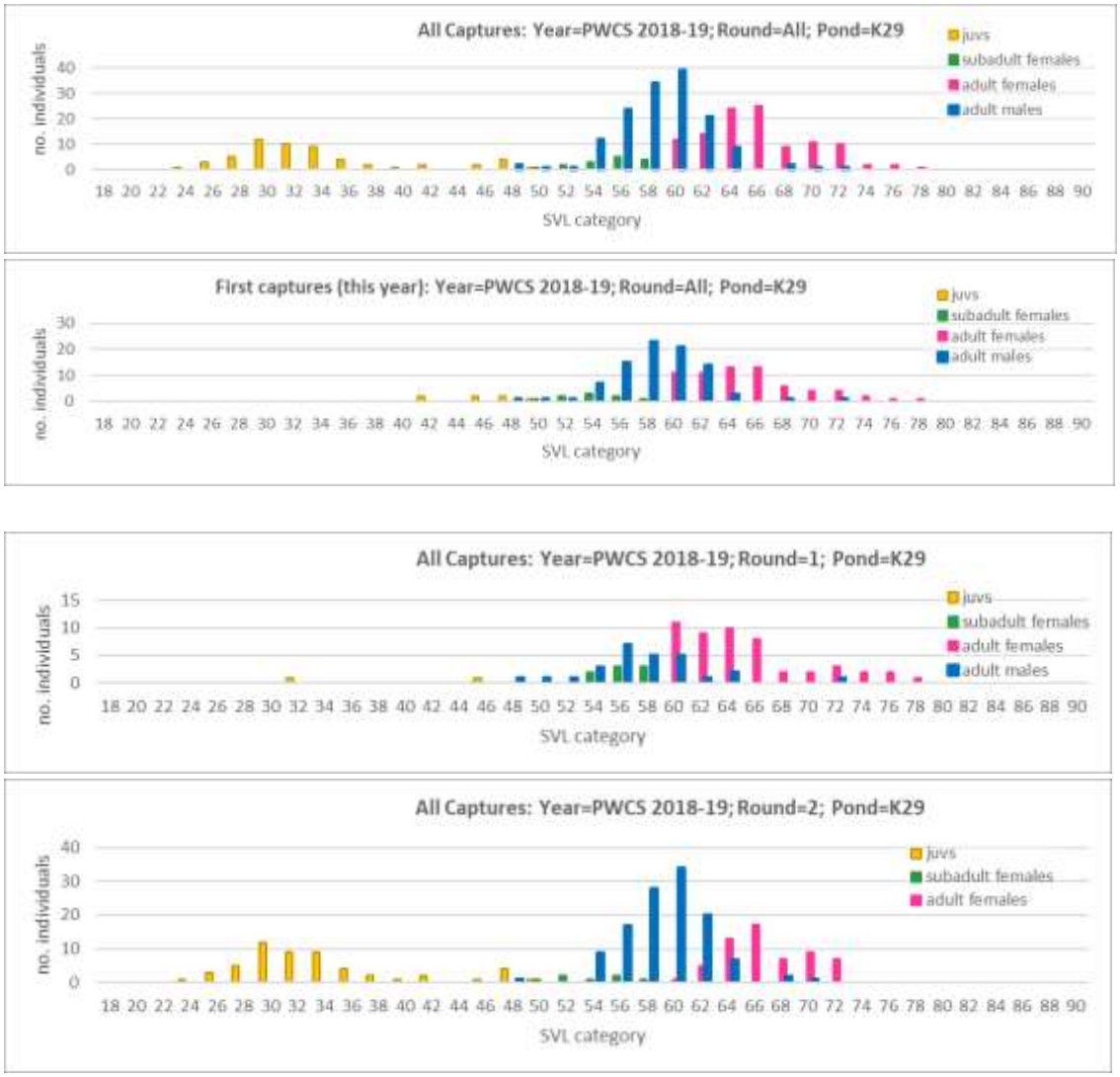


Figure 3.4.6: Frequency distribution of size classes at K29. Top: Data for all captured animals (above) and tagged individuals (below), summed across all three rounds. Bottom: Frequency distribution per round, for rounds 1 and 2. See Fig. 3.4.1 for legend and Fig. 3.4.4. for explanation of size classes.

CMR wetlands: The number of *L. aurea* detected at K29 was low compared to the previous two years, but with a comparatively high proportion of adult females (Figure 3.4.6). The large numbers of small juveniles present in Round 2 are thought to have been spawned in the nearby K105A (as part of a very large breeding event) and which moved to K29 following metamorphosis.

The numbers in K29 are the lowest since the 2015-16, when heavy summer rain apparently resulted in *L. aurea* leaving this refuge wetland and dispersing to flooded ephemeral breeding habitat, in particular the nearby K106A and K106B wetlands. It is interesting that in the 2018-19 we again saw large numbers of *L. aurea* leaving K29 after heavy rain and moving to a large nearby wetland that was the focus of a breeding event – in this case, K105A. Note that this interpretation of movement in and out of K29 is confirmed by direct data on movement **(Section 3.5** below).

K29 was directly affected by the January 2019 grass fire, with all terrestrial and most (but not all) of the aquatic vegetation destroyed in the fire. Due to the proximity to the active ground fire we were unable to survey K29 in Round 3. By May 2019 the aquatic vegetation had almost completely recovered.

K104

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

Frequency distribution of size classes at **K104** (Figure 3.4.7) shows at local scale the pattern of breeding and recruitment outlined above for the whole island. A cohort of mid-sized juveniles in Round 1 were presumably animals spawned in autumn 2018; these increased to become large juveniles / small adults by Round 2, by which time another cohort of smaller juveniles was present. Those smaller juveniles were spawned in the rainfall events of September and October 2018; by round 3 (late January 2019) these grown to a modal SVL of 38 mm.

Note that, whilst *Gambusia* was present in K104, densities of the fish were low, presumably due to this wetland drying out in the previous season.

The large number of males captured in the first round (October) were consistent with the high levels of breeding behaviours seen across the highly following the spring rains in September and early October. K104 is not well connected to other permanent/ semi-permanent wetlands, but in isolation often appears to act as a microcosm of *L. aurea* ecology on Kooragang Island. The very small number of captures in round 3 was likely affected by the extended dry summer; at the time of that survey the wetland was almost completely dry and the detected frogs were seen close to the remaining water.

K22-23

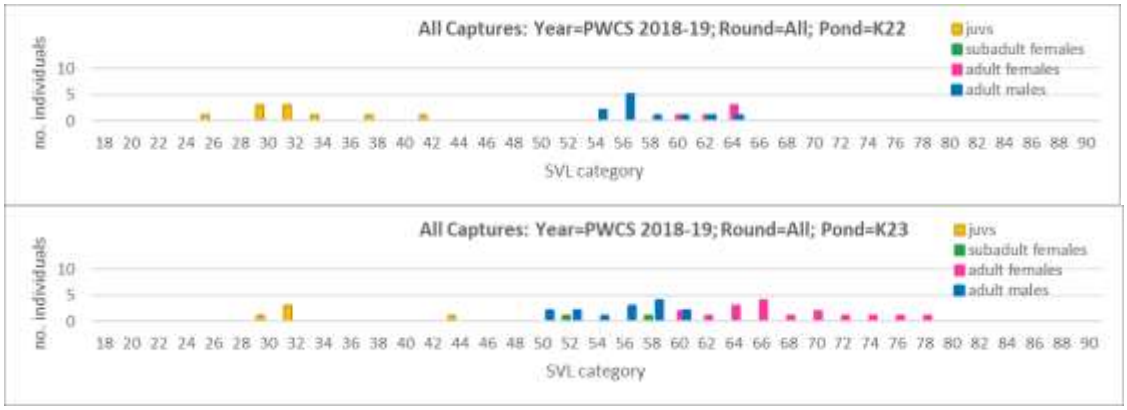


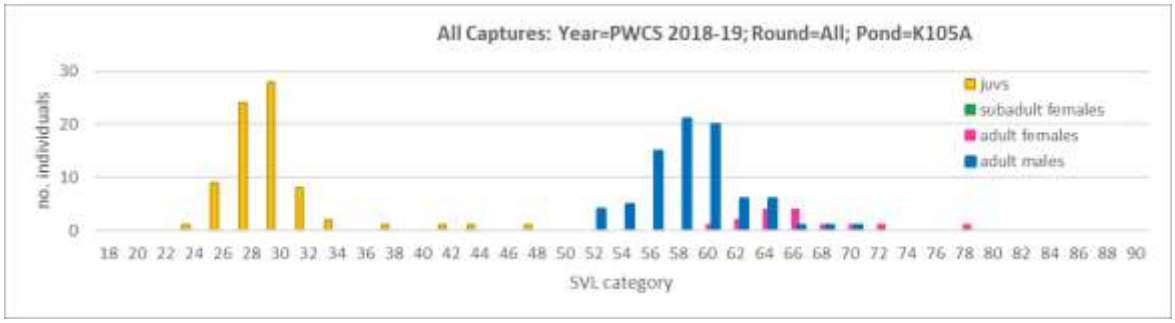
Figure 3.4.8: Top: frequency distributions for K22 and K23 wetlands, 2018-19. Refer to Fig. 3.4.6 for explanation of charts.

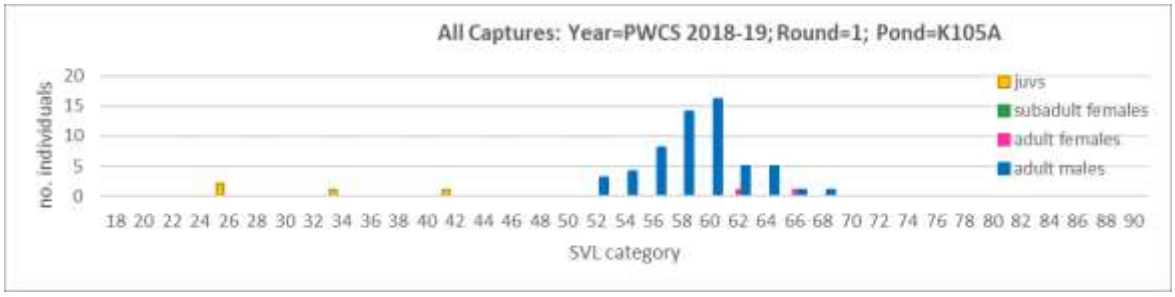
K22 and K23 are a pair of wetlands in close proximity to each other, situated immediately north of the PWCS rail line and adjacent to the north shore of K105A. Historically, these wetlands have held large numbers *of L. aurea* and have been the focus of intensive CMR surveys; however, since 2016-17 numbers have been steadily less than in previous years (see discussion in Section 4.4, and data in Table 4.4.1).

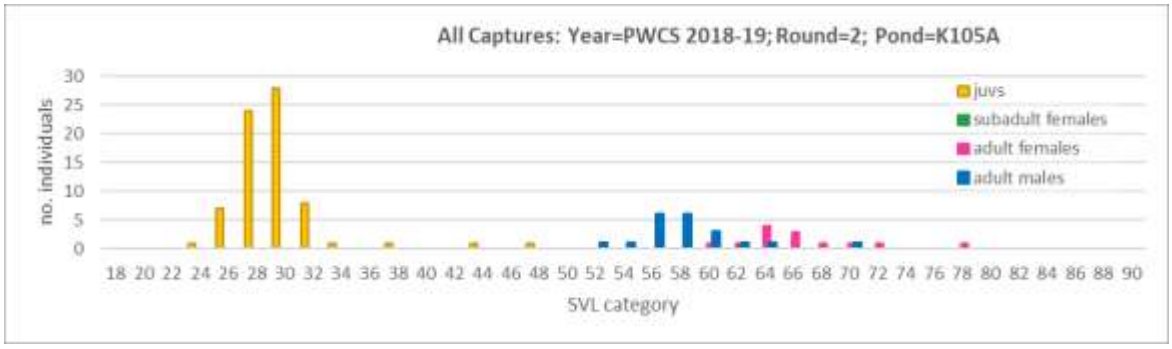
The total number of VES detections in these wetlands during the 2018-19 season was lower still; in both rounds 1 and 2, initial attempts to commence CMR surveys did not provide sufficient captures to justify continuation (Figure 3.4.8) and only VES were conducted in those rounds.

Both K22 and K23 were heavily damaged by the January 2019 grass fire, with most aquatic and terrestrial vegetation destroyed in the fire. There were several direct instances of fire mortality recorded (Alexandra Callen, pers. comm.). Because of their proximity to the active ground fire zone following the grass fire, we were not able to conduct a survey in Round 3.

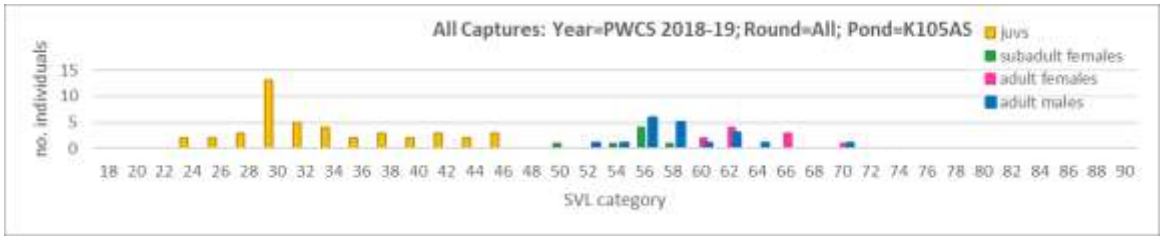
K105A

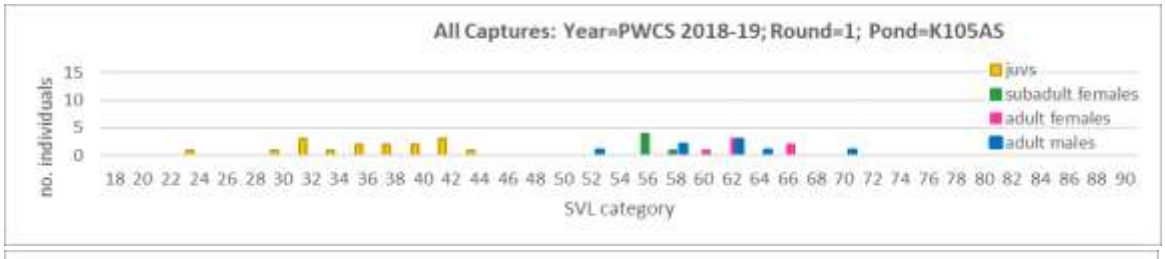


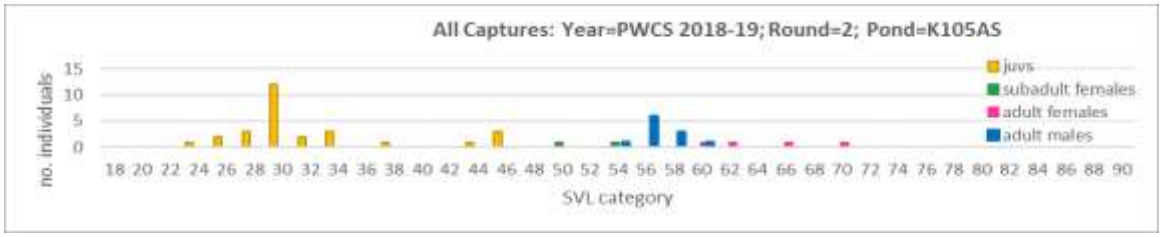




K105AS







K105B

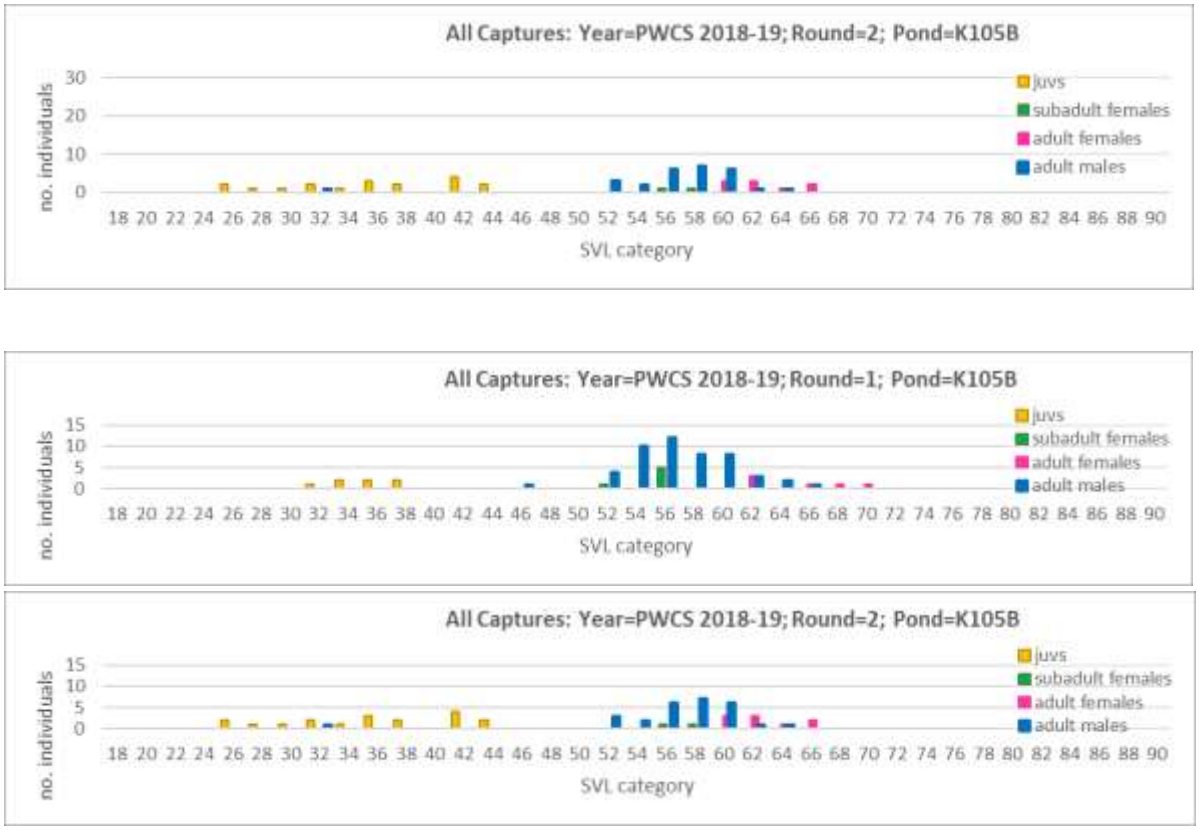


Figure 3.4.9: Frequency distributions for the large **K105** wetlands west of K29. Refer to Fig. 3.4.6 for explanation of charts.

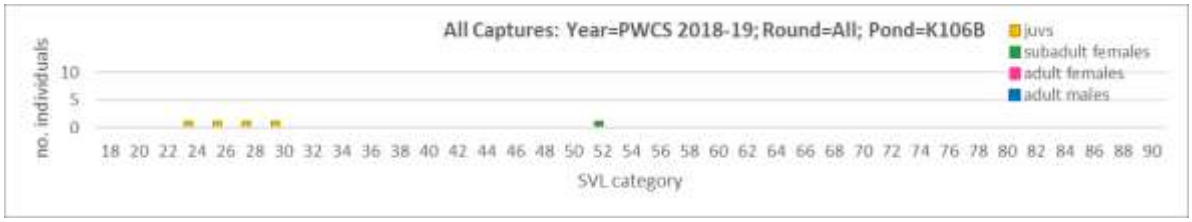
'Deep pond' was originally a single very large wetland in the NW part of the Industrial Zone; it sits on the original substrate of the island (rather than on artificial substrate, as is the case with some other wetlands), and appears to be a remnant of the natural wetlands in this part of Kooragang that 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.

We detected many more *L. aurea* at **K105A** than in previous seasons. This wetland was the focus of a significant breeding event in October (Round 1), which resulted in large numbers of juveniles being present by early summer (Round 2) (Figure 3.4.9). The large numbers of males (most of whom were calling) in Round 1 were surpassed by the number of juveniles present in Round 2, which appear as a well-defined cohort with a modal SVL of 30 mm. The southern edge of K105A (i.e. **K105AS**) shows a similar pattern, although there is also a clearer cohort of larger juveniles present in Round 1 as well.

K105B had fewer numbers captured than K105A, although search effort was less. As with K105AS, there was a cohort of large juveniles detected in Round 1, indicating animals that had been spawned late in the previous season. The presence of these animals in K105B and K105AS but not K105A is consistent with the location of observed breeding behaviours in late March 2018. The cohort of small juveniles detected in Round 2 may indicate that K105A had the highest levels of recruitment in spring 2018-19.

There is little evidence of K105A being affected by the January grass fire, even though the fire came close to this wetland. K105AS and K105B were both well away from the fire zone and suffered no damage.

K106B



K106C

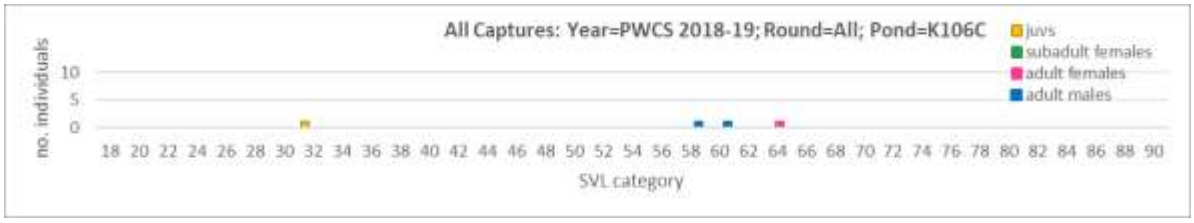


Figure 3.4.10: Frequency distributions for the K106B and C wetlands immediately west of K29. Refer to Fig. 3.4.6 for explanation of charts.

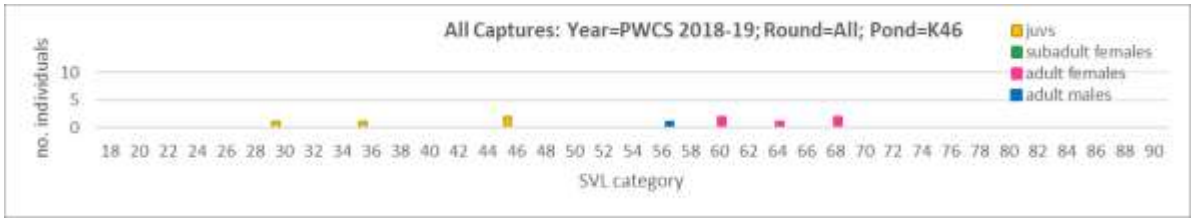
K106B is a temporary ephemeral wetland, and along with **K106A** was the site of a very large breeding event in 2016-16. It held water through the spring of 2018, but it had dried by early summer. It is very close to K105A and it is likely that the small juveniles detected (in Round 2) had been spawned in K105A in October 2018 (Figure 3.4.10). Given the documented connectivity between K105A and K29, it is possible that those small juveniles were moving between those larger wetlands.

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 small refuge wetlands exemplified by the cluster ponds (C1 and C2). It usually contains a lot of adults, but this season had a small number of *L. aurea* (Figure 3.4.10). Data from tagged animals showed that one frog previously tagged in K106C was recaptured in K105A this season, and given the high density of adult *L. aurea and* breeding activities (especially chorusing) it seems likely that the *L. aurea* usually present at K106C moved to K105A after the spring rainfall event.

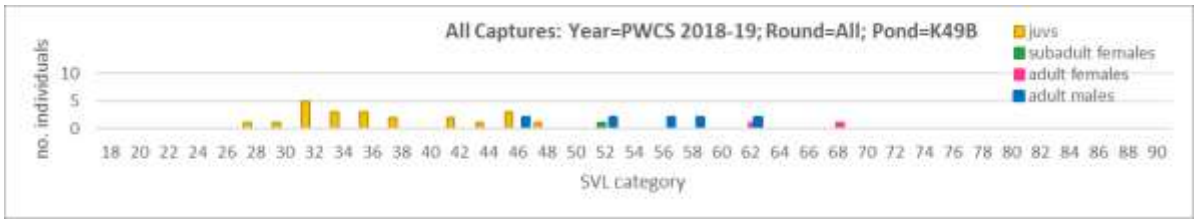
Many of the adults that have been captured at K106C in previous seasons have been subsequently recaptured in K29, K105A, and K105AS, indicating that the wetland is highly connected (in terms of *L. aurea* movements) to those nearby wetlands (**Section 3.5**).

K106A, K106B, and K106C were all extensively damaged by the grass fire in January, with most aquatic and terrestrial vegetation being burnt out. These wetlands were also partially affected by the ensuing ground fire for several months after January 2019. By May 2019 most of the aquatic vegetation had at least partially recovered.

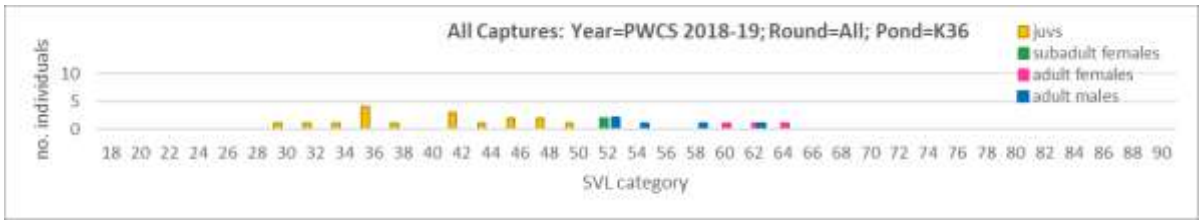
K46



K49B



K36



K102

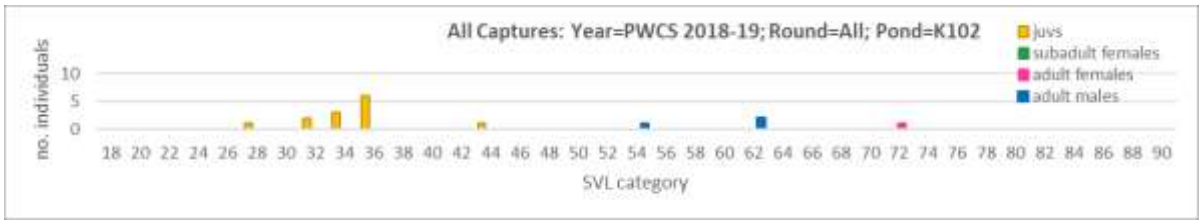


Figure 3.4.11: Frequency distributions for selected wetlands in the southern part of the industrial site. Refer to Fig. 3.4.6 for explanation of charts.

Southern Industrial Zone 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.

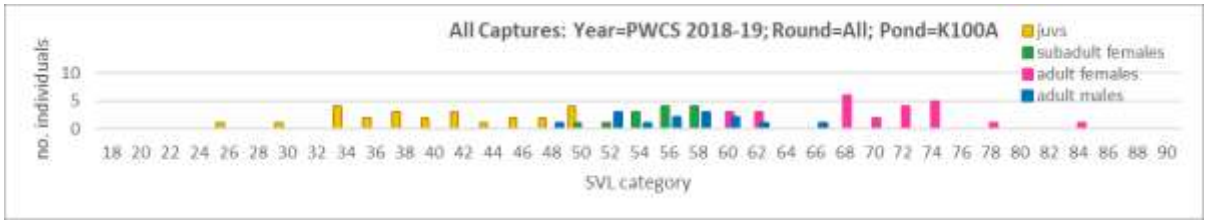
The number of adults present in **K46** was lower than the previous season, and no chorusing was detected. The presence of small juveniles indicates breeding in the general area; whether that occurred at K46 or at a nearby wetlands (e.g. K117) is unknown.

The number of *L. aurea* detected at **K49B** was larger than the previous season, and in particular included many more juveniles. The adjacent **K36** also contained more juveniles than the previous season, although the number of adults was similar. Each of these wetlands are classed as permanent wetlands and have retained water through the previous dry years; as such, they have consistently contained *Gambusia*. However, they both appeared to have dried out in early March 2019 and thereafter no *Gambusia* could be detected. It remains to be seen if they will provide breeding habitat next season; at present, it seems likely that the

juveniles present in K36 and K49B were spawned in nearby wetlands, such as K121, where breeding is known to occur.

K102 ('Boomerang' pond) is a very large wetland but has lower densities of *L. aurea* than the large wetlands (K105A, K29, K104) in the northern region of the Industrial Zone. Several metamorphs and small juveniles were detected, indicating that breeding may have occurred in the spring 2018 rainfall events, most likely in the open flooded *Paspalum* grass at the western end of the wetland. *Gambusia* were present, but at low densities.

K100A



K115

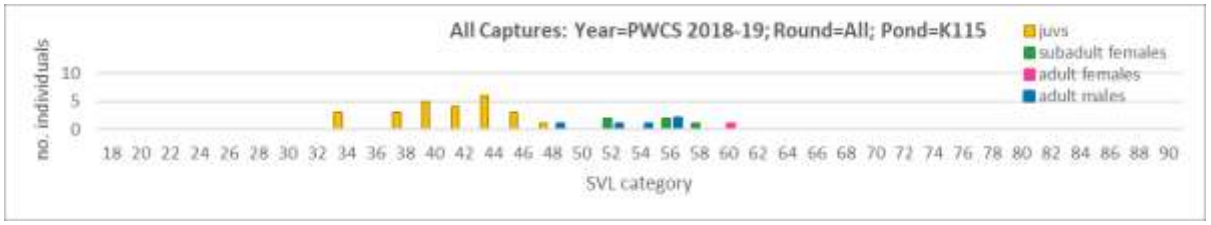
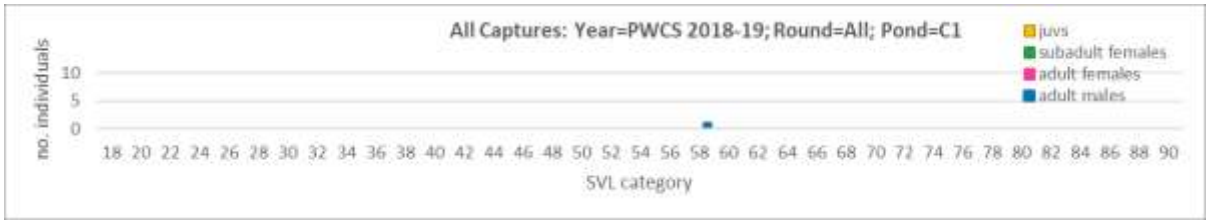


Figure 3.4.12: Frequency distributions for selected wetland immediately near the NCIG rail loop. Refer to Fig. 3.4.6 for explanation of charts.

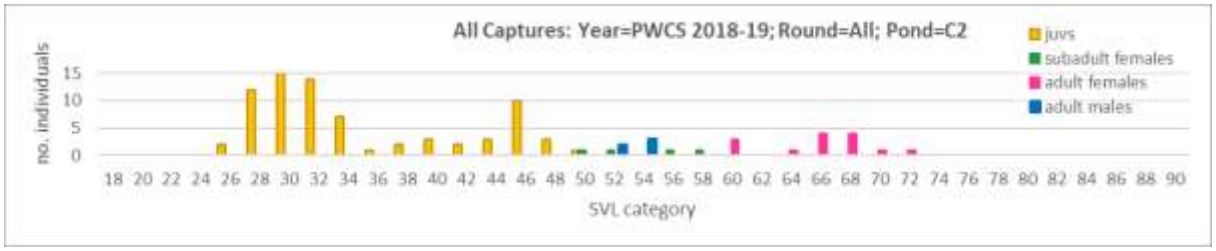
K100A is a deep permanent wetland alongside Windmill Road, on the eastern edge of the Industrial Zone. It is surrounded by dense stands of *Casuarina* trees, and contains *Gambusia* in very high densities. It often has relatively large numbers of *L. aurea*, but does not appear to support breeding. This general pattern was again seen 2018-19; in particular, there were some very large adult females present. The number of juveniles detected was larger than previous seasons; these are considered likely to have been spawned in the nearby K111 wetland where breeding is known to occur.

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* reeds at its western end. As with previous seasons, in 2018-19 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



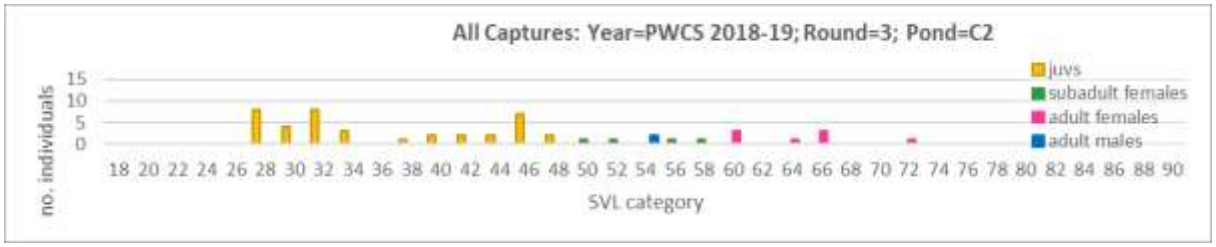


Figure 3.4.13: Frequency distributions for the PWCS 'Cluster Ponds'. Refer to Fig. 3.4.6 for explanation of charts.

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 2016-17 season.

In 2018-19, **C1** contained almost no *L. aurea* across most of the season (Figure 3.4.13). This is a very different situation to the preceding four seasons. Given the very large numbers of adult *L. aurea* present at K105A, on balance it seems possible that the adult *L. aurea* that would usually have been present at C1 had instead moved to K105A. Note that C1 and K106C seem to provide similar habitat value for *L. aurea* (i.e. small refuge wetlands; see Section 4.4.b), and as noted above K106C also had very low numbers in 2018-19. As with K106C, C1 is closely connected with K29 and K105A in terms of *L. aurea* movement, with many frogs moving between these, and two frogs previously tagged in C1 were recaptured in K105A this season (**Section 3.5**).

C1 was extensively damaged by the grass fire that swept across the northern part of the Industrial Zone in early January; the surrounding terrestrial vegetation was completely burnt, as was large parts of the aquatic vegetation. The tubs themselves were all partially melted and their capacity to hold water has been substantially decreased. Nonetheless, in the period immediately after the fire they still contained some water and several *L. aurea* were detected there (despite the severe reduction in vegetation cover) during inspections of the fire zone through late January, February, and March (Grant Moylan, pers. comm.). The potential of the cluster pond design to provide refuge following fire seems to be another potential role for these constructed wetlands.

The number of *L. aurea* detected at the **C2** cluster ponds has been steadily increasing since their first detection there in 2016-17, and in 2018-19 had the highest numbers yet recorded (Figure 3.4.13). As with the previous two seasons, it appears to provide suitable habitat for large adult females, but this season also provided habitat for large numbers of juveniles, especially in Round 2 and Round 3. Interestingly, the size distribution of the juvenile *L. aurea* at C2 was similar in those two rounds, even though the surveys were some nine weeks apart.

The C2 clusters are the only well vegetated permanent wetlands in the *K10 South* and *K10 North* subregions. They do not appear to provide breeding habitat themselves but are close to several wetlands where high levels of breeding activity was recorded in both 2017-18 and 2018-19; the closest of the wetlands, K123, has had large numbers of *L. aurea* tadpoles and metamorphs detected in both years. It appears that the C2 clusters provide habitat for animals that have been spawned in those nearby wetlands (Round 2, Figure 3.4.12).

As the surrounding wetlands dried during the middle and late part of the summer, the number of *L. aurea* at C2 remained high (Round 3, Figure 3.4.13), highlighting the potentially important role of these wetlands in providing habitat during extended dry periods.

'New clusters': C3, C4, C5

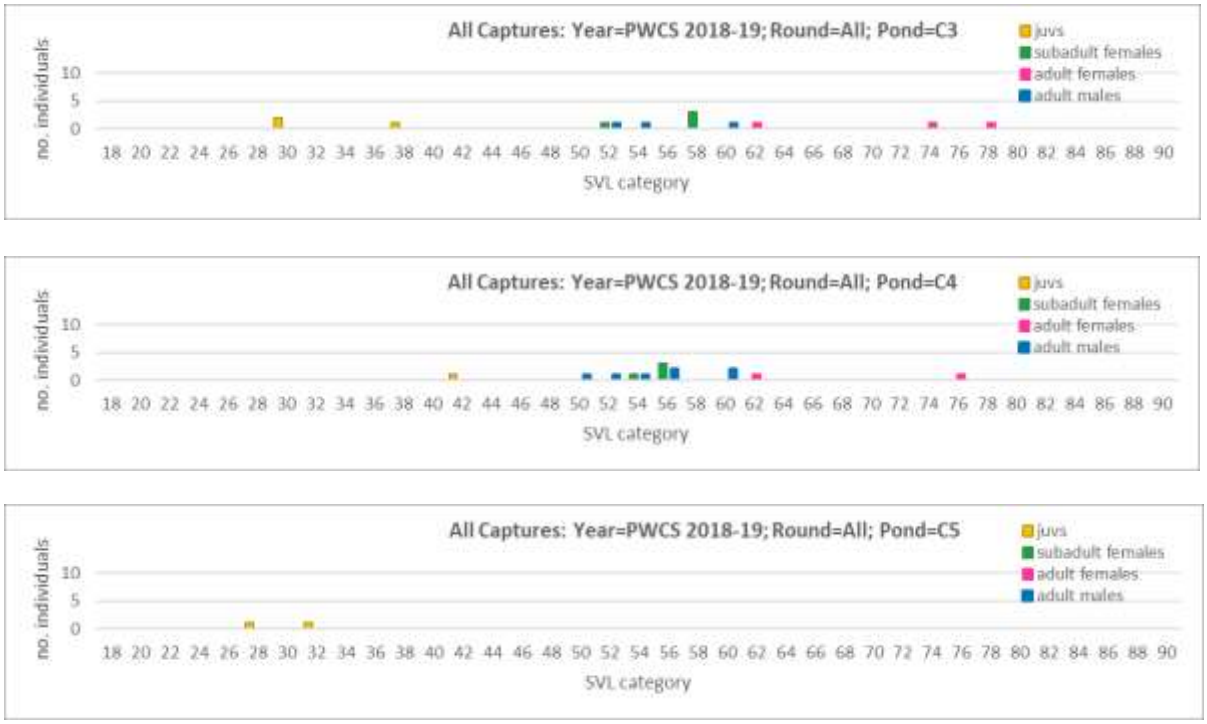


Figure 3.4.14: Frequency distributions for the 'new cluster ponds'. Refer to Fig. 3.4.6 for explanation of charts.

During the 2018-19 season, three new sets of smaller cluster ponds were installed in the *K10 South* and *K10 North* subregions. These new clusters each comprised two 4,500 litre tubs (comparable to the size of the tubs in each of the C1 and C2 clusters), and were located close to the HDC wetlands in those subregions. The intent was to provide additional wetlands that could function in the way that the C1 and C2 clusters appear to; i.e. providing small but permanent wetlands in their respective habitat mosaics.

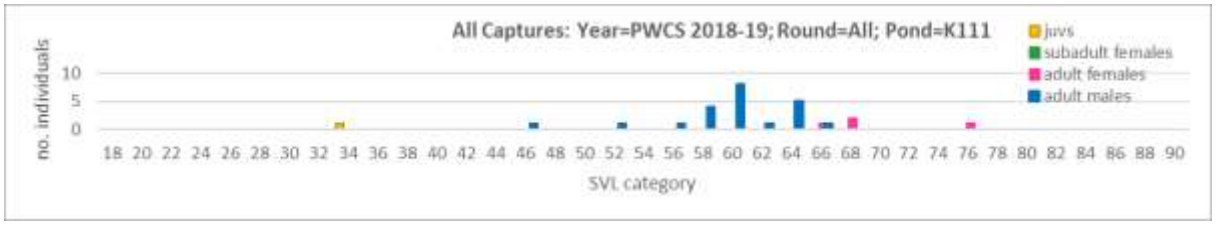
The C3 cluster was installed in K10 South, in between K121 and K122. The C4 and C5 clusters were located in K10 North; C4 in between K113 and K114, and C5 in between K111 and K112. Installation was November 2018.

The newly installed tubs were partially filled with water (~20% capacity). Artificial structures and potted aquatic plants (*Schoenoplectus* sp.) were installed in the following weeks, before C3 and C5 were completely filled up in late January 2019.

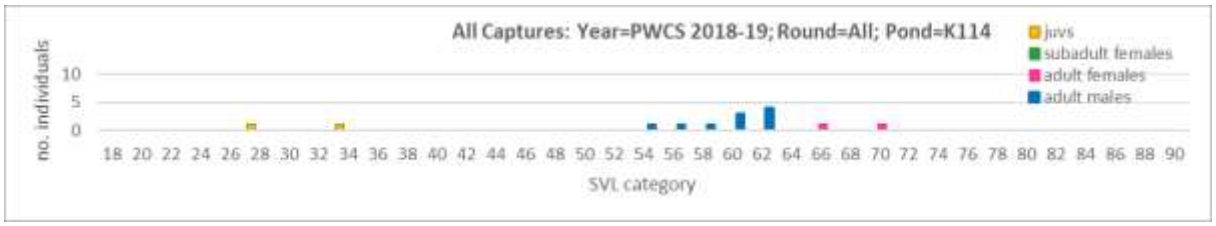
When partially full, the new clusters were very quickly colonised by several species of frogs; *Litoria aurea*, *Litoria peronii*, *Limnodynastes peronii*, and *Limnodynastes tasmaniensis*. The *L. aurea* present were mainly adult males and subadult females, although some large adult females were present (Figure 3.3.14) After C3 and C5 were completely filled neither *Litoria* species were detected at these again, but *L. aurea* persisted at C4 (which was not fully filled).

HDC constructed wetlands: the wetlands K111-K114 (in the rail loop *K10 North*) and K117-K118 (in the KIWEF *K2* subregion) were completed in 2015 and all supported adult *L. aurea* by the 2016-17 season. Breeding has been detected in each one in at least one season since 2015, and K111 and K114 have supported breeding in every season.

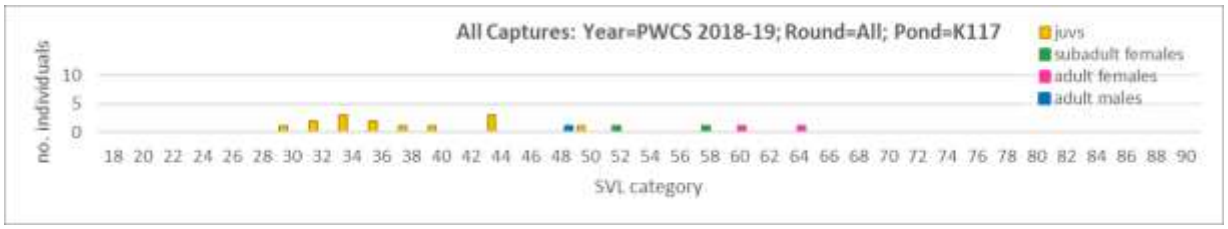
K111



K114



K117



K118

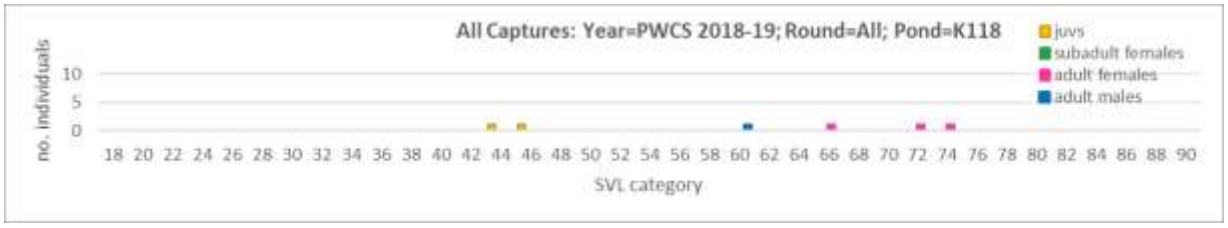
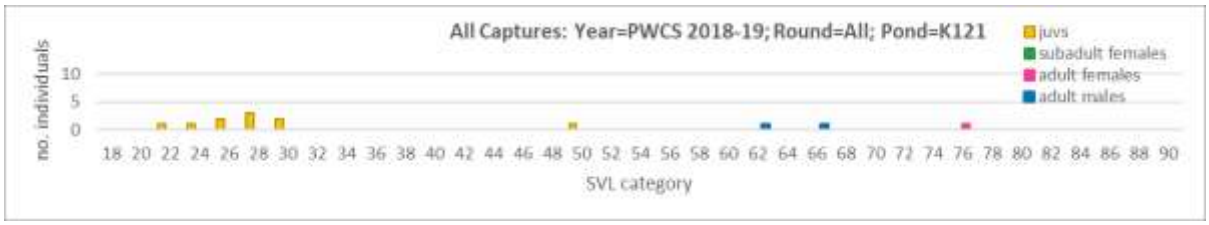


Figure 3.4.15: Frequency distributions for selected HDC constructed wetlands. Refer to Fig., 3.4.6 for explanation of charts.

In the 2018-19 the number of adults detected was greater at K111 than K114 (a contrast to the previous seasons); in both wetlands males were more common and many of these were calling during the early part of the season. Metamorphs were detected at K111 but not K114.

K117 and **K118** both supported adults and juveniles, with the larger numbers in K117 (again, a contrast to the previous season). Breeding evidently took place in K118 this year, with tadpoles detected in Round 2. The presence of juveniles in these wetlands may be linked to breeding within them, K46, or K105B. K118 had dried by the end of summer but K117 was one of the few wetlands to retain water through the season.

K121



K122

K123

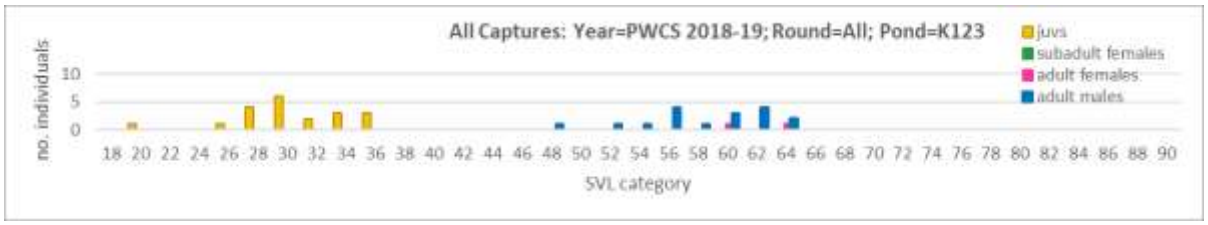


Figure 3.4.16: Frequency distributions for HDC constructed wetlands in the *K10 South* subregion. Refer to Fig., 3.4.6 for explanation of charts.

K121, **K122**, and **K123** were constructed in 2016-17 and are located in the *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. Despite having minimal aquatic vegetation in 2017-18, they were immediately used for breeding by *L. aurea.*

Unlike the previous season, adults were detected at each of these, with larger numbers at K122 and K123. The small amount of aquatic vegetation present in 2018-19 appears to have provided a more suitable environment for adult *L. aurea* to remain at these wetlands. The presence of tadpoles, metamorphs, and small juveniles indicates that these wetlands continue to provide suitable breeding habitat. Together with C2 and K36, the *K10 South* subregion now appears to provide a habitat mosaic capable of support both adult *L. aurea* and consistent breeding behaviour.

K108; the Eastern Ponds ('rail loop')

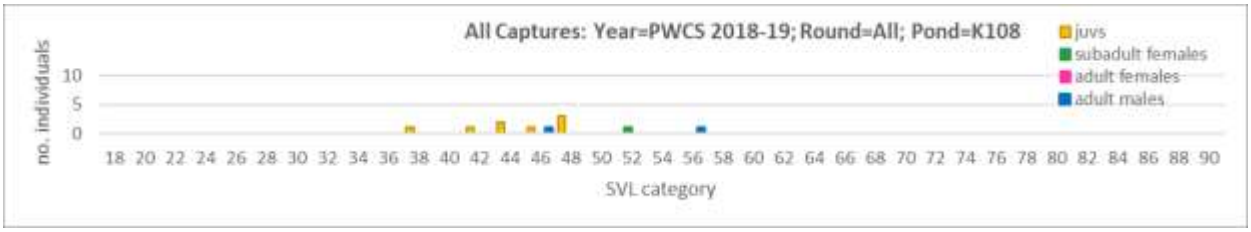


Figure 3.4.17: Frequency distributions for K108, the 'rail loop' wetland within the Eastern Ponds. Refer to Fig., 3.4.6 for explanation of charts.

The 'Eastern Ponds' are the only part of the *K10 North* subregion that are not recently constructed wetlands. **K108** – previously known as the 'rail loop' pond, is the largest wetland of these. Prior to the construction of the NCIG rail loop it was a large semi-permanent / permanent wetland that consistently held large numbers of *L. aurea*. However, in recent years the hydroperiod of this wetland has decreased from semi-permanent to seasonal to temporary; it was dry for the entire 2016-17 and 2017-18 seasons, but held water for a number of weeks in late 2018 following heavy Spring rainfall in September and October 2018. Prior to this, *L. aurea* had not been detected in K108 since February 2016, but in the first half of the 2018-19 season a small number of juveniles and adults were detected.

Breeding is not thought to have occurred in K108, as neither calling, tadpoles, or metamorphs were detected. It is likely that the juveniles detected were spawned in nearby wetlands such as K111. Note that K100A, which often contains large numbers of adults and appears to act as a refuge habitat, is very close to K108.

Area 2 Fence project

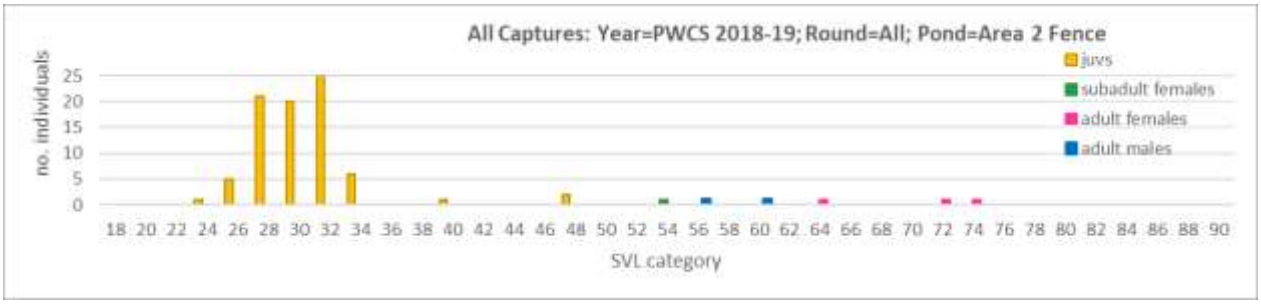


Figure 3.4.18: Frequency distributions for *L. aurea* captured in the Area 2 drift fence. Refer to Fig., 3.4.6 for explanation of charts.

As part of a separate research project, in 2018 HDC and UoN collaborated to investigate the use of terrestrial habitat in the Industrial Zone by *L. aurea.* The project used an array of drift fences, located to the east of Deep Pond, to trap and identify frogs from May 2018 until January 2019 (the project was intended to run until the end of the summer but the drift fences were destroyed by the grass fire in January 2019).

Although the full results will be published separately, the fence successfully trapped appreciable numbers of *L. aurea* that were using this terrestrial part of the Industrial Zone. Almost all were captured during spring and early summer following rain. Most of these were small and very small juveniles and even a small number of metamorphs, which had presumably spawned in the nearby K105A and were dispersing following the rainfall events. Two of the adults captured had been previously tagged and showed movement from K29 and C2 (Section 3.5)

NCIG CHEMP wetlands

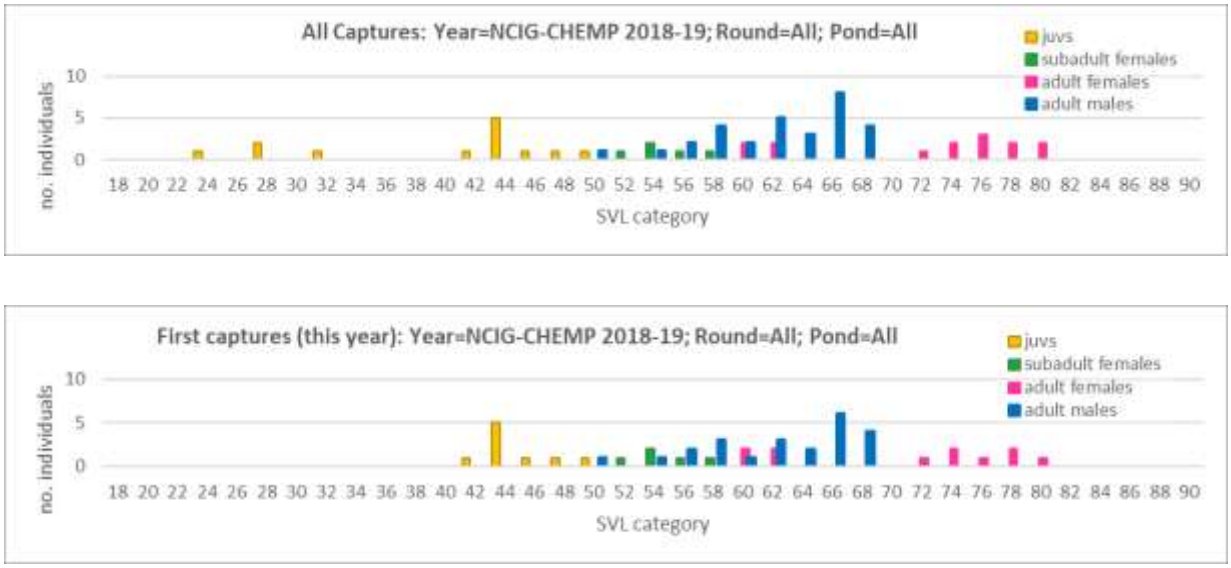


Figure 3.4.19: Frequency distributions for the NCIG CHEMP wetlands. Top, all captures; bottom, first captures only. Refer to Fig., 3.4.6 for explanation of charts.

The NCIG CHEMP wetlands were established in 2016 with the aim of providing suitable habitat for *Litoria aurea* in the Northern region of Kooragang Island. At that time, the *L. aurea* population in the north of the island was very low (and had been for some 10 years previous; John Clulow, pers. comm.).

Not all of the NCIG CHEMP wetlands were surveyed as part of the island-wide surveys during the 2018-19 season; we surveyed 11 of these wetlands in each survey round, and a further 8 were surveyed opportunistically in at least one round. In those surveys, 62 *L. aurea* were captured, and PIT tags indicated that 48 of those captures were unique individuals. The captured animals ranged from small to large juveniles, adult males, and subadult and adult females (Figure 3.4.19).

Although 62 captures over the season is not a large number compared to wetlands in the Central and Industrial Zones of the island, it is considerably more than the numbers in previous seasons. In the northern zone, there were only 5 detections of *L. aurea* in non-CHEMP wetlands; thus the NCIG_CHEMP are currently providing important habitat in this region of the island, and the number of *L. aurea* there appears to be increasing.

The BHP CHEMP are a focus of a separate research agreement and the demographics of those will be reported separately.

3.5. Longitudinal data: persistence, movement and growth

The best measures of how animals grow, how they move around the study site, and how long they live comes from repeated surveys at 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. Five of these were from the island-wide research program (i.e. 2014-15, 2015-16, 2016-17, 2017-18, and 2018-19). We also included datasets from other research and monitoring projects conducted at the UoN Amphibian Research Laboratory. Combined, these nine 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
IWS 2018-19 (McHenry & Maynard)	2018-19
SOS surveys (Beranek, Lenga, McHenry, Maynard	2018-19

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 usually 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 743 frogs had more than 6 months between first and last capture; for most of these (448; 19.1% of all recaptured frogs) the period was less than 12 months. Only 295 frogs were recaptured more than 12 months after first capture. The number of frogs that persisted more than 2 years was 46, and 12 of these lasted longer than 3 years. Four 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). 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	4	0.2%
3 < x < 4 years	8	0.3%
2 < x < 3 years	34	1.1%
1 < x < 2 years	249	7.0%
6 < x < 12 months	448	19.1%
x < 6 months	2,413	
Total	3,156	

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 8914 Total animals recaptured 3168	up to 2017-18	seen in 2018-19
Total movements detected	514	243	271
Within BHP_CHEMP (Ramsar Rd West)	328	117	211
Within NCIG CHEMP stages	22	14	8
Between K22-23	53	52	1
Other movements	110	63	47

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). Data up to the 2017-18 season was detailed in the annual report for 2017-18 (McHenry et al. 2019) (middle column). Additional movements detected in the current 2018-19 season are summarised in the right-hand column. Most detected movements are between neighbouring CHEMP wetlands and between K22 and K23). The 'Other movements' involving movement detected in the current 2018-19 season are detailed in **Tables 3.5.4** and **3.5.5** and Figures 3.5.1 and **3.5.2**.

Approximately 16% of recaptures (516 out of 3,168) indicated *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 in the Ramsar Rd West subregion, between K22 and K23, or within stages in the NCIG CHEMP wetlands.

Details of the 63 'other' movements detected from 2014 to 2018 are provided in the 2017-18 annual report (McHenry et al. 2019). A further 47 'other' movements were detected in the 2018-19 season and these are shown here; in Table 3.5.4 (for movements involving previous seasons) and Table 3.5.5 (for movements within the current season), and in Figures 3.5.1 and 3.5.2 respectively.

A notable feature of the movement data in the 2018-19 season was the large number of movements to and from Deep Pond (K105A, K105AS, and K105B); 26 of the 53 movements tabulated in Tables 3.5.4 and 5.5.5. This highlights that the large breeding event detected at these wetlands in spring 2018 were not just *L. aurea* that are always resident around Deep Pond, but also involved animals that moved towards K105 during the breeding event. Most of these were from the wetlands that are understood to form a consistent habitat mosaic in that part of the Industrial Zone: K29, C1, and K106; but Deep Pond is a very large wetland and so K22 and K23 to the north and K117, K118 and K46 to the south also lie close to it.

Fifteen of the movements involving K105A were by animals captured at K29, C1, K106C, or K23 in previous seasons; ten of these fifteen came from K29. Two more *L. aurea* were detected at K105A having been captured at K29 early in Spring 2018. During Round 2 in early Summer, five *L. aurea* that had been at K105A in Spring 2018 were recaptured in K29, including three animals that had been first captured in K29 in previous seasons or at the very start of Spring 2018. This data provides support for the suggestion that *L. aurea* will move from 'refuge' habitats (K29) to habitats that provide suitable breeding habitat at a particular time (in Spring 2018, K105A). That suggestion is consistent with the observation that *L. aurea* abundance at K29 and C1 was much lower than in previous seasons. Given the large amounts of chorusing at K105A in Spring 2018, it is seems likely that strong chorusing may stimulate other *L. aurea* to move towards a wetland.

Animal ID (PIT #)	Sex	Initial date	Starting point	End date	Destination	Minimum distance (metres)
In/out of CHEMP (includes between NCIG stages)						
0007D308C6	M	19/12/2017	BHP-14B	1/11/2018	BHP-2A	1,022
0007A109D9	M	23/03/2018	BHP-14B	21/11/2018	BHP-2C	1,184
0007D3C527	F	18/01/2018	NCIG_1.2	18/10/2018	NCIG_4.5	935
0007D6438B	M	28/02/2018	NCIG_1.3	18/10/2018	NCIG_4.9	1,081
00078A91D7	M	1/03/2018	NCIG_7.2	11/12/2018	NCIG_5.1	253
Area 2 Fence						
0007A0F010	F	6/03/2018	C2	10/10/2018	Area 2 Fence	1,411
In/out of K105A						
0007A1067F	M	16/12/2016	K29	11/09/2018	K105A	201
0007A1096D	M	12/01/2018	K29	11/09/2018	K105A	201
000791EE3F	M	8/01/2017	K29	15/10/2018	K105A	201
00079204A0	M	11/01/2018	K29	15/10/2018	K105A	201
0007A10A74	M	21/11/2017	K29	15/10/2018	K105A	201
0007A11360	M	21/11/2017	K29	15/10/2018	K105A	201
0007D216E9	M	22/11/2017	K29	15/10/2018	K105A	201
0007D340C4	M	21/11/2017	K29	15/10/2018	K105A	201
0007A0D1E6	F	10/01/2018	K29	10/12/2018	K105A	201
0007A0FF26	F	19/12/2016	K29	10/12/2018	K105A	201
0007DE4086	M	16/03/2018	C1	15/10/2018	K105A	408
000792056D	M	13/12/2016	C1	10/12/2018	K105A	408
0007DE4044	M	18/01/2018	K106C	15/10/2018	K105A	170
956000003491405	M	14/03/2018	K23	15/10/2018	K105A	52
0007A10B7E	M	14/11/2017	K23	15/10/2018	K105A	52
In/out of K29						
0007D192B2	M	1/12/2017	K13	8/10/2018	K29	1,265
0007A0AE49	F	17/11/2017	K23	11/12/2018	K29	367
000791EA95	M	2/03/2018	C1	9/10/2018	K29	65
0007A0F35E	M	16/03/2018	C1	13/12/2018	K29	65
0007D3A54D	F	25/01/2018	K115	11/12/2018	K29	1,235
0007A10F8F	M	14/12/2016	K29	18/10/2018	K103	181
Other movements						
0007DE11E3	M	6/03/2018	C2	19/10/2018	K123	51
0007D2DA97	M	7/12/2017	K100A	22/10/2018	K111	206
956000003476093	F	15/01/2018	K106C	18/10/2018	K105AS	493
0007DE4008	M	28/02/2018	K106C	18/10/2018	K105AS	493
0007D2658F	M	16/01/2017	K115	18/10/2018	K102	479
956000003460731	M	18/01/2018	K36	19/10/2018	K122	296
0007D2CE39	F	4/12/2017	K36	13/12/2018	K49B	95
0007633E52	M	23/01/2018	K46	6/12/2018	K105B	465

Table 3.5.4: Detected movement between study seasons. Data sourced from multiple studies (see text). Coloured fonts show individuals where multiple movements were detected (compare with Table 3.5.5 and Figure 3.5.1, and with previous year's report).

Animal ID (PIT #)	Sex	Year of first capture	Starting point	Year of recapture	Destination	Minimum distance (metres)
In/out of CHEMP (includes between and within NCIG stages)						
0007D1F34C	M	12/09/2018	BHP-14B	20/12/2018	NCIG_4.9	2,129
0007D3D932	M	19/09/2018	NCIG_5.1	11/12/2018	NCIG_5.2	48
0007A35266	M	19/09/2018	NCIG_7.1	15/01/2019	NCIG_7.2	18
Area 2 Fence						
0007DDFC54	F	13/12/2018	K29	18/12/2018	Area 2 Fence	505
0007DDFAFF	JF	29/11/2018	Area 2 Fence	10/12/2018	K106B	60
In/out of K105A						
00079204A0	M	15/10/2018	K105A	11/12/2018	K29	201
0007A33b38	M	15/10/2018	K105A	11/12/2018	K29	201
0007A10A74	M	15/10/2018	K105A	12/12/2018	K29	201
0007DE2F5B	M	15/10/2018	K105A	12/12/2018	K29	201
0007920726	M	15/10/2018	K105A	13/12/2018	K29	201
0007920726	M	9/10/2018	K29	15/10/2018	K105A	201
0007DE436D	M	9/10/2018	K29	15/10/2018	K105A	201
In/out of K29						
0007D192B2	M	8/10/2018	K29	4/12/2018	K104	1,290
Other movements						
0007A0ECDE	M	29/10/2018	K100A	30/11/2018	K114	735
0007DF4829	M	22/10/2018	K108	17/12/2018	K100A	97
0007DF5328	M	22/10/2018	K112	26/11/2018	K123	155
0007A0ECDE	M	30/11/2018	K114	17/12/2018	K100A	735
0007DE3E02	F	11/09/2018	K46	16/10/2018	K105B	465

Table 3.5.5: Detected movement within the 2018-19 study season. Data sourced from multiple studies (see text). Coloured fonts show individuals where multiple movements were detected (compare with Table 3.5.4 and Figure 3.5.2)

Interestingly, not all movement to K105 were from nearby wetlands. One animal that had been tagged at C2 in March 2018 was captured in the Area 2 drift fence immediately adjacent to the eastern shore of K105A in October 2018; it had moved a distance of 1.4 km and was evidently moving towards K105A.

In terms of distance, other notable movements detected in 2018-19 included:

i. BHP-14 to BHP-2 (~1.2 km) (x 2)
ii. NCIG_1.3 to NCIG_4.9 (1 km)
iii. K13 to K29 (1.3 km)
iv. K115 to K29 (1.2 km)
v. K106C to K105AS (0.5 km) (x 2)
vi. BHP-14B to NCIG_4.9 (2.1 km)
vii. K29 to Area 2 Fence (0.5 km)
viii. K29 to K104 (1.3 km)

Of these, the movement BHP-14B and NCIG_4.9 is a rare example of connectivity between the Central and Northern Zones. Likewise, the movement between K104 and K29 shows that, despite its distance from other surveyed wetlands, K104 is not completely isolated.

As predicted in the report for the previous season (McHenry et al. 2019), multiple seasons of tagging *L. aurea* in the southern region of the Industrial Zone resulted in a greatly increased number of detected movements in 2018-19, including:

i. from K108 to K100A
ii. from K112 to K123
iii. from K36 to K122
iv. from K36 to K49B
v. from K46 to K105B (x2), and
vi. an animal that moved from K100A to K114 in the Spring, and then back to K100A in the Summer.

Many of these movements are towards wetlands were breeding was recorded in 2018-19.

Most movements detected in the last five years are less than 500 m distance, with 34 of these being less than 100 m (note that this does not 382 movements between adjacent CHEMP wetlands and between K22 and K23, which all involve small distances). However, 14 movements are greater than 1 km (Table 3.5.6).

minimum distance of movement (m)	count (*n*)
0-100	34
101-500	52
501-1000	8
>1000	14

Table 3.5.6: frequency of movement distance for movements detected since 2015.

Most (313) of the movements 516 movements detected since 2015 involve males, 9 of which were first caught as juveniles (Table 3.5.7). Of the 115 females detected, 12 were first caught as juveniles.

Age/Sex class	n
J (J)	73
J (M)	9
J (F)	12
M	304
F	115

Table 3.5.7: Age/sex class summary of the 516 movements detected between 2012 and 2019. Brackets indicate sex at maturity for animals first captured as juveniles. See text for discussion.

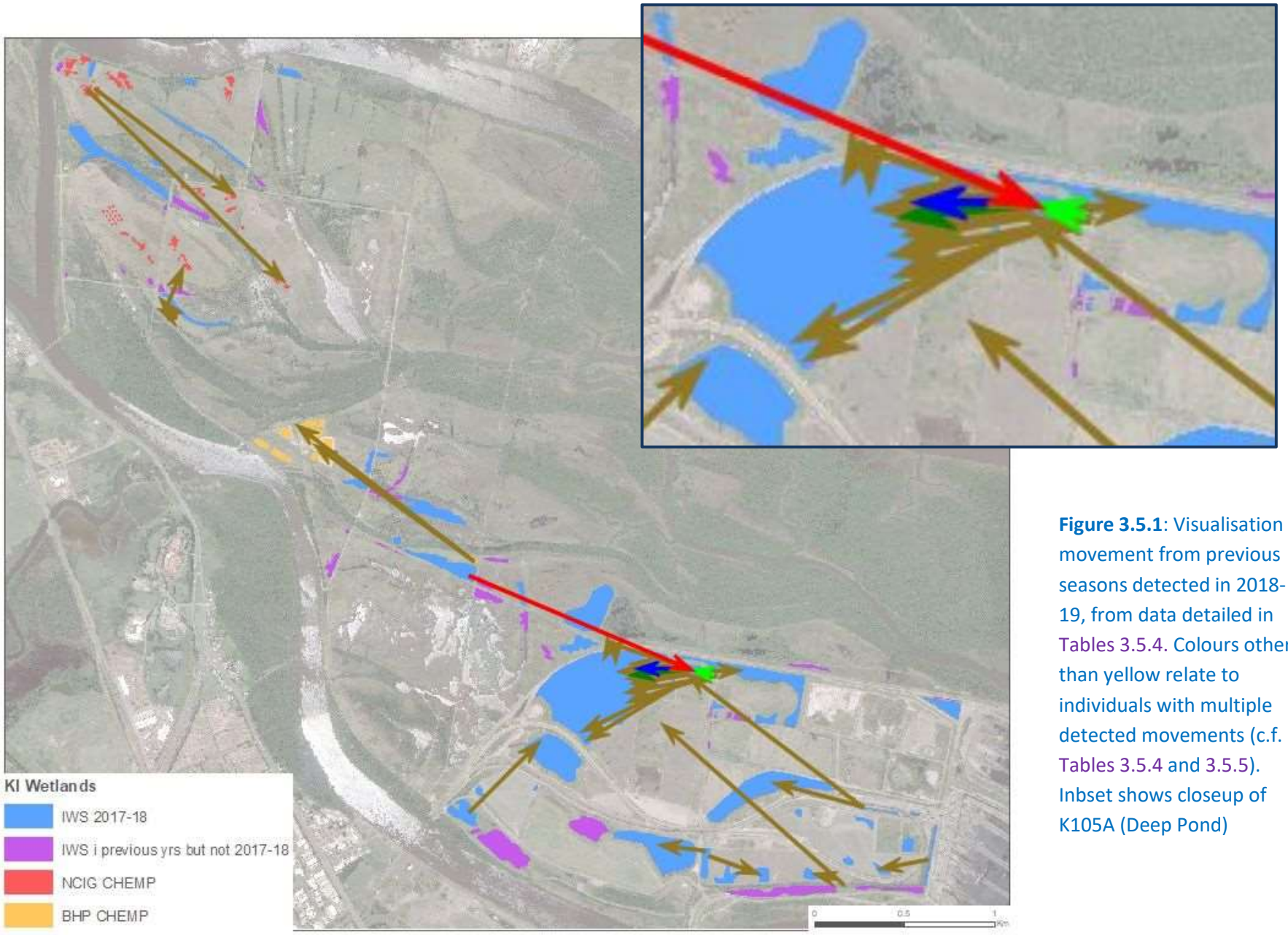


Figure 3.5.1: Visualisation of movement from previous seasons detected in 2018-19, from data detailed in Tables 3.5.4. Colours other than yellow relate to individuals with multiple detected movements (c.f. Tables 3.5.4 and 3.5.5). Inbset shows closeup of K105A (Deep Pond)

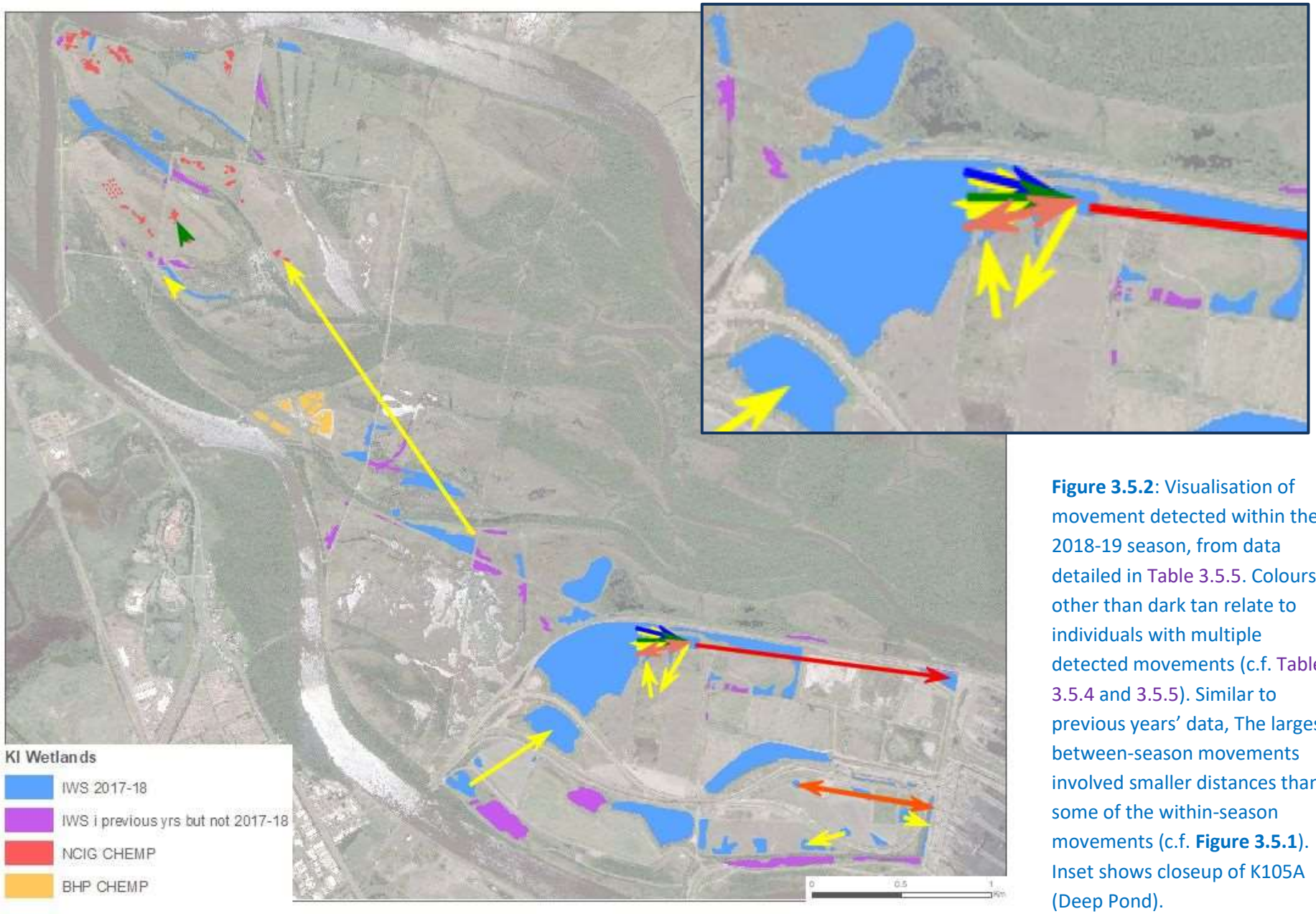


Figure 3.5.2: Visualisation of movement detected within the 2018-19 season, from data detailed in Table 3.5.5. Colours other than dark tan relate to individuals with multiple detected movements (c.f. Tables 3.5.4 and 3.5.5). Similar to previous years' data, The largest between-season movements involved smaller distances than some of the within-season movements (c.f. **Figure 3.5.1**). Inset shows closeup of K105A (Deep Pond).

Interaction between movement and persistence

As highlighted in the 2017-18 annual report (McHenry et al. 2019), a *prima facie* reading of the longitudinal data suggests that *Litoria aurea* on Kooragang Island show a high level of philopatry; the vast majority (2,652 out of 3,168) of *L. aurea* that are tagged and recaptured are re-caught in the same wetland as their first capture. However, as shown above most final recaptures are only a short time after the initial capture; 2,413 of the recaptured frogs are not encountered more than six months after their initial capture. The probability of detecting a movement in this time must inevitably be lower than for individuals with a greater time between first and last capture, and we showed last year that this is exactly the pattern shown by the data; for *L. aurea* that are recaptured more than 2 years after their initial capture, more than 40% had moved to a different wetland.

The addition of the 2018-19 season data to the longitudinal dataset does not change that overall pattern. Table 3.5.8 shows that, of the 3,156 recaptured animals, 2,413 were captured for the last time less than size months after their first capture. Of the 3,156, we detected movement within the first six months in 410 animals, a proportion of 13%. For 326 animals, that was the last movement detected. Of the 2,413 frogs whose final capture was less than 6 months after their first, 313 had moved (again, a proportion of 13%), although multiple movements were detected for some of these and the total number of movements for those 313 animals was 367.

The probability of detecting movement increases as individual *L. aurea* persist in the landscape. Individuals that have survived for more than two years after initial capture have a 33% chance of having moved in that time (15 animals that had moved out of 46 animals that persisted more than 2 years). For animals that persisted more than three years, that proportion is 67%.

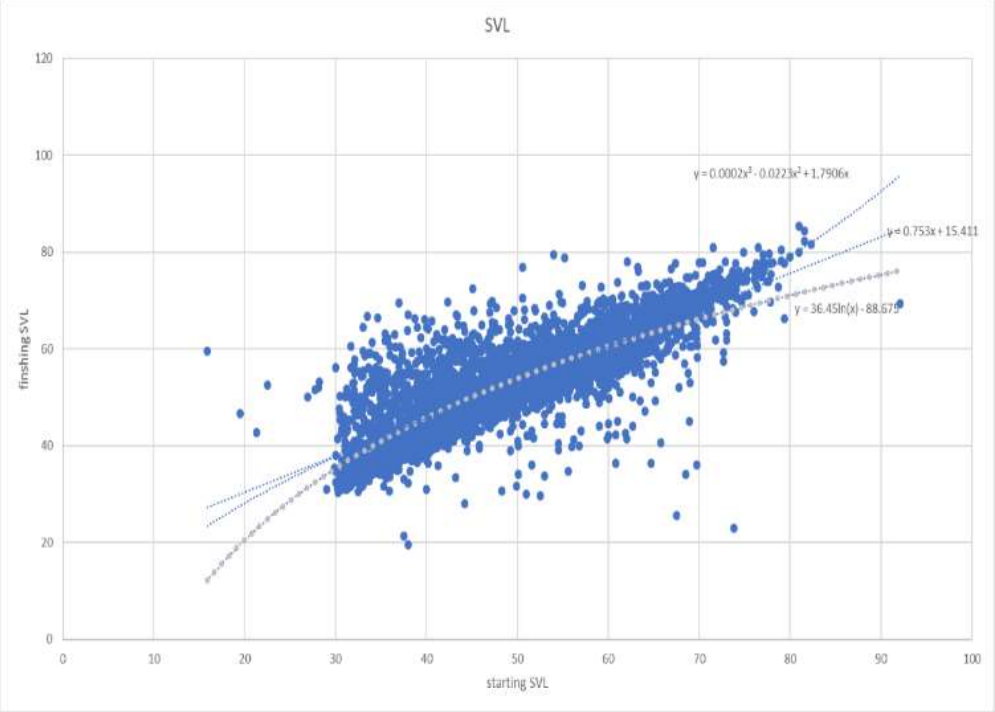
	maximum 'age' (non-cumulative)				'age' at movement (cumulative)			
	number of animals	oldest 'age' of animals that moved	number of movements detected		cumulative total of animals that made it to this age	animals that moved	most recent movement	% moved
x < 6 months	2413	313	367		3156	410	326	13%
6 < x < 12 months	448	148	180		743	191	157	26%
1 < x < 2 years	249	94	128		295	101	77	34%
2 < x < 3 years	34	17	35		46	15	13	33%
3 < x < 4 years	8	6	8		12	8	6	67%
4 < x < 5 years	4	4	10		4	3	3	75%

Table 3.5.8: 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. See text for discussion.

Growth

Growth rates are an important part of an organism's biology; they can indicate general health, and they underpin the time taken to reach sexual maturity. Understanding growth rates are key to interpreting age from body size; in the context of *L. aurea* on Kooragang Island, where annual mortality is known to be elevated as a result of chytridiomycosis, information on the age of adult animals is critical to understanding the effective population size.

Unfortunately, growth rates are a product of age and size and whilst the latter can be measured directly, the former is difficult to ascertain. Attempting to plot growth rates using only size data is be problematic (Figure 3.5.3). Plots incorporating the time between capture events contain a great deal of noise (Figure 3.5.3), even when data are sorted into categories reflecting size at first capture (Figure 3.5.4).



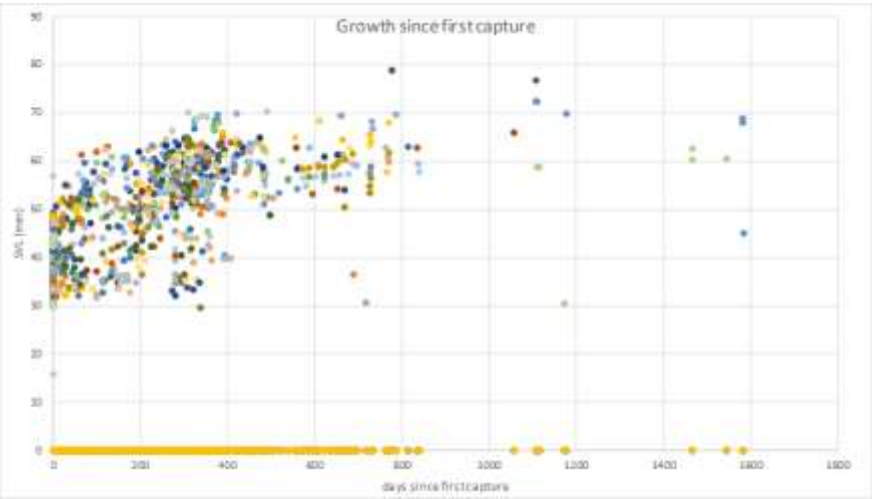


Figure 3.5.3: Growth (measured as change in measured SVL), for animals with > 200 days between first and last capture. Upper chart shows SVL at a given capture (capture *n*) plotted against SVL (capture *n+1*). Lower chart shows SVL of individuals at every recapture (data for each individual is coloured alike).

The wide scatter in each chart results from a combination of measurement error, databasing errors stemming from missing values, and real variation in growth rates of *L. aurea*.

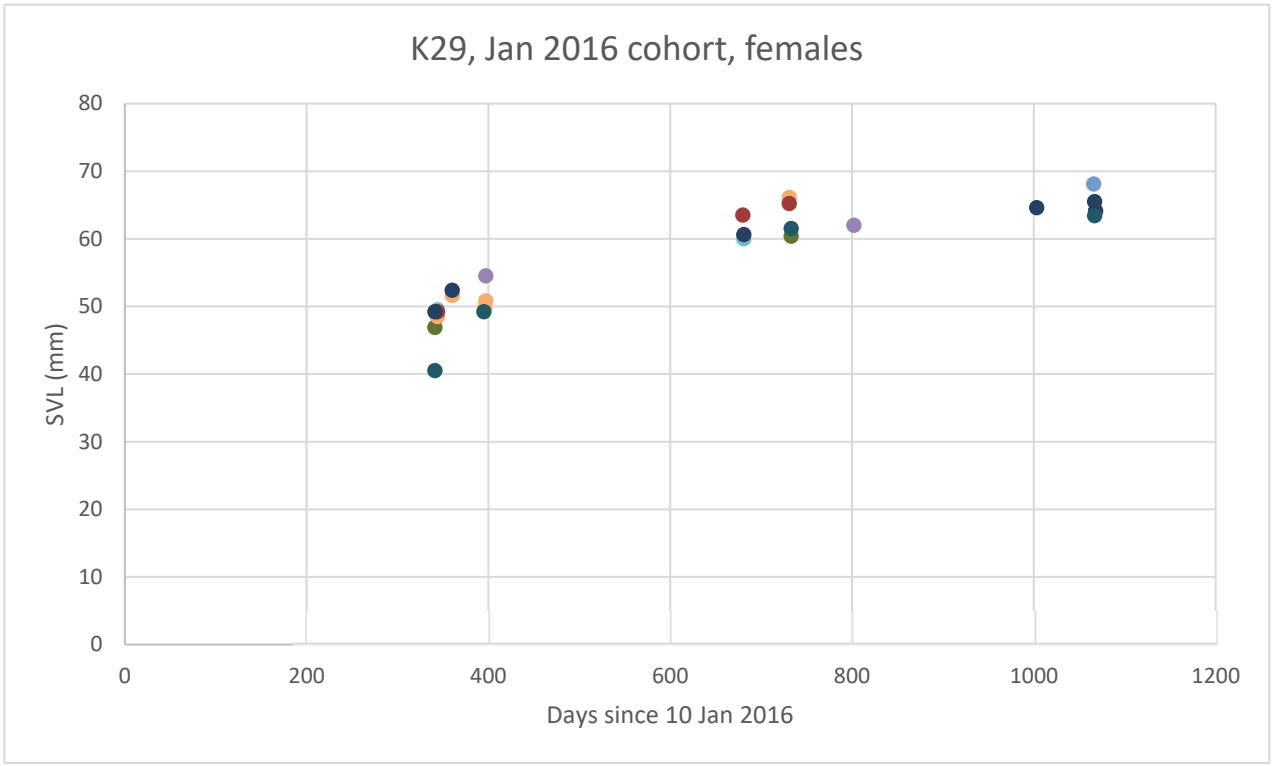
Figure 3.5.4: Growth between captures (delta SVL) against days since first captures, with data points coloured according to the size category of the frog at first capture (legends are labelled by upper boundary of each size category). Regression lines are logarithmic, plotted using Excel's default trendline function.

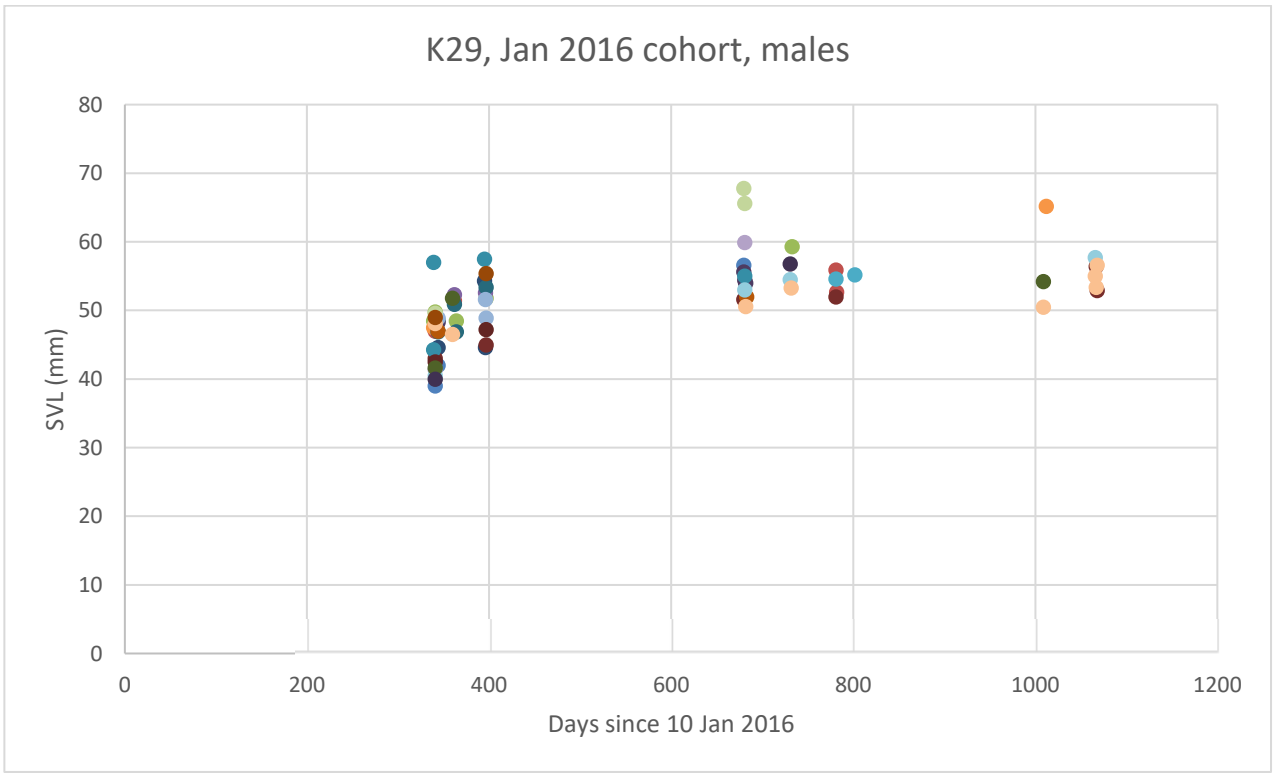
Note that, as might be expected, regression lines for animals who were 30-40 mm SVL (grey) and 40-50 mm SVL (yellow) at first capture show higher growth rates than animals who were 50-60 mm (blue), 60-70 mm (green), or 70-80 mm (brown). As with the data shown in Figure 3.5.3, the wide scatter in each chart results from a combination of measurement error, databasing errors stemming from missing values, and real variation in growth rates of *L. aurea*

Although measurement and databasing errors undoubtedly contribute to the noise in these charts, part of the problem is that the age at first capture is not known. However, there are a small number of *L. aurea*, who have been recaptured multiple times, whose age can be reasonably surmised as they are part of cohorts of animals recruited during specific large breeding events. One of those events was at K106 in January 2016, and another K104 in October 2016. The animals spawned at K106 are believed, with some confidence, to have moved to K29 and were detected as a large cohort of juveniles during CMR surveys in the Spring of 2016, whilst the *L. aurea* spawned at K104 are evidently remained in that wetland, where they formed a cohort that could be detected through the Summer of the 2016-17. The details of both these cohorts are provided in the 2016-17 annual report (McHenry et al., 2017).

Several of the animals spawned at K104 in October 2016 where recaptured through the rest of that season, and provide data on growth rates in the first six months of their life (Figure 3.5.5). Note that this growth occurred over the course of late Spring and Summer. However, only one animals was recaptured and measured after that season, so long term growth rates are not documented for that cohort.

K29


K29, Jan 2016 cohort, females
SVL (mm)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
Days since 10 Jan 2016


K29, Jan 2016 cohort, males
SVL (mm)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
Days since 10 Jan 2016

K104

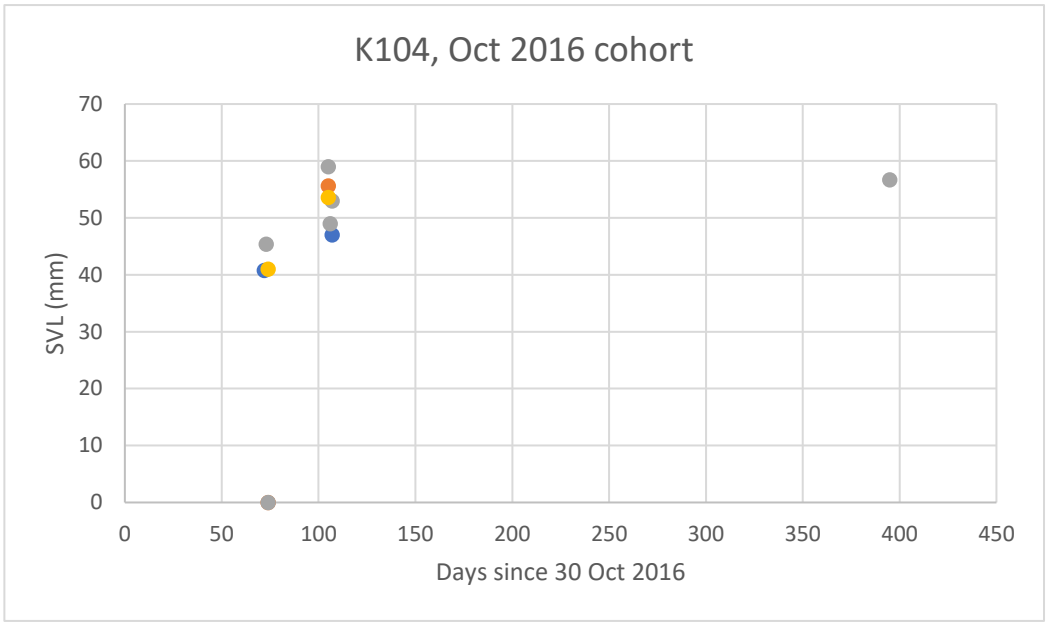


Figure 3.5.5: Growth curves for two cohorts of PIT-tagged animals that could be identified to specific breeding events. Explanation of the cohorts is provided in the 2016-17 Annual Report (McHenry et al. 2017).

The two charts on the previous page show individuals at K29 presumed to have spawned in January 2016, separated by sex (females above, males below). Data points from each individual frog are coloured alike. The chart on this page shows individuals assumed to have been spawned at K104 in October 2016, and subsequently captured on multiple occasions since. See text for discussion.

In contrast, many more of the animals first captured as juveniles in K29 in the 2016-17 season persisted for one or even two seasons after their initial capture (Figure 3.5.5). Together, these provide enough data to reconstruct separate growth curves for male and female *L. aurea* on Kooragang Island. Females grew to 40-50 mm SVL by 12 months after they were spawned (note that these animals were spawned in the middle of the breeding season and had over-wintered as small juveniles and their growth rates are thus slower than animals spawned at the start of the breeding season, as was the case for the K104 data). By the 2017-18 breeding season all of the females still persisting had reached 60 mm SVL, with the largest being 66 mm. By their third full season in 2018-19, during which they turned three years old, they had reached sizes of 64-68 mm SVL. The asymptote for their growth trajectory appears to be just below 70 mm SVL.

Growth rates for males were similar initially, but included some animals that reached 58 mm SVL by the end of February 2017 (i.e. 13 months old). However, their growth appears to have plateaued shortly after; one male grew larger than 66 mm SVL in its second full season, but most were between 50 and 60 mm, notably smaller than the females from the same cohort. That size did not increase in their third full season; unlike females, males reach maximum size in their second year and many actually achieve this by the end of their first.

3.6 Breeding and recruitment

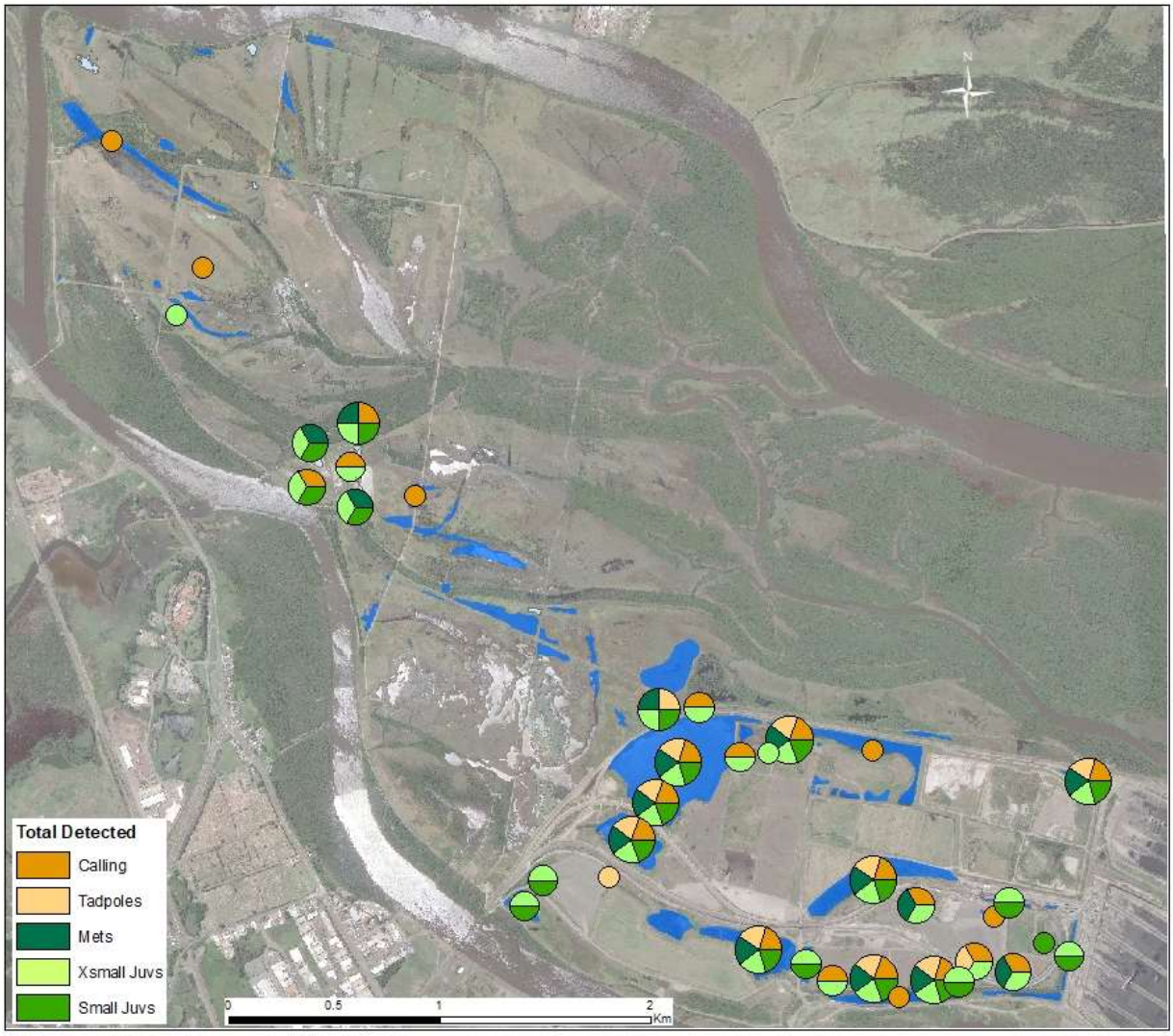


Figure 3.6.1: *L. aurea* breeding (i.e. calling, detection of tadpoles and/or metamorphs, small juveniles) during the 2018-19 survey season. 'Xsmall' juveniles have SVL < 35 mm; 'Small' juveniles have 35 < SVL < 40 mm. Note that the size of the segments within the pie charts denotes only presence of an age/six class or breeding behaviour; it does not indicate the quantity within each category. See Figure 3.6.2 for close up of Industrial Zone wetlands.

As outlined above, the 2018-19 season was marked by a large breeding event in the first half of the season, which followed high levels of spring rainfall in early September and especially early October 2018. Calling was widespread through September, October, and into December 2018 (Figure 3.6.1); the largest chorus witnessed was at K105A in October and that wetland appears to have been a focus for *L. aurea* breeding activity in the southern part of the island (see 'movement' results in **Section 3.5** above).

Calling does not necessarily indicate that breeding took place, however; the most direct evidence is the presence of *L. aurea* tadpoles. These were detected across a large number of wetlands across the Industrial Zone (Figure 3.6.2); they were also detected in the BHP CHEMP wetlands, although that data is not shown here. Within the Industrial Zone, tadpoles were found at K29, K105A, K105AS, K105B, and K104 in the northern region, and K118, K102, K49B, K122, K123, and K112 in the southern.

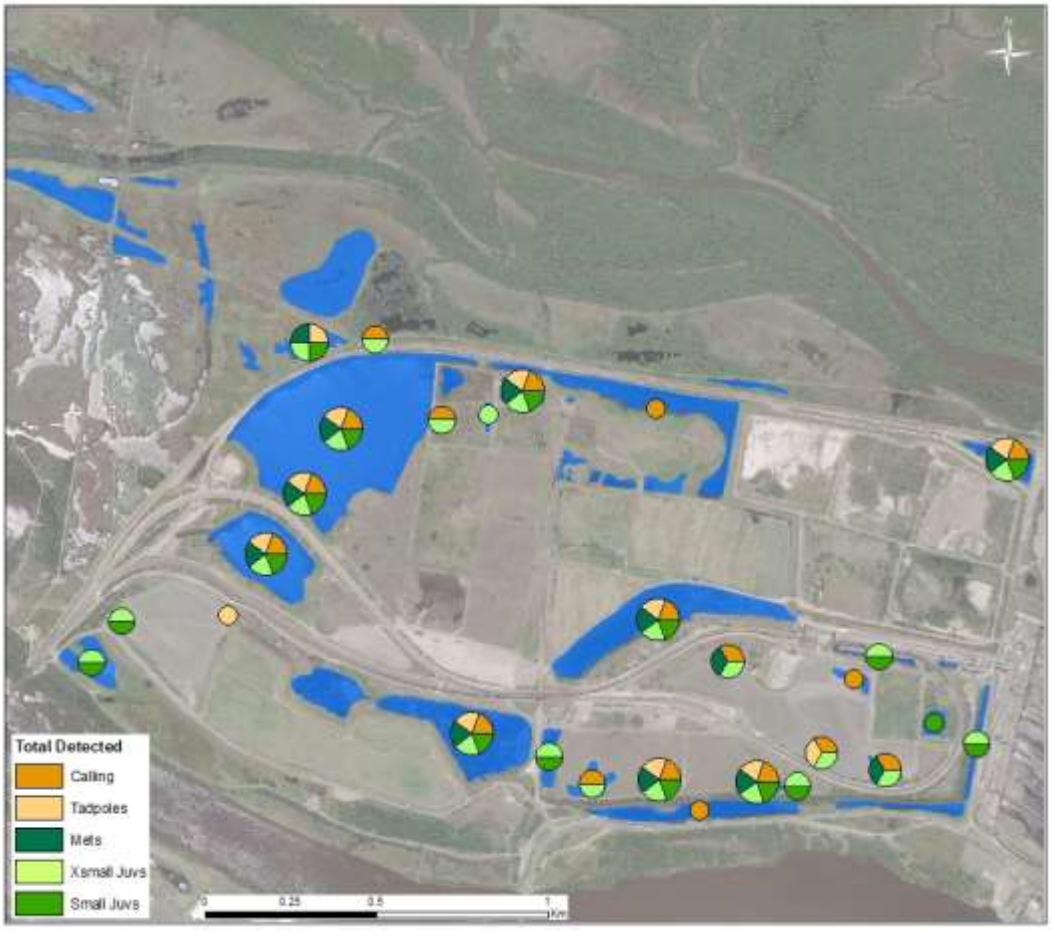


Figure 3.6.2: Evidence for *L. aurea* breeding in southern Kooragang Island. See Fig. 3.6.1 for explanation.

A difficult with detecting *L. aurea* tadpoles is that positive identification in the field is difficult. In contrast, *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. Metamorphs are known to disperse over terrestrial habitat and so do not always indicate breeding at a specific wetland; but if present in large numbers (as was the case with K105A in December 2018, for example) then breeding can be confidently said to have occurred. In the Industrial Zone, metamorphs were detected at every wetland in which there were tadpoles (see above), with the exception of K118; metamorphs were also seen at K111 and K114. Note that Figure 3.6.1 shows only the presence/absence of tadpoles, metamorphs etc., not their abundance; by far the largest numbers of metamorphs were seen at K105A, but they were also present in large numbers at K104, K105AS, K29, K114, and K123. Almost all metamorphs were detected in Round 2 (December 2018), also some were detected in K123 in Round 3 (Figure 3.6.3) and in the BHP CHEMP wetlands (Chad Beranek, pers. comm.)

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. Large numbers (≥ 10) of very small juveniles were detected in K104, K105A, K105AS, K105B, K29, and C2 in Round 2, and in K123 and C2 in Round 3. In the case of C2, breeding is not thought to have occurred in those cluster ponds, but instead in the nearby wetlands such as K123. Note, however, that the largest number of very small juveniles were captured in the Area 2 drift fence, i.e. terrestrial habitat up to 300 metres away from the nearest wetland from which they might have originated.

Within the Industrial Zone, the 13 wetlands within which either tadpoles or metamorphs were detected was the highest number yet detected (note that data K105A and K105AS are shown separately but these are parts of the same wetland). Six of these were HDC constructed wetlands (Figure 3.6.2); of these, the largest number of tadpoles and metamorphs were seen at K114 and K123.

Of the rest, the highest numbers of tadpoles and metamorphs were detected at K105A (including K105AS), K29, and K104; interestingly, these are all permanent (i.e., 'nearly permanent' or 'deep permanent' in the hydroperiod categories detailed in **Section 3.2**), demonstrating that *L. aurea* are not necessarily limited to ephemeral wetlands for large breeding events. Two of these (K29 and K104) are understood to provide refuge habitat for large numbers of adult *L. aurea* over multiple seasons. However, the characteristic that all of these wetlands did have in common in the Spring of 2018 was that *Gambusia* densities were very low or zero.

Calling was very closely associated with periods of recent rain between September and December 2018 (Figure 3.6.3). 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 (Figure 3.6.3). The large numbers of very small ('Xsmall'; SVL < 35 mm) and small (35 < SVL < 40 mm) juveniles indicate several potential cohorts, possibly resulting from:

1. Frogs that were spawned in March-April 2018, following significant rain.
2. Frogs that were spawned in early spring 2018 following rain in late August to early September.
3. Frogs that were spawned in mid spring 2018, following significant rain in early October, and
4. Frogs that were spawned during late spring rain in late November/early December.

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), very small ('Xsmall'; SVL < 35 mm; light green) and small (35 < SVL < 40 mm; dark green in bottom chart) juveniles. Numbered arrows related to potential cohorts outlined in the text.

Size at sexual maturity

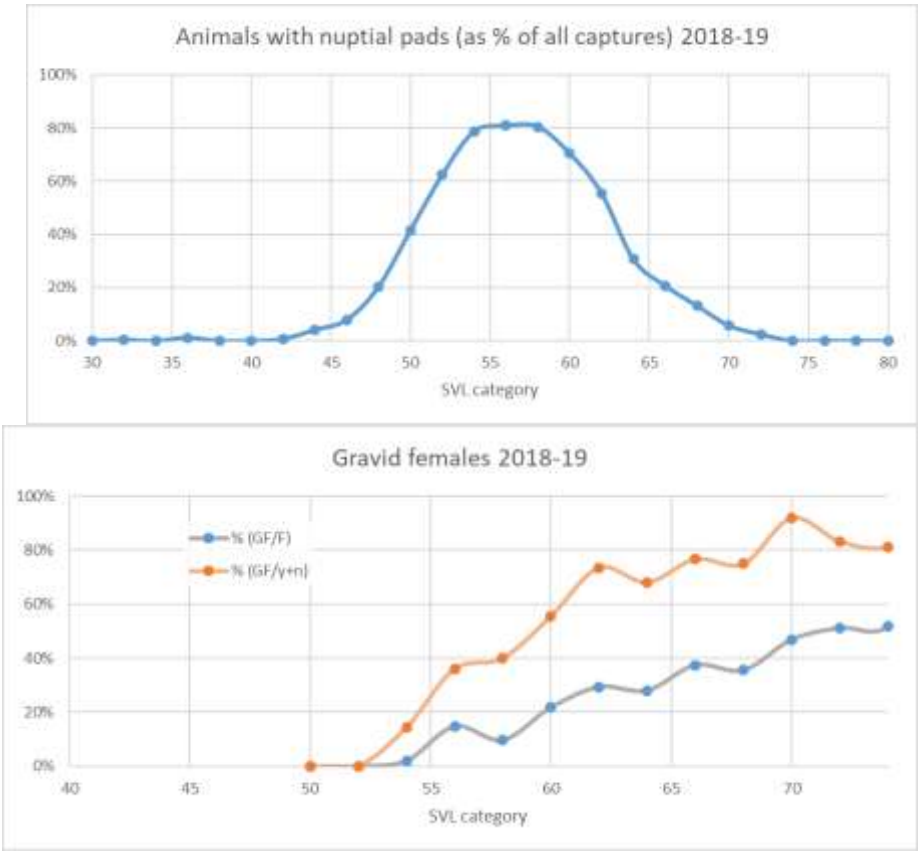


Figure 3.6.4: Proportions of animals with nuptial pads (top), and proportion of gravid animals (bottom). See text for discussion.

Data from the 2017-18 season (Figure 3.6.4) is broadly consistent with the observation from the previous seasons (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, and that latter percentage was the plateau point for the 2018-19 data as well (Figure 3.6.4). 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 or 2018-19 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 the 2018-19 indicates that some females achieve sexual maturity at 54 mm SVL (Figure 3.6.4), similar to the 52 mm size recorded in the 2017-18 data (McHenry et al. 2019). By 62 mm SVL, approximately 75% of the females candled were gravid.

The size threshold used to delineate between adult and juvenile females in 2016-17 was 58 mm SVL; we here cautiously 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
2018-19	tads/mets	3	11
	no tads/mets	10	49

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.

The data presented in Table

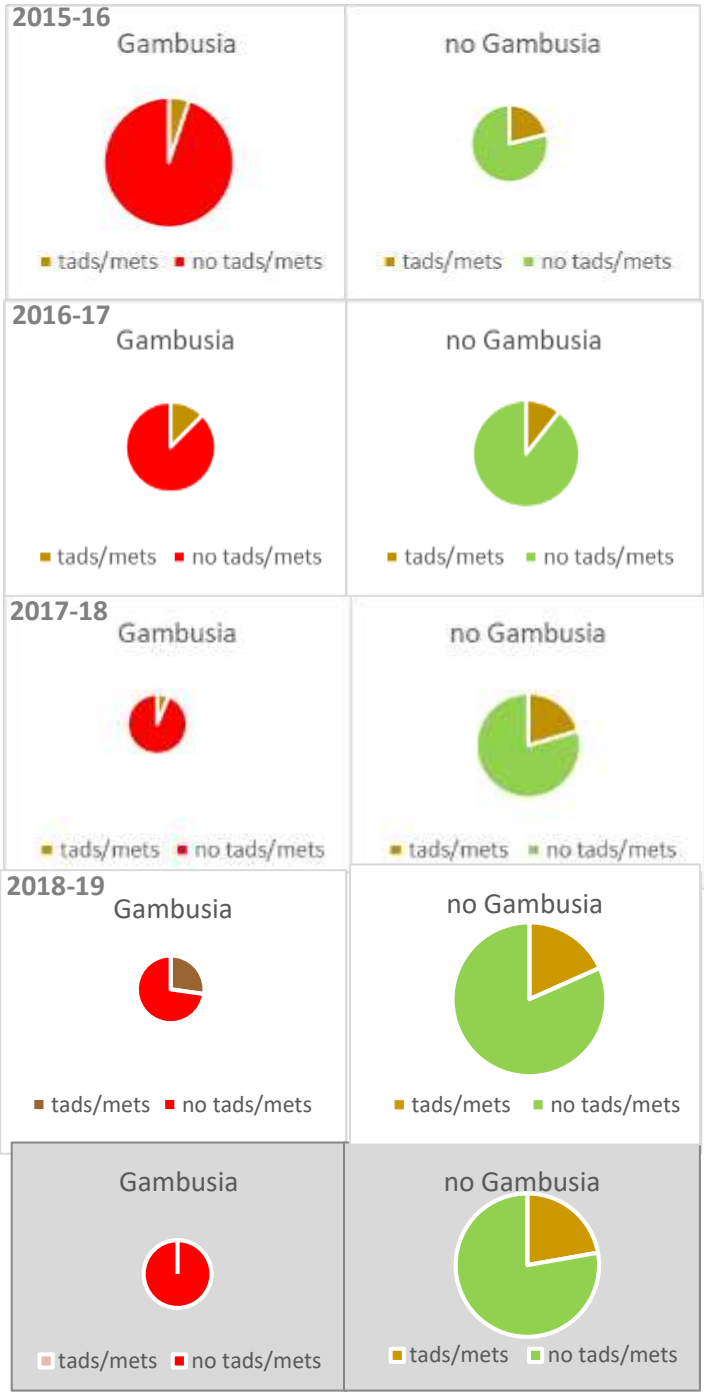


Figure 3.6.5: Graphical representation of the data presented in Table 3.6.1. The filled charts at the bottom show the 2018-19 adjusted to show counts with low and/or zero densities of *Gambusia*.

3.6.1 and Figure 3.6.5 shows a strong interaction between the presence of *Gambusia* and breeding by *L. aurea in* 2015-16 and 2017-18. However, based only on binary presence-absence data, there appears to be no effect for the 2016-17 and 2018-19 data. As noted previously (McHenry et al. 2019), looking simply at 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. In the current season, *Gambusia* was recorded at three wetlands where *L. aurea* tadpoles and metamorphs were detected: K102, K104, and K105AS. However, the density of *Gambusia* at each of these was much less than in previous seasons. Adjusting for the charts so that these wetlands with low density and absence of *Gambusia* are grouped together again indicates that breeding is seen more frequently when *Gambusia* is not abundant (Figure 3.6.5).

The differences in *Gambusia* density are directly related to the hydrology of the wetland prior to the breeding season, and each of these almost completely dried out in the 2017-18 season; whilst *Gambusia* were not eradicated completely, their numbers at each wetland were evidently substantially reduced.

3.7 Microhabitat and Habitat

Vegetation (microhabitat)

Structures	*n* (captures)
trees	58
emergent vegetation	2,668
water	332
ground	177
man-made structure	99
ground vegetation	342
shrubs	61

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, Bolboschoenus,* and *Schoenoplectus*, in addition to the introduced species *Juncus acutus* (Table 3.7.2). They were also on frequently found on the ground, especially on *Paspallum* grass. 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 bitou, lantana, or pampas. They were also regularly found in trees (Table 3.7.2), especially mangroves.

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	4
Casuarina	1
tree	11
branch	7
dead branch	0
fallen tree	0
mangrove	35
Baumea	1
Bolboschoenus	743
Eleocharis	13
Juncus	99
Phragmites	302
Schoenoplectus	104
Typha	1399
reed indet.	7
water	205
algae	39
flooded grass	88
bank	34
ground	43
mud	7
rock	68
road	25
sand-bag	25
sump wall	1
fence trap	56
tub	13
post	4
Foeniculum	0
Hydrocotyle	11
Lomandra	22
Ludwigia	7
Paspallum	234
grass	68
Chrysanthemoides	14
Cortaderia	8
Lantana	13
nest	0
nightshade	12
Ricinus	0
shrub	0
vine	14

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 3.6.3: Qualitative scores used for preliminary analysis of the effects of wetland physiognomy upon *L. aurea* abundance; c.f. Fig. 3.6.1, Fig.3.6.2.

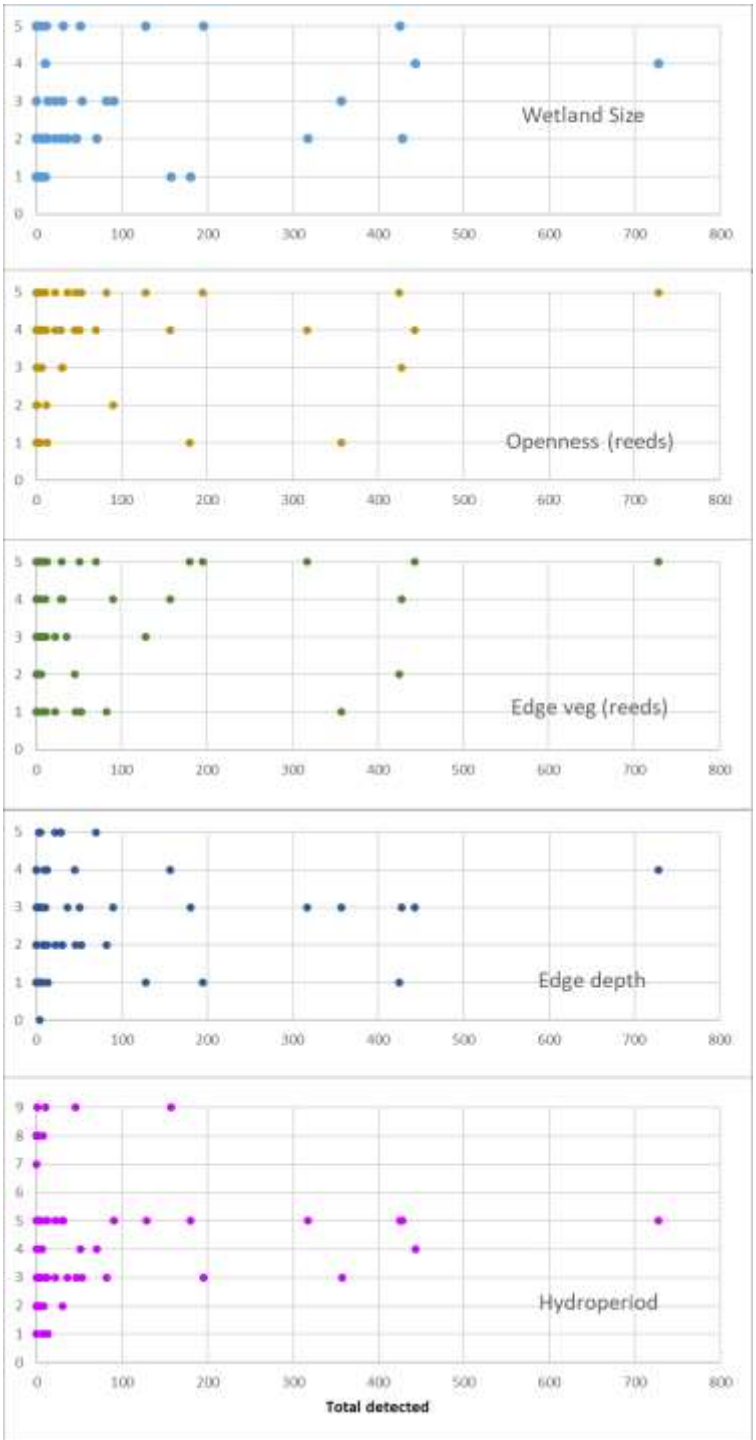


Figure 3.7.1: Scores for wetland size, openness, edge vegetation, edge depth, and hydroperiod, plotted against values of **Total Detected** bell frogs for each wetland surveyed in 2018-19.

An important question in understanding *L. aurea* ecology concerns the habitat requirements of this species. Figures 3.6.1 and 3.6.2 show visualisations of potential 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 visualisation of the relationships between these traits and *L. aurea* 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 with 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 deep permanent wetlands.

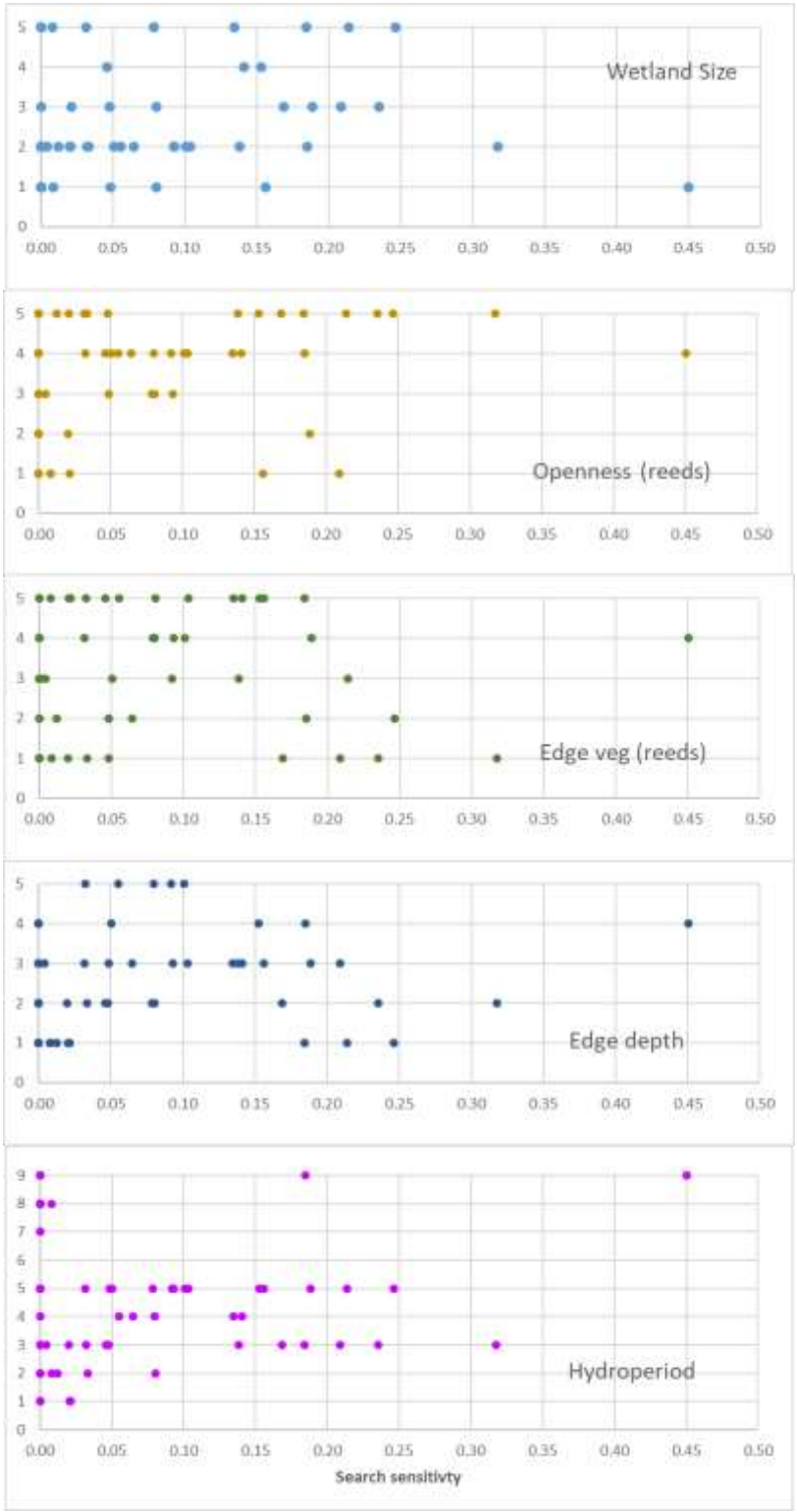


Figure 3.7.2: Scores for wetland size, openness, edge vegetation, edge depth, and hydroperiod, plotted against values of **Search Sensitivity** for each wetland surveyed in 2018-19.

The highest values **for Search sensitivity** (Figure 3.7.2) are likewise strongly affected by high scores for Openness, but are less affected by Edge vegetation, than was Total Detected. Wetland Size has a very weak interaction with Search Sensitivity**.** The relationship with Hydroperiod is similar to Total Detected, although the highest densities were found at a managed wetland (effectively, deep permanent).

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

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 4.4**.

3.8 Population size

Population estimate of wetlands surveyed using Capture-Mark-Recapture

Usually, we aim to conduct Capture-Mark-Recapture (CMR) surveys were conducted at three wetlands; K22/23, K29, and K104. (Table 3.8.1). As detailed in **Section 2.6**, 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, or because drying wetlands contain deep mud that makes intensive surveying treacherous. During the 2018-19 season, the CMR surveys at K22-23 were abandoned in Rounds 1 and 2 due to insufficient detections on the first night. In Round 3, the CMR at K104 was abandoned due to a combination of treacherous conditions as the wetland dried, and low capture rate. The Round 2 CMR surveys at K29 and K22/3 were not attempted due to the ground fire in the Industrial Zone.

Wetland	Dates of primary survey periods	no. secondary surveys	*L. aurea* captures (total; unique)	Final recap. rate (%)	Naïve population estimate
	Round 1				
K22/23	-	-	-	-	-
K29	8-11 Oct 2018	4	87; 63	8%	143
K104	23-25 Oct 2018	3	303; 206	17%	391
	Round 2				
K22/23	-	-	-	-	-
K29	10-12 Oct 2018	3	257; 106	30%	164
K104	3-5 Dec 2018	3	205; 97	22%	210
	Round 3				
K22/23	-	-	-	-	-
K29	-	-	-	-	-
K104	18 Feb 2019	1	20; 3	-	-

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 K22/23 in any round, or at K29 and K104 in round 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*)
	K29				
2	φ(.) *G'(.) G"=0 p=c*(sess) f0(sess)	14	-586.713	0.4212	0.310
4	φ(.) *G'=G"(.) p=c*(sess) f0(sess)	14	-584.516	2.6177	0.103
7	φ(t) *G'=G"(.) p=c*(.) f0(sess)	15	-578.160	8.9738	0.004
	K104				
2	φ(.) *G'(.) G"=0 p=c*(sess) f0(sess)	13	-1496.56	1.1119	0.240
4	φ(.) *G'=G"(.) p=c*(sess) f0(sess)	14	-1494.42	3.2470	0.083
6	φ(t) *G'=G"(.) p=c*(.) f0(sess)	9	-1492.28	5.3919	0.028

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, 2018-19. In the best ranked 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.

The top ranked models produced highly convergent estimates of population size (N-hat values) 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
K29											
#2	101	81	139	0.59	191	169	227		-	-	-
#4	101	81	140	0.65	190	169	227		-	-	-
#7	83	73	100	0.65	212	186	252		-	-	-
K104											
#2	396	335	489	0.33	253	206	331		-	-	
#4	396	335	489	0.33	253	206	331		-	-	-
#6	396	335	489	0.34	253	206	331		-	-	-

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.

Note the low numbers estimated for K29 in Round 1; an 'N-hat' of ~100 frogs is much less than estimates in the previous two seasons, and is consistent with the movement data (Section 3.5) showing that many of the frogs normally resident at K29 had moved to K105A during the breeding event of late spring/early summer.

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	416	497	628	534
Round 2	375	444	558	374

Table 3.8.4: Total population estimates for CMR surveyed wetlands, for each round. Notes that only K29 and K104 were surveyed in each of the two rounds. 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. There is some degree of 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	2.16	4.49	**5.32**	6.71	24.82
K29	2.02	3.94	**4.64**	5.83	26.23
K104	4.15	5.36	**6.44**	8.14	10.85

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.

Note that this number should consider only 'taggable' frogs, i.e. adults and juveniles with an SVL of at least 40 mm; since only taggable frogs can be used to calculate the n-hat in the robust modelling of the CMR data, the conversion factor should only consider 'taggable' frogs detected during the VES. For captured frogs, this can be determined with confidence, but for uncaptured juveniles it represents a potential source of error as there is not way to determine how many may have been smaller than 40 mm SVL.

The pooled conversion factor for the 2018-19 data was 5.3; i.e., for every ≥ 40 mm SVL *L. aurea* detected during VES, we expect that a total of ≥ 40 mm SVL 5.3 frogs were actually present but that 4.3 remained undetected (the conversion factor is thus the inverse of the detection probability). This pooled value was affected by a very low value for K29; the value of 6.4 for K104 is more similar to the values from previous years. It is possible that the low value for K29 is linked to the small number of L. aurea that were present in the first round; many of these were adult females (Figure 3.3.5), and these consistently have the highest detection probabilities (Table 3.1.3).

Combining the min, mean, and max values for the detected/population ratio with the 'N-hat', and also lower and upper 95% confidence intervals se 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.

The range of values for conversion factors are then used to generate estimates of population size at the 62 wetlands that were surveyed only by VES.

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 (*L. aurea* ≥ 40 mm SVL) 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	830	1,724	2,045	2,576	9,531
Round 2	1,535	3,187	3,781	4,763	17,623
Round 3	306	608	722	910	3,214
CHEMP wetlands					
Round 1	251	521	618	778	2,879
Round 2	188	391	463	584	2,159
Round 3	151	314	373	470	1,738
Total VES wetlands					
Round 1	1,081	2,244	2,662	3,355	12,411
Round 2	1,723	3,578	4,244	5,347	19,783
Round 3	457	923	1,095	1,380	4,952

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 3.8.5) Note that VES counts include K22-23 for all rounds, and K104 for 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 64 wetlands surveyed on Kooragang Island over the 2018-2019 season (Table 3.8.7).

Total population size	min-lower	mean-lower	mean-N-hat	mean-upper	max-upper
Round 1	1,497	2,660	**3,159**	3,983	13,039
Round 2	2,098	3,953	**4,688**	5,905	20,341
Round 3	457	923	**1,095**	1,380	4,952

Total population size (not including CHEMP wetlands)					
Round 1	1,246	2,140	**2,542**	3,204	10,159
Round 2	1,910	3,562	**4,225**	5,321	18,181
Round 3	306	608	**722**	910	3,214

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 64 surveyed wetlands was between the 'min-lower' and 'max-upper' limits (i.e. between 1,497 and 13,039 in October 2018).
- It is **probable** that the population was between the 'mean-lower' and the 'mean-upper' figures (i.e. between 3,953 and 5,905 in December 2018)
- The model estimation for the **approximate** population is the 'mean-N-hat' figure, i.e. 4,688 in December 2018.

It is not correct to say that that the population was 3,159 in round 1; rather, the population was **approximately** 3,159.

Note that these estimates include, for only the second season, 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)

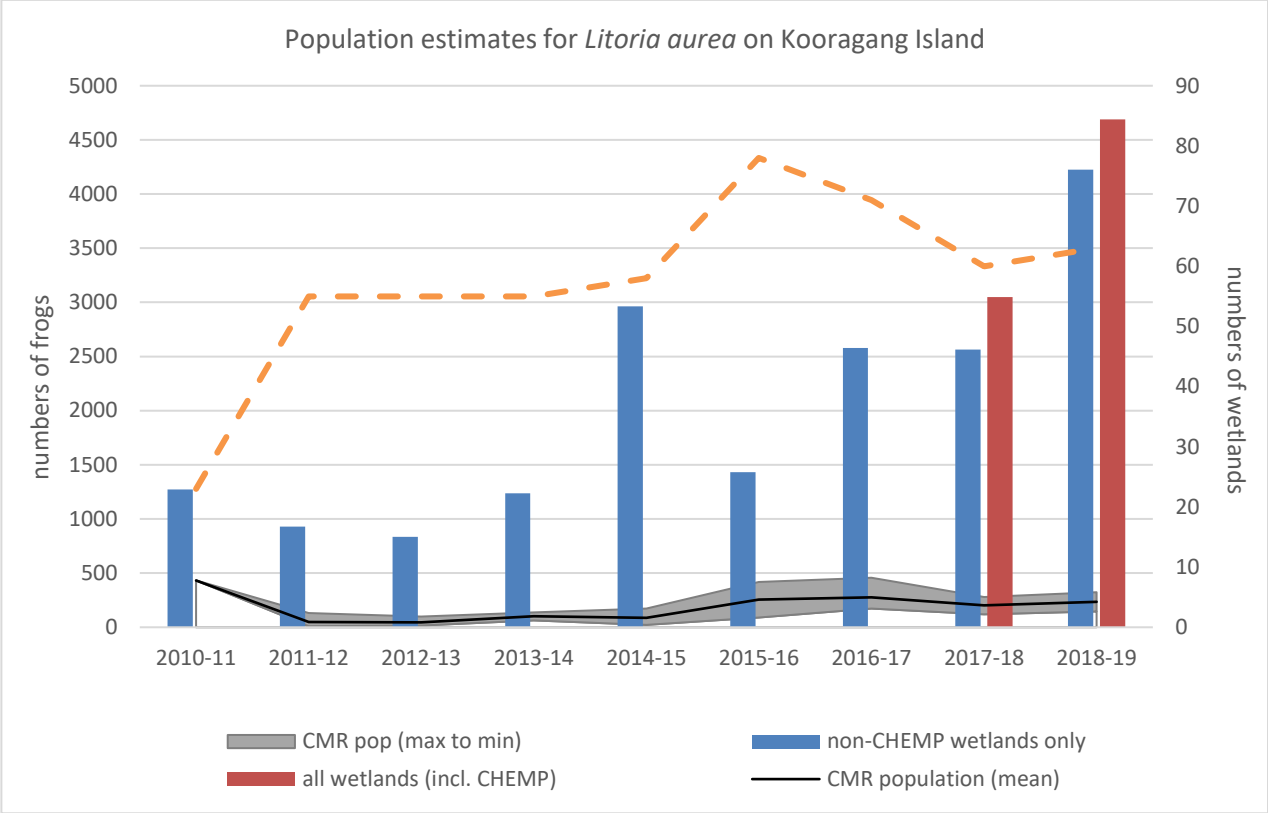


Figure 3.8.1: Population estimates for *Litoria aurea* on Kooragang Island. Data for 2010-2018 is from previous annual reports for the current project, while the 2018-19 data is from the current report. Blue columns show maximum population estimates derived from CMR-VES counts for the non-CHEMP wetlands only, while the red column shows the maximum 2017-18 and 2018-19 estimates 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 greater 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 rounds; 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 2018-19 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. The apparent increase to approximately 4,000 in 2018-19 may be real, but may be an artefact of high detection probabilities during the very large breeding event in Spring 2018, especially at K105A, which included large numbers of juvenile animals. 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 2015-19. Overall, the population seems to be at least stable, especially in the last five seasons, and there is no evidence for a sustained decline across the last eight 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. five 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:

ix. **VES detected** (number of *L. aurea* detected during primary VES surveys)
x. **Total detected** (number of *L. aurea* detected during all surveys, including CMR)
xi. **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.

Note that the patterns for the four seasons from 2014-15 to 2017-18 were outline in detail in the 2017-18 annual report (McHenry et al. 2018). The following description of the data is intended to append, rather than replicate, that account.

	2014-15	2015-16	2016-17	2017-18	2018-19
Jurisdiction					
NPWS	2028	3693	2758	1460	1560
NCIG_CHEMP	0	0	0	296	2228
BHP_CHEMP	30	279	0	1523	1483
PoN	1475	697	1033	423	641
PWCS	2347	2224	3305	4563	4600
NCIG	104	348	319	574	680
HDC	393	720	848	1681	1677
HDC (BHP)	1304	615	442	582	506
RMS	298	278	156	0	0
Zone					
Nth	1027	1617	1056	1040	3014
Central	2423	3052	2735	2662	2898
Southern	4446	4185	5070	7400	7463
Region					
Hunter North River	611	657	395	414	1021
School House	469	960	661	626	1993
Cobbans Creek	458	1132	651	1728	1805
Bellfrog Way	1995	1920	2084	934	1093
Industrial Zone North	2093	1783	2887	3924	3840
Industrial Zone South	2353	2402	2183	3476	3623
Subregion					
Scott's Point	174	264	201	259	726
Riverside park	437	393	194	155	295
Wet meadow	395	678	448	410	426
Millam's Pond	74	282	213	216	1567
Ramsar Road West	110	564	258	1601	1587
Ramsar Road East	348	568	393	127	218
Bellfrog Way West	152	403	350	205	201
Bellfrog Way NE	270	588	465	306	251
Bellfrog Way SE	1573	929	1269	423	641
Delta Ponds (K104)	435	195	570	881	845
KIWEF *K7*	1436	1441	1823	2037	1007
NCIG rail central & east	240	507	496	775	941
Rail loop *K10 Nth*	393	606	596	902	730
Cormorant Road	298	278	156	0	0
Rail loop SW *K10 Sth*	27	110	112	725	906
NCIG rail south	1345	555	474	405	529
KIWEF *K2*	50	346	349	669	517
Deep pond	222	147	494	1006	1988

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.

The search effort (measured in person.minutes) of VES surveys across the last five seasons is shown in Table 3.9.1. Total search effort has increased steadily across this time (c.f. Table 2.5.1). Each wetland takes a minimum of 90 person.minutes to survey over the season, and most take considerably more; as new wetlands have been constructed (HDC wetlands in the Industrial Zone, CHEMP wetlands in the Central and Northern Zones), the number of NPWS, PWCS, HDC (BHP) and RMS wetland surveys have been reduced slightly to keep survey logistics manageable. Search effort remains well distributed across the island as a whole (Figure 2.5.2).

	2014-15	2015-16	2016-17	2017-18	2018-19		2014-15	2015-16	2016-17	2017-18	2018-19
	All						Adults				
Jurisdiction											
NPWS	34	25	11	13	17		27	17	7	4	15
NCIG_CHEMP	0	0	0	5	87		0	0	0	2	65
BHP_CHEMP	0	19	0	394	298		0	13	0	178	138
PoN	59	42	109	50	48		27	13	65	44	29
PWCS	323	87	588	703	1012		128	52	303	377	508
NCIG	0	10	83	83	125		0	3	60	47	65
HDC	15	16	393	151	206		10	9	34	41	95
HDC (BHP)	10	2	48	58	54		6	0	18	35	20
RMS	0	0	6	0	0		0	0	3	0	0
Zone											
Nth	8	3	0	6	92		4	2	0	3	70
Central	85	83	120	456	358		50	41	72	225	177
Southern	348	115	1118	995	1397		144	64	418	500	688
Region											
Hunter North River	0	0	0	1	2		0	0	0	1	2
School House	8	3	0	5	90		4	2	0	2	68
Cobbans Creek	13	31	3	404	301		13	20	2	180	141
Bellfrog Way	72	52	117	52	57		37	21	70	45	36
Industrial Zone North	322	86	546	649	837		127	52	278	347	463
Industrial Zone South	26	29	572	346	560		17	12	140	153	225
Subregion											
Scott's Point	0	0	0	1	2		0	0	0	1	2
Riverside park	0	0	0	0	0		0	0	0	0	0
Wet meadow	8	2	0	1	8		4	2	0	1	4
Millam's Pond	0	1	0	4	82		0	0	0	1	64
Ramsar Road West	1	25	2	404	301		1	14	2	180	141
Ramsar Road East	12	6	1	0	0		12	6	0	0	0
Bellfrog Way West	3	2	0	2	4		2	2	0	1	2
Bellfrog Way NE	8	4	3	0	5		6	3	1	0	5
Bellfrog Way SE	61	46	114	50	48		29	16	69	44	29
Delta Ponds (K104)	204	62	101	153	162		33	36	57	65	96
KIWEF *K7*	116	19	358	276	87		92	13	182	215	70
NCIG rail central & east	0	11	98	95	154		0	3	72	54	77
Rail loop *K10 Nth*	15	16	383	82	66		10	9	28	16	46
Cormorant Road	0	0	6	0	0		0	0	3	0	0
Rail loop SW *K10 Sth*	0	0	16	51	236		0	0	10	19	63
NCIG rail south	9	2	58	42	69		5	0	20	19	23
KIWEF *K2*	2	0	11	76	35		2	0	7	45	16
Deep pond	2	5	87	220	588		2	3	39	67	297

Table 3.9.2: VES Detected numbers for the last five 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.

Data for **VES Detected** (Table 3.9.2) shows that the 2018-19 had the highest numbers of *L. aurea* detected. The high numbers detected in 2018-19 are likely a result of several factors; recruitment in the autumn rain of the previous season, the large breeding event in spring and early summer of the 2018-19 season; and a growing population in the NCIG and especially the BHP CHEMP wetlands. In particular, the probability of detection was likely higher than normal at K105A, K105AS, and K105B during the breeding event, leading to high VES counts.

	2014-15	2015-16	2016-17	2017-18	2018-19		2014-15	2015-16	2016-17	2017-18	2018-19
	All						Adults				
Jurisdiction											
NPWS	0.02	0.01	0.00	0.01	0.01		0.01	0.00	0.00	0.00	0.01
NCIG_CHEMP	-	-	-	0.02	0.04		-	-	-	0.01	0.03
BHP_CHEMP	0.00	0.07	-	0.26	0.20		0.00	0.05	-	0.12	0.09
PoN	0.04	0.06	0.11	0.12	0.07		0.02	0.02	0.06	0.10	0.05
PWCS	0.14	0.04	0.18	0.15	0.22		0.05	0.02	0.09	0.08	0.11
NCIG	0.00	0.03	0.26	0.14	0.18		0.00	0.01	0.19	0.08	0.10
HDC	0.04	0.02	0.46	0.09	0.12		0.03	0.01	0.04	0.02	0.06
HDC (BHP)	0.01	0.00	0.11	0.10	0.11		0.00	0.00	0.04	0.06	0.04
RMS	0.00	0.00	0.04	-	-		0.00	0.00	0.02	-	-
Zone											
Nth	0.01	0.00	0.00	0.01	0.03		0.00	0.00	0.00	0.00	0.02
Central	0.04	0.03	0.04	0.17	0.12		0.02	0.01	0.03	0.08	0.06
Southern	0.08	0.03	0.22	0.13	0.19		0.03	0.02	0.08	0.07	0.09
Region											
Hunter North River	0.00	0.00	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	0.05		0.01	0.00	0.00	0.00	0.03
Cobbans Creek	0.03	0.03	0.00	0.23	0.17		0.03	0.02	0.00	0.10	0.08
Bellfrog Way	0.04	0.03	0.06	0.06	0.05		0.02	0.01	0.03	0.05	0.03
Industrial Zone North	0.15	0.05	0.19	0.17	0.22		0.06	0.03	0.10	0.09	0.12
Industrial Zone South	0.01	0.01	0.26	0.10	0.15		0.01	0.00	0.06	0.04	0.06
Subregion											
Scott's Point	0.00	0.00	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	0.00	0.00
Wet meadow	0.02	0.00	0.00	0.00	0.02		0.01	0.00	0.00	0.00	0.01
Millam's Pond	0.00	0.00	0.00	0.02	0.05		0.00	0.00	0.00	0.00	0.04
Ramsar Road West	0.01	0.04	0.01	0.25	0.19		0.01	0.02	0.01	0.11	0.09
Ramsar Road East	0.03	0.01	0.00	0.00	0.00		0.03	0.01	0.00	0.00	0.00
Bellfrog Way West	0.02	0.00	0.00	0.01	0.02		0.01	0.00	0.00	0.00	0.01
Bellfrog Way NE	0.03	0.01	0.01	0.00	0.02		0.02	0.01	0.00	0.00	0.02
Bellfrog Way SE	0.04	0.05	0.09	0.12	0.07		0.02	0.02	0.05	0.10	0.05
Delta Ponds (K104)	0.47	0.32	0.18	0.17	0.19		0.08	0.18	0.10	0.07	0.11
KIWEF *K7*	0.08	0.01	0.20	0.14	0.09		0.06	0.01	0.10	0.11	0.07
NCIG rail central & east	0.00	0.02	0.20	0.12	0.16		0.00	0.01	0.15	0.07	0.08
Rail loop *K10 Nth*	0.04	0.03	0.64	0.09	0.09		0.03	0.01	0.05	0.02	0.06
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	0.26		0.00	0.00	0.09	0.03	0.07
NCIG rail south	0.01	0.00	0.12	0.10	0.13		0.00	0.00	0.04	0.05	0.04
KIWEF *K2*	0.04	0.00	0.03	0.11	0.07		0.04	0.00	0.02	0.07	0.03
Deep pond	0.01	0.03	0.18	0.22	0.30		0.01	0.02	0.08	0.07	0.15

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.

Nonetheless, the overall trend seems to be an increase in the abundance of *L. aurea* over the five years from 2014-15 to 2018-19. This does not appear to be a simple result of the increase in search effort; **Search Sensitivity** (Table 3.9.3), which is defined as the number of animals detected during VES per unit of search effort, has also increased steadily over this time, although the highest values were in the 2016-17 season (following very high levels of recruitment the previous year). Likewise, the **Total Detected** (Table 3.9.4) number of *L. aurea* has also increased from 2014-15 to 2018-19, but with a peak in the 2016-17 season. Note, however, that the number of CMR surveys in both 2017-18 and 2018-19 were lower than in

	2014-15	2015-16	2016-17	2017-18	2018-19		2014-15	2015-16	2016-17	2017-18	2018-19
	All						Adults				
Jurisdiction											
NPWS	44	29	27	13	17		35	20	14	4	15
NCIG_CHEMP	0	0	0	10	97		0	0	0	5	74
BHP_CHEMP	0	19	0	394	318		0	13	0	178	142
PoN	420	220	455	330	98		294	98	247	271	71
PWCS	534	922	2464	1918	2102		316	410	1389	1130	1156
NCIG	0	12	86	87	136		0	4	62	50	71
HDC	66	36	393	209	353		45	26	34	52	133
HDC (BHP)	11	2	48	68	59		7	0	18	39	24
RMS	0	2	6	0	0		0	2	3	0	0
Zone											
Nth	10	4	0	11	102		6	3	0	6	79
Central	454	264	482	736	428		323	128	261	452	223
Southern	611	974	2997	2282	2650		368	442	1506	1271	1384
Region											
Hunter North River	0	0	0	3	3		0	0	0	3	3
School House	10	4	0	8	99		6	3	0	3	76
Cobbans Creek	13	34	5	404	320		13	22	2	180	144
Bellfrog Way	441	230	477	332	108		310	106	259	272	79
Industrial Zone North	532	921	2420	1858	1962		314	410	1362	1094	1101
Industrial Zone South	79	53	577	424	688		54	32	144	177	283
Subregion											
Scott's Point	0	0	0	3	3		0	0	0	3	3
Riverside park	0	0	0	0	0		0	0	0	0	0
Wet meadow	10	3	0	1	8		6	3	0	1	4
Millam's Pond	0	1	0	7	91		0	0	0	2	72
Ramsar Road West	1	28	3	404	320		1	16	2	180	144
Ramsar Road East	12	6	2	0	0		12	6	0	0	0
Bellfrog Way West	4	2	7	2	5		3	2	2	1	3
Bellfrog Way NE	12	4	4	0	5		9	3	2	0	5
Bellfrog Way SE	425	224	466	330	98		298	101	255	271	71
Delta Ponds (K104)	209	859	718	559	720		38	364	372	236	428
KIWEF *K7*	321	57	1603	991	465		274	43	939	771	327
NCIG rail central & east	0	13	103	99	165		0	4	76	57	83
Rail loop *K10 Nth*	66	36	383	101	105		45	26	28	22	66
Cormorant Road	0	2	6	0	0		0	2	3	0	0
Rail loop SW *K10 Sth*	0	0	16	89	301		0	0	10	25	88
NCIG rail south	11	2	58	45	79		7	0	20	21	29
KIWEF *K2*	2	0	11	90	38		2	0	7	52	17
Deep pond	2	5	99	308	689		2	3	51	87	340

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 most 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.

2016-17; due to their intensive nature, the CMR surveys provide a notable increased in values of Total detected at these respective wetlands (although they have no effect on Search Sensitivity).

Within these overall trends, the data also provide an overview of the recent occupancy by *L. aurea* in different parts of the island. In terms of Jurisdiction, detections in NPWS wetlands (VES and Total) have decreased, although Search Effort has also been reduced and thus Search Sensitivity remains similar

(albeit at low levels). In contrast, both numbers and density have increased at the CHEMP wetlands; by large degrees for the BHP_CHEMP, but also with smaller increases at the NCIG_CHEMP wetlands. In 2018-19, the numbers of *L. aurea* detected at the NCIG_CHEMP wetlands exceeded for the first time the numbers detected at NPWS wetlands.

VES detections have also increased at the PWCS and NCIG wetlands across the five year period, although the density (Search Sensitivity) has been high since 2016-17, and Total Detections in the PWCS wetlands have decreased slightly from a peak in 2016-17. This is likely to be at least partly a result of reduced CMR surveys in the last two seasons; four, compared with the six in 2016-17.

At the HDC wetlands, VES detections, Search Sensitivity, and Total detection reached a peak in 2016-17, although this was heavily affected by a large breeding event seen in the survey of K111 during that season. Counts and densities of adult *L. aurea* indicate that the 2018-19 season had the highest numbers yet detected. The 'old' BHP wetlands, labelled 'HDC (BHP)', have steady numbers. The two RMS wetlands are no longer surveyed but only ever had small numbers of *L. aurea*.

One notable trend is the decrease in the counts and densities in the PoN wetlands; these include K22 and K23, which have historically been considered to be significant wetlands for the *L. aurea* populations of Kooragang Island. VES detections and Search Sensitivity have decreased markedly from a peak in 2016-17. Total detections have decreased by even more, although this is strongly affected by the reduction of CMR surveys at K22/23 in the last two seasons. At a subregional level, this decline matches the VES Detected counts for Bellfrog Way SE (although it does not quite match the values for Search Sensitivity). This pattern of declines is also visible along the other subregions of Bellfrog Way, although the abundance in Bellfrog Way West (at BHP-14B) is higher than shown here (Chad Beranek, pers. comm.). Even so, the abundance of *L. aurea* all Bellfrog way appears to be much less than in its heyday 10 years ago (M. Mahony, pers. obs.).

In other subregions, VES detections, Search Sensitivity, and Total detections have all increased steadily for the NCIG rail central & east, Rail loop SW *K10 South*, NCIG rail south, and Deep Pond subregions. Total Detected values in the Rail loop *K10 North* subregions were high in 2014-15, due to the abundance of *L. aurea* at K108, but whilst numbers at that wetland have decreased since then, numbers at the newly constructed HDC ponds in the Rail loop have increased and in 2018-19 exceeded the levels in 2014-15. As noted above, the highest values for VES Detected, Search Sensitivity, and Total Detected were in 2016-17 due to the large numbers of juveniles in K111, but the number of adults in the subregion was higher in 2018-19 than in any of the previous four years.

At a regional level, these trends mean that the number of VES detections in both the northern and southern regions of the Industrial Zone have increased, but the rate of increase has been more rapid for the Southern region and in 2018-19 the number of adult *L. aurea* detected in the Southern region during VES was nearly half of the number for the Northern region. This compares with values of 13% and 23% in 2014-15 and 2015-16. The gap between the two regions for Total Detections data is more pronounced; but the northern regions contains two wetlands that are regularly intensively surveyed for CMR studies, whilst with the exception of the 2014-15 season the southern region has none.

In the Central Zone, counts and density in the Cobban's Creek region are slightly down on the 2017-18 but remain high comparted to previous years. That increase has been driven by the Ramsar Rd West subregion, i.e. the BHP CHEMP wetlands.

In the Northern Zone, the counts and density in the School House region also increased markedly in the 2018-19, driven by increases at the NCIG CHEMP wetlands, primarily in the Millam's Pond subregion (which contains NCIG stage 4, 5, and 7). Numbers in the Hunter River North region and in the School House subregion remain very low.

4. Discussion

Conservation biology of *L. aurea* on Kooragang Island

1. **Population size**: Robust modelling at intensively surveyed wetlands indicates that a total of approximately 5 *L. aurea* of 40 mm SVL or greater were present for every ≥ 40 mm SVL detected during VES. Based this ratio, and the number of VES detections during the island-wide surveys of 64 wetlands, the population size of (medium to large juvenile and adult) *Litoria aurea* on Kooragang Island is approximately 4,000-5,000 individuals (**Section 3.8**). This is slightly higher than the most recent annual (2014-15 season and later) estimates, and appears to represent an increase in population levels compared to the four seasons between 2010 and 2014. Note, however, that the large breeding event in the early part of the 2018-19 may have inflated estimates of population size by (1) skewing the calculated detection ratio in K29 due to reduced numbers of adults (mainly females) present in Round 1, (2)increased detection probability of adults, especially calling males, engaged in breeding behaviour, and (2) the presence of large numbers of juveniles following successful recruitment.

   These caveats, along with the uncertainties inherent in generating the population estimates, mean that the apparent trend of an increasing population may be affected by various sampling biases. The detection probability of 1:5 calculated from the 2018-19 CMR data was affected by a low ratio for K29; the ratio for K104 was 1:6 and this is more similar to the ratio calculated from previous seasons (1:6 in 2016-17, and 1:7.5 in 2017-18). Of course, if the actual ratio was higher than 1:5 this season, that would provide an even larger population estimate than the figure of 4,000-5,000 given above. Conversely, per round VES detection total were overall quite similar to those years. Importantly, however, 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. For a fuller discussion of the limitations of population estimates based on statistical modelling, see the equivalent section in the 2017-18 annual report (McHenry et al. 2019).

   Raw counts of abundance and density (**Section 3.9**) also suggest that, from 2014, population levels have not declined across the island, but have increased over the five most recent breeding seasons. This increase is seen across the Northern, Central, and Industrial zones of the island, albeit to differing degrees.

2. **Demography**
   a. Age/sex class structure: For those frogs were age/sex class was identified, between a third and a half of the *L. aurea* detected in each round were metamorphs or juveniles. Of the individual adults captured and identified, two-thirds were males. These proportions are broadly consistent with the pattern from recent seasons.

      Several cohorts of younger *L. aurea* could be identified, linked to different breeding events (themselves apparently linked to rainfall) in the late part of the previous season and the early part of the 2018-19 season. There was a clearly identifiable cohort of animals that had overwintered as tadpoles and which were large juveniles or small adults by late summer (Figure 3.4.5). Another cohort were spawned in the spring of the 2018-19 season and had become small juveniles by summer. Within these, variations in growth may possibly be linked to different rainfall events during Spring and early Summer of 2018-19 (Figure 3.6.3).

      Data on growth rates, analysed for the first time in the current report (**Section 3.6**) suggests that females smaller than 70 mm SVL may be in their second or third year; in previous analyses we have assumed that third year females will be larger than this size. We note,

however, that this growth curve was based upon a cohort of animals who spawned in mid-summer and thus overwintered as small juveniles; the effect of time of spawning on long term growth rates is not understood.

b. Recruitment: Thirteen wetlands within the Industrial Zone held either tadpoles and/or metamorphs at some point during the 2018-19 breeding season, the largest number recorded in the last five seasons. Breeding was also recorded in many of the BHP CHEMP wetlands. Within the Industrial Zone, there was a significant breeding event at K105A (including K105AS) following high levels of Spring rainfall in September and October 2018 (Figures 3.2.1, 3.6.3). The density and abundance of adult *L. aurea* at K105A at this time was far greater than has been seen in previous seasons, and the chorusing during October was the largest experienced by the current survey team, whilst chorusing at K105B was also large. By December 2018 there were high numbers of metamorphs and small juvenile *L. aurea* across both of these wetlands, with the greatest numbers at K105A.

   Although *L. aurea* have been detected at K105A every season, neither abundance or density have been high prior to this breeding event. Data on movement of tagged individuals (**Section 3.5**) shows that many adult *L.aurea* moved towards K105A at this time from the nearby wetlands K23 and K29; those usually hold large numbers of adults and are considered to be refuge habitats (see below for discussion of habitat traits of wetlands). Animals previously tagged at other nearby wetlands, including C1 and K106C, were also found to have moved to K105A during this breeding event (Table 3.5.4). One individual detected at a drift fence close to K105A had been tagged at the C2 wetland 1.4 km away the previous autumn. In December 2018, several adult males who had been detected at K105A in October were recaptured in K29 (Table 3.5.5).

   Taken together, this event suggests a picture of explosive breeding during highly suitable environment conditions. The very loud chorusing at K105A and K105B likely attracted adults from nearby wetlands and thus this event became self-reinforcing. During the breeding event abundance at several nearby wetlands – including K29, K23, K106C, and C1 that are close to K105A, and K46, K117, and K118 that are close to K105B – was much lower than in the two previous seasons. Previous studies have suggested that *L. aurea* disperse to ephemeral wetlands for breeding after significant rain, but K105A is not an ephemeral wetland. However, in the 2018-19 K105A did lack *Gambusia* (or, at least, high densities of *Gambusia*) for the first time following a prolonged dry period the previous summer. It is unlikely to be a coincidence that, the very first season after *Gambusia* was almost completely removed from this wetland, it was the site of the largest *L. aurea* breeding event we have witnessed.

   Other factors may have been involved; we have previously (McHenry et al. 2019) suggested that extensive cover of emergent reed species around the edge of a wetland, a large amount of open water, and at least one vegetated shallow slope that becomes 'flooded grass' (or similar) after significant rain are all traits that appeared to be linked with sizeable breeding events. These factors were all present at K105A in the spring of 2018; the extent of open water is always large at this wetland, but the coverage of emergent reeds around the edge was increased from the previous season. Likewise, the almost complete drying of the wetland at the end of the previous summer led to extensive *Paspallum* grass cover growing down the shallow slope of the outer edge of the wetland base, and when the wetland refilled after good rain this provided a microhabitat of shallow flooded grass, which *L. aurea* appear to use during breeding. This combination of factors – lack of *Gambusia*, open water, edge vegetation, and shallow grass – was also present during a large breeding event in K105B the previous season.

Apart from K105A (and K105AS), good sized breeding events were also detected at K29 and K104 (permanent wetlands and refuge habitats), and K105B, K114, and K123 (semi-permanent wetlands) (**Section 3.6**). Large breeding events also took place at the BHP CHEMP wetlands (Chad Beranek, pers. comm.) As with previous seasons, the constructed HDC wetlands provided suitable breeding habitat, as did the constructed BHP CHEMP wetlands. There remains a strong link between significant breeding events and low or zero densities of *Gambusia*.

c. Gravid females: Data from candling adult females for signs of gravidity suggest that more than half of the females larger than 60 mm SVL are producing eggs (Figure 3.6.4). Using 58 mm as the threshold for the onset of female reproductive maturity means about one third of individual adult *L. aurea* on Kooragang island are adult females (Figure 3.4.3A); 272 individual PIT tagged females were detected across the 2018-19 (Table 3.1.3). This number is similar to the corresponding data from the two previous seasons and indicates that the effective population size of *L. aurea* on Kooragang Island is sufficient for at least the immediate persistence of the population. The low survival rates of adult *L. aurea* on Kooragang Island, however, mean that the population remains vulnerable; just two consecutive years of poor recruitment is predicted to have a strong negative effect on population size.

Samples of urine from gravid female *L. aurea* were collected for hormone analysis, in order to investigate the reliability of candling as an indication of gravidity. The analysis of these results is pending.

3. Longitudinal data

a. Persistence: As seen in the 2017-18 annual report (McHenry et al. 2019), persistence (and, by extension, survivorship) of marked frogs was low (**Section 3.5**). 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. It also means that the population remains vulnerable to consecutive years of poor recruitment.

b. Movement: Again, similar to last year, most tagged frogs are recaptured in the same wetland that they were first encountered (Table 3.6.3). However, when the pattern of persistence is taken into account, it becomes clear that when *L. aurea* are recaptured more than one year after their initial capture, the probability of them having moved to another wetland is > 30%. Thus, previous interpretations of high rates of philopatry in *L. aurea* (e.g. McHenry et al. 2017) were the result of survivorship bias. After accounting for that bias, it is clear that *L. aurea* readily move across the landscape. Although most of these movements are less than 500 m, several movements recorded since 2015 have been in excess of 1 km (Table 3.5.6).

As discussed above, a large number of those movements in the 2018-19 season centred upon K105A and were clearly connected with breeding event at that wetland (see 2b above) (Figures 3.5.1, 3.5.2; Tables 3.5.4, 3.5.5). Other notable movements included: from K115 to K29; from C2 to K105A, from K29 to K104; from K100A to K114 and back again; from K108 to K100A; from BHP-14B to BHP-2; and from NCIG_1.3 to NCIG_4.9. One movement, from BHP-14B to NCIG_4.9, was the largest movement recorded this year at 2.1 km and is a rare indication of connectivity between the Northern and Central Zones.

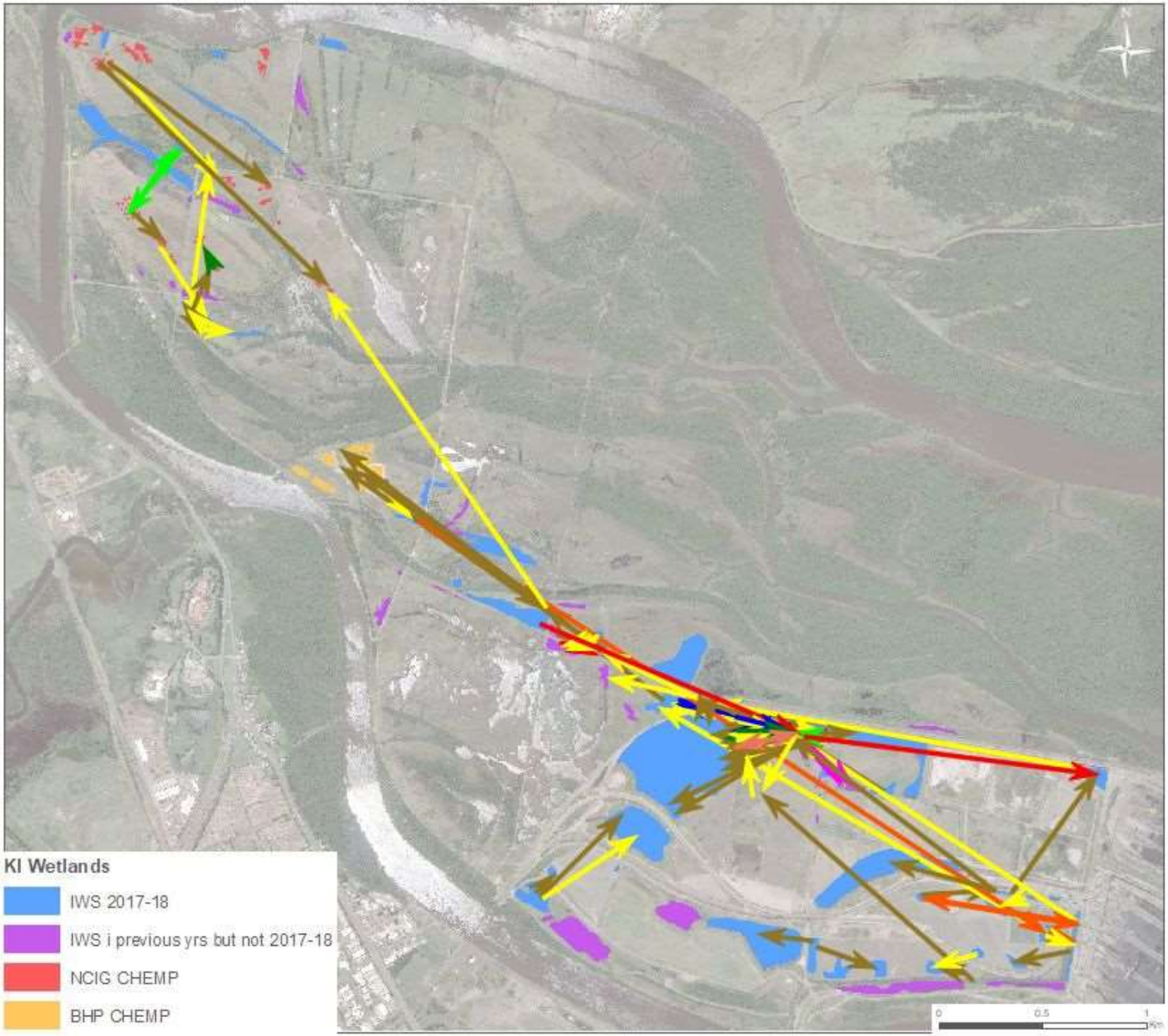


Figure 4.3.1: Recorded movements of individual tagged *Litoria aurea* on Kooragang Island, based upon combined data from the studies listed in Table 3.5.1. Brown arrows show movements detected between seasons, and yellow arrows show movement within a single season. Coloured movements correspond to individual animals with more than one movement recorded (see Tables 3.5.4 and 3.5.5, and corresponding tables in the previous annual report).

Note that this map is a combination of the maps shown in **Section 3.5** of the current annual report, and that from last year.

At least 14 movements recorded in the 2018-19 season involved movements across or underneath rail infrastructure (see point 6 below). There were more than twice as many detected movements by males (Table 3.5.7); however, males are more likely to be detected in any case (Figure 3.4.1).

As noted in last year's report, the movement data now available is a result of intensive survey effort in the preceding seasons, especially the CMR surveys at K29, K104, and K22/23. A summary of movements recorded is shown in Figure 4.3.1; this provides an insight into wetland connectivity (see point 4 below).

c. Growth: Reliable growth curves rely upon being able to follow growth of individuals across their lifespan, and knowing both size and age for each data point. Usually, the age of *L. aurea* encountered in field work is not known and this is a significant challenge for field studies. However, following known breeding events in January and October 2016 we were able to identify cohorts of *L. aurea* that have persisted at intensively surveyed wetlands (K29 and K104 respectively), and multi-year data from those has allowed growth trajectories of wild *L. aurea* on Kooragang island to be plotted (Figure 3.5.5).

4. Landscape use

a. Distribution: As has been the case for many years, 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 4.4.1, Tables 3.9.2 & 3.9.4). In 2017-18 increased densities and abundance of *L. aurea* were detected in the southern Industrial zone and in the Ramsar Road West subregion of Cobban's Creek, and this trend persists in the 2018-19 data (Figure 4.4.1, Table 3.9.3). Although absolute numbers remain lower than for the Northern Industrial Zone (Table 3.9.2), these increased densities are linked to the construction of new wetlands; respectively, the HDC wetlands and the BHP CHEMP wetlands.

Both densities and absolute numbers in the **Northern Zone** of the island remain low, but increased markedly in 2018-19 compared to previous seasons (Figure 4.4.1, and Tables 3.9.2, 3.9.3). This increase is clearly linked with the NCIG CHEMP wetlands.

Within the **Central Zone**, the abundance of *L. aurea* along Bellfrog Way continues to be low 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* complicates assessment of the situation (Table 3.9.2). The small numbers at K23 in 2018-19 are likely linked to the large breeding event in K105A as discussed in point 2b above, but may signify a trend of declining L. aurea abundance (Table 4.4.1).

K22-23	Search effort	VES detections	Seach Sensitivity
2014-15		57	
2015-16	506	40	0.08
2016-17	889	83	0.09
2017-18	423	49	0.12
2018-19	641	37	0.06

Table 4.4.1: Search effort, VES counts, and Search Sensitivity for the K22/23 wetlands.

In the southern part of the **Industrial Zone** both the density and abundance of *L. aurea* in this region have increased over the last five seasons, and appreciable numbers of *L. aurea* are present in all its subregions (Tables 3.9.2, 3.9.3, 3.9.4). Within the rail loop, *L. aurea* were detected in K108 for the first time since 2016 following partial charging of this wetland in spring 2018, but numbers were much lower than prior to 2015 and the wetland held water for only a few weeks after the rain; the importance of K108 wetland for the *L. aurea* of this region is lower than prior to 2015. However, this 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 are located in the southern Industrial Zone.

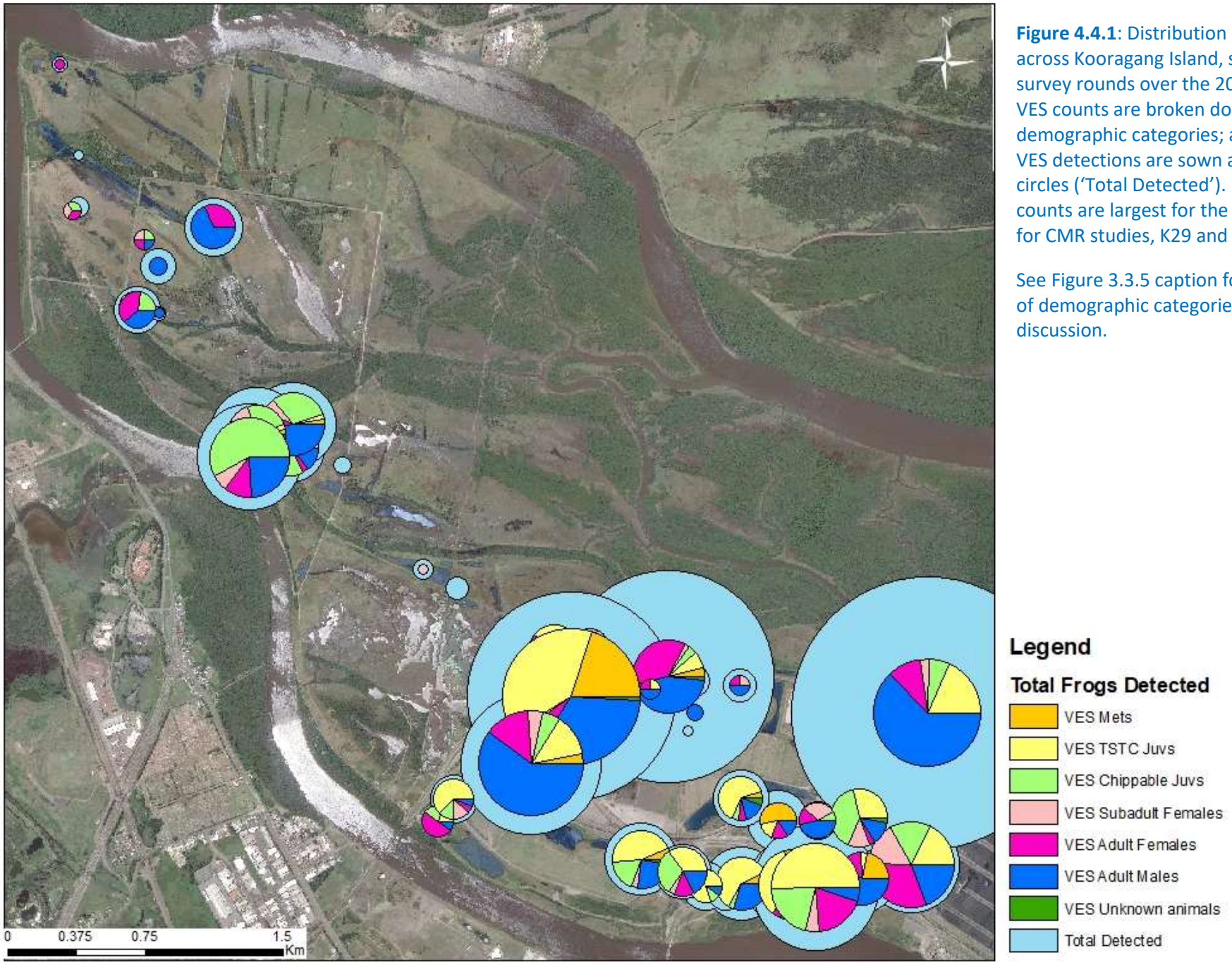


Figure 4.4.1: Distribution of *Litoria aurea* across Kooragang Island, summed for all survey rounds over the 2018-19 season. VES counts are broken down into demographic categories; additional non-VES detections are sown as light blue circles ('Total Detected'). Non-VES counts are largest for the wetlands used for CMR studies, K29 and K104.

See Figure 3.3.5 caption for explanation of demographic categories, and text for discussion.

Within the northern part of the **Industrial Zone**, the largest numbers of *L. aurea* were detected at K105 during the breeding event at that wetland in spring and early summer. As noted above, K29, K106C, and C1 held fewer numbers than in previous season, and movement adult *L. aurea* from these towards K105A is at least a partial factor in this pattern. Large numbers of *L. aurea* remain at K104 and K105B, and appreciable numbers were found at K103 and K102. Bell frogs were largely absent from K34, K31, and K42.

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

i. **Habitat**: Understanding the habitat requirements of *L. aurea* is key information for effective environmental management. Frogs such as *L. aurea* of course make use of both aquatic and terrestrial habitats; the adults appear to depend upon access to permanent water through the year and so *L. aurea* is characterised as an 'aquatic' frog of mesic environments (Vidal-Garcia and Keogh 2015). This is not a trivial observation; even apart from rain, frogs can access water from the ground water (e.g. mud cracks) or atmosphere (dew) and don't automatically require access to standing water for physiological survival; but *L. aurea* shows a clear preference for permanent wetlands. Even within those broad categories, however, there remain fundamental questions about the nature of habitat and microhabitats that are required for the long-term persistence of *L. aurea* populations.

Aquatic habitats are used for foraging, short-term occupancy, and with respect to connectivity of habitat, as 'stepping stones' across the landscape. 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). 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).

Note that structurally open habitats, with aquatic and fringing vegetation, have been demonstrated to be important for the closely related southern bell frog *Litoria raniformis* (Heard et al. 2008, Wessens et al. 2010). Klop-Toker (2016) found *that L. aurea* abundance on Kooragang Island is positively associated with riparian bushes, but negatively associated with trees and grass.

Breeding habitats are not necessarily large or of a long hydroperiod, as long as they have low densities of *Gambusia* (see below) in combination with open water and some shallow sloped banks that have inundated vegetation after heavy rainfall. As drying removes *Gambusia* from a wetland, shorter period wetlands appear to provide suitable breeding habitat, but as demonstrated by the breeding event at K105A this year, large permanent wetlands will be used for breeding if Gambusia densities are low or zero and the other habitat requirements are met. This most recent episode adds to the other recorded breeding events that have been detected at large wetlands that provide refuge habitat (e.g. K104, K105B) once *Gambusia* densities are low.

Other wetlands that may be important to *L. aurea* populations include small, permanent, well vegetated wetlands that may act as '**stepping stones**' or '**small refuges**'; these are discussed in last years' report, and may be exemplified by K106C, C1, and C2. They 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 larger 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. It is possible that K115, K100A, and K36 also perform this role; together with C2, they also provided habitat for small juvenile *L. aurea*, especially as the system dried during late summer, even though breeding is not thought to have occurred at any of them (Figures 3.4.10 – 3.4.13). Thus, these wetlands might also be characterised as small (non-breeding) refuge wetlands.

Terrestrial habitat suitable for *L. aurea* appears to be widespread on Kooragang and is not though to be limiting. However, Klop-Toker (2016) noted a potential negative effect of *Kikuyu* grass pasture with *L. aurea* distribution. As *Kikuyu* is more common on the Northern Zone of the island, this should be considered as a potential factor in the lower numbers of *L. aurea* in that zone. Terrestrial habitats in the Industrial Zone have more open ground vegetation (John-Paul King, pers. comm.) and this may be more suitable for *L. aurea* dispersal and foraging in terrestrial habitats.

ii. ***Gambusia***: As has been detailed in previous reports, 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 3.6.5). 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, and in addition to examples from previous seasons (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) the instance of the first recorded large breeding event at K105A in the 2018-19 season followed the near elimination of *Gambusia* from that wetland for the first time.

Note that it is the density, rather than the simple presence, of *Gambusia* that is the key link to breeding behaviour in *L. aurea* (Section 3.6); this can confound analysis using binary correlations (see Figure 3.6.5).

The unusual abundance of animals and large volume of chorusing at K105A this season suggests that *L. aurea* are actively choosing and advertising potential breeding site that lack fish. Whether they are doing this by directly detecting the fish or by using other cues (such as densities of aquatic invertebrates) is not clear, but it is worth noting that many ecologists on our survey teams can quickly surmise the presence and density of *Gambusia* via the number of water beetles visible when first looking into the water.

iii. **Chytrid**: In the early spring 2018 survey round we sampled (using swabs) for chytrid on ~120 captured *L. aurea*, with the objective of measuring chytrid load at that time. Analysis of that data is pending.

Chytrid is known to be strongly affected by temperature and salinity, with temperatures above 22°C and salinity levels greater than 3 ppt substantially reducing infection load (Heard et al. 2015; Stockwell et al. 2012). Within its former range, *L. aurea* is understood to persist only in locations where environmental conditions lead to reduced chytrid load via temperature and salinity effects.

For wetlands on Kooragang Island, salinity is affected by wetland connections with estuarine groundwater and/or sediments with concentrations of salts. Based on work by Heard and colleagues on microhabitat factors in wetland in central Victoria, temperature is affected by wetland size (larger wetlands are warmer) and the amount of tall vegetation shading the water surface (Heard et al. 2015). Both of these factors are known to vary across Kooragang, and it is therefore likely that a number of wetlands on the island have environmental conditions that reduce chytrid load and thus provide some protection to *L. aurea*.

Discerning these relationships in the field is difficult, however, Callen (2018) noted that, whilst the presence of saline wetlands in the landscape is likely an important factor in the local survival of *L. aurea*, a straightforward connection between salt levels and *L. aurea* survival at specific wetlands cannot be demonstrated in the field – despite the fact that such a relationship can be clearly demonstrated in laboratory experiments (Stockwell et al. 2012). Rather than establishing a straightforward connection between salinity and *L. aurea* survival at specific wetlands, Callen emphasises that *L. aurea* survival is likely increased if they have access to saline wetlands somewhere within their local landscapes. A similar pattern may apply for temperature, and this logic is a key component of the concept of the **habitat mosaic** (see next point). It would be useful to have a 'wetland-by-wetland' or 'region-by-region' insight into how chytrid load varies across the island, but this requires very high levels of sampling and has thus far not been attempted.

iv. **The habitat mosaic**: Again, as noted in previous years, 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. This aspect of habitat for large populations and/or metapopulations has been termed the 'habitat mosaic', and is currently understood to be a key part of long-term persistence of *L. aurea* populations.

Based upon statistical analysis of intensive survey data Klop-Toker (2016) confirmed that wetland connectivity is (logically) a key component of successful habitat mosaics, whilst Callan (2018) identified variation in hydroperiod as another important factor.

Our multi-year surveys of *L. aurea* populations across Kooragang suggest that variation in wetland size may also be an important factor, although this has not yet been examined statistically. Combined with the potential habitat effects of salinity and temperature on chytrid load at individual wetlands, suitable habitat mosaics appear to provide the following habitat traits:

a. High connectivity: there must be a number of wetlands within a small distance.
b. Variation in hydroperiod: the mosaic should include ephemeral, semi-permanent, and permanent wetlands.
c. Size: the mosaic should include large, medium, and small wetlands.
d. Salinity: at least some of the wetlands in the mosaic should provide salinity levels between 2 and 8 ppt at any one time.
e. Vegetation structure: the mosaic should include wetlands with open water and dense edge vegetation (emergent reeds) (Klop-Toker 2016), as well as access to shallow flooded ground vegetation following significant rain. Well shaded (by trees) wetlands have lower evaporation rates and will thus retain water for longer in dry conditions, but at least some of the wetlands in the mosaic should have low levels of shading.

f. Depth and bottom profile: Hydroperiod is strongly affected by depth, so the mosaic should have a variety of maximum depths. Shallow sloping edges provide flooded ground vegetation after rain (c.f. breeding behaviour); ideally, the degree of slope should result in gradual retraction of the water edge during drying, at a rate where e.g. Paspalum can colonise newly exposed but still moist ground. If the slope is too steep or too flat then water retreat is too slow or too fast (respectively).

Interactions between these are important for regulating temperature (wetland size, vegetation, depth). Chytrid load is in turn affected by interactions between salinity, temperature and hydroperiod (chytrid load will be reduced in completely dry wetlands) – wetlands that are both warm and saline have been shown to provide environmental protection from chytrid for *L. raniformis* (Heard et al. 2014). *Gambusia* is strongly controlled by hydroperiod. Depth interacts with open water – deeper wetlands cannot be 'choked' by emergent reeds such as *Typha* and *Phragmites* – and vegetation structure is also affected by hydroperiod and salinity. Wetland size and vegetation structure is expected to have a strong affect on population size at a particular wetland.

The contribution of these traits and combinations of traits has yet to be statistically tested on our multi-year dataset. At a qualitative level, however, two specific areas of the Industrial Zone provide good example of habitat mosaics that combine these factors. Perhaps the best example is based in the *K7* KIWEF subregion, where K29 provides important refuge habitat and is surrounded by 17 wetlands of varying size and hydroperiod, all within a 500 metre radius of K106 (Figure 4.4.2); these wetlands consistently have the highest abundance of *L. aurea* on Kooragang Island. A second habitat mosaic centred around the Rail loop *K10 North* encompasses at least 13 wetlands and has the next highest concentration of *L. aurea* on the island (Figure 3.3.8); it has considerable variation in wetland hydroperiod, although perhaps less variation in wetland size and without a genuinely large refuge wetland.

Comparison with the habitat mosaics in the Northern and Central Zones (Figure 4.4.3) show clear differences between the parts of the island with high and low abundance of *L. aurea*. Connectivity, wetland size and area, and variation in hydroperiod is obviously lower in the Northern Zone. Wetland area, size, and hydroperiod variation in the BHP CHEMP mosaic is in reality higher than indicated in Figure 4.4.3, but are nonetheless higher than in the Northern Zone and connectivity in the BHP CHEMP mosaic is much higher, and population density is comparable to the highest levels seen in the Industrial Zone.

v. **Northern Zone of island**: The abundance of *L. aurea* in the Northern Zone of the island has been low for at least a decade, for reasons that remain poorly understood. This zone differs from the rest of the island in a range of large scale to small scale factors, including:

a. It is in the 'upper catchment' of the creeks that drain west and south towards the northern arm of the Hunter River (Figure 2.1.2), and thus has low salinity.
b. It is in a part of the river that has markedly less saltwater influence due to its position in the estuary (John-Paul King, pers. comm.)
c. It has a history of intensive grazing.
d. It has been gazetted as a National Park and now has low levels of landscape scale disturbance, with the result that many older wetlands are now at successional climax with extensive overhanging trees and are 'choked' by emergent reeds (*Typha* and *Phragmites*).

e. It has poor quality terrestrial habitat, with extensive pastures of *Kikuyu* grass.
f. It has low quality of habitat mosaic for *L. aurea*, i.e. lacks large permanent wetlands, has low variation in wetland size and hydroperiod, and has low connectivity (Figure 4.4.2).

Some of these potential factors are contradictory (c and d), but many are potentially synergistic (a, b, d, e, f). The construction of the NCIG CHEMP wetlands has improved connectivity within the zone, the total area of wetland habitat, and variation in hydroperiod, and the abundance of *L. aurea* is showing signs of increasing (Section 3.8). However, the Northern Zone still lacks large permanent wetlands and connectivity to the other zones on the islands remains poor.

Figure 4.4.2: visualisation of *L. aurea* habitat mosaics in the Industrial Zone. The circle on the upper left denotes a mosaic of 17 wetlands loosely centred around K106 and including large refuge wetland K29; this mosaic consistently has the greatest abundance of *L. aurea* on Kooragang Island, contains small, medium and large sized wetlands, and encompasses almost the full range of wetland hydroperiods detailed in Table 3.2.2 (shown in the legend).

The circle to the lower left, loosely centred around the 'Rail loop (*K10 North*)' subregion but also including wetlands from the 'NCIG rail central & east' and the 'Rail loop SW (*K10 South*)' subregions, contains the second largest concentration of L. aurea within the Industrial Zone and also has a large variation in wetland hydroperiod, although wetland size is perhaps more homogeneous and it lacks a large refuge wetland.

See text for discussion, and compare with Figure 4.4.3.

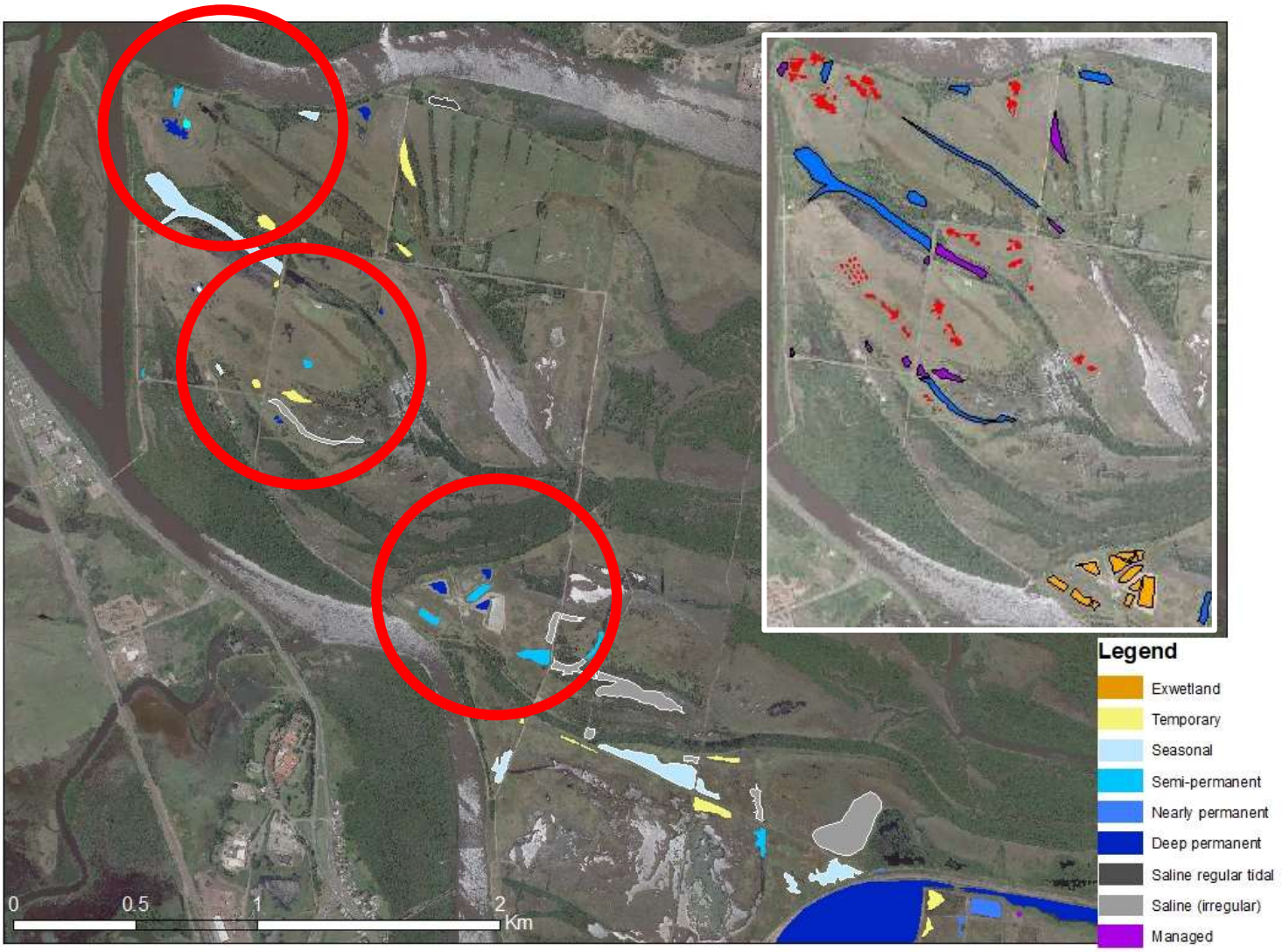


Figure 4.4.3: visualisation of *L. aurea* habitat mosaics in the Northern and Central Zones. The circle at the upper left is loosely centred around NICG Stage 1, the middle circle around NCIG Stage 5, and the lower right circle around the BHP CHEMP wetlands.

Abundance of *L. aurea* at the 'BHP CHEMP' mosaic is high, but is lower in the middle mosaic and is almost zero in the upper left.

Compared with the mosaics in Figure 4.4.1, all of these lack variation in hydroperiod and size. The average size and connectivity of wetlands in the BHP CHEMP mosaic is greater than the others. Even though not all CHEMP wetlands are shown in this map (compare with inset), wetland area, connectivity, and variation in hydroperiod is far greater in the Industrial Zone mosaics (Figure 4.4.1) than in the Northern Zone (upper left and middle mosaics of this figure).

Specific management issues relevant to research partners

5. **Habitat corridor mitigation strategy**: The extent of wetland habitat, connectivity, and variation in wetland hydroperiod 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). The density and abundance of *L. aurea* in that region has increased markedly over the last three seasons (**Section 3.9**), and breeding occurs frequently in the southern part of the Industrial Zone (**Section 3.6**). As such, the strategy to improve *L. aurea* populations in the 'southern corridor' has been somewhat successful, due in large part to the addition of nine constructed wetlands by HDC since 2015.

   The one component of a full habitat mosaic currently lacking in the southern Industrial Zone is a large, permanent, refuge wetland. This role was previously filled by K108, but the decline of this wetland (in terms of both hydroperiod and extent of open water; 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.

6. **Rail infrastructure mitigation strategy**: At the time that the NCIG rail infrastructure was constructed, there was (reasonable) concern that this infrastructure would reduce the extent and connectivity of wetland habitat across the southern part of the Industrial Zone. Direct impacts upon the existing wetland habitat were contained to stretch of wetland at the east edge of K102, where the dump station is now located, and the embankment over southern part of Deep Pond that now divides K105A and K105B (Figure 4.6.1). Indirect impacts may include the change in wetland hydroperiod of the Eastern Ponds (K108). What is unequivocal is the separation of large parts of the Southern Industrial Zone from the Northern region by rail tracks and associated infrastructure.

   Although the potential for railways to impede movement of animals across the landscape is real, the *L. aurea* of Kooragang Island do not appear avoid traversing them. Twelve of the 63 significant movements ('other' movements of Table 3.5.3) reported in the 2017-18 annual report involved crossing of railways (McHenry et al., 2019), and a further 14 (out of 47) movements detected in the 2018-19 season required *L. aurea* to move over or under rail lines (Tables 3.5.4 and 3.5.5; see discussion in point 3b above). Although it is not yet possible to say if railway infrastructure represents a partial hindrance to movement of *L. aurea* across the landscape, it is clear that it does not constitute an absolute barrier.

   The indirect effects of the NCIG rail construction were discussed in the 2017-18 annual report (McHenry et al. 2019); there may have been a negative effect on K108, but there has been a very positive effect on K105B and K105AS. Data from the 2018-19 does not change that basic conclusion.

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

   Each of these phases are now occupied by *L. aurea* at some level. Abundance has been low in the NCIG CHEMP, but increased markedly in the 2018-19 season (Figures 3.8.2, 3.8.3, 3.8.4), although it remains lower than the others (see discussion in point 4b.iv above). Both the **NCIG** and the

Figure 4.6.1: Comparison of the Industrial Zone in 2005 (top) and 2018 (bottom), showing the NCIG rail infrastructure constructed in that time. The alteration of the wetland that previously existed at the site now occupied by the dump station can be clearly seen, as can the rail embankment that has divided Deep Pond into K105A and K105B. The alteration to the Eastern Ponds is also visible, as are the new HDC wetlands also constructed across the Southern Industrial Zone in that period. Images from Google Earth; see text for discussion.

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

During the 2018-19 a fifth set of artificial wetlands based on the **cluster pond** design were installed in the Southern Industrial Zone by HDC and UoN (see Figure 3.4.14 and accompanying text for details). The purpose of these was to produce additional deep permanent small refuge habitat in and around the rail loop, as that wetland type is currently not present in the habitat mosaic. All three of the 'new clusters' were occupied by *L. aurea* shortly after installation, and they will be fully monitored in the coming seasons.

The pattern of *L. aurea* occupancy at the already established 'PWCS' **cluster ponds** (C1 and C2) were described in detail in the previous annual report (McHenry et al. 2019). However, that pattern changed somewhat in 2018-19. The C1 clusters (in the Northern region of the Industrial Zone) had very low occupancy in the first half of the season (Figure 3.4.13); this was a very different pattern to previous season, and seems to be linked to the movement of *L. aurea* towards K105A from other wetlands in that mosaic (**Section 3.5**; see also discussion in point 3b above).

The grass fire in early January caused extensive damage to the C1 cluster ponds and the surrounding area; all terrestrial vegetation was burnt out along with a large part of the aquatic vegetation with in the ponds, and the upper parts of the plastic tubs themselves were melted, reducing their water holding capacity. However, even in this damaged state they evidently provided some level of habitat for *L. aurea* as several were seen on multiple occasions in the months after the fire during monitoring of the nearby active ground fire in Area 2 (Grant Moylan, pers. comm.). The vegetation at the ponds is expected to recover and they should provide some level of suitable habitat in the coming season, although active repair measures may be required to restore them to the level of 'small refuge'/'stepping stone' wetland that they have been up until this season.

As detailed in previous reports, the southern of cluster ponds (C2) were unoccupied for several years prior to 2016, even though the contemporaneous C1 ponds were well occupied by then. The connectivity of the C2 ponds was poor until the construction of HDC wetlands in *K10 North*; the C2 ponds were occupied by *L. aurea* shortly thereafter, and appear to have played an important role in the rapid arrival of *L. aurea* at K121, K112, and K123 following their construction in 2017. Since the 2016-17 season these cluster ponds have been used as a small refuge wetland (c.f. discussion in point 4b.i above), particularly by adult females. The ponds are deep and well shaded by *Acacia* trees, and during the dry summer of 2017-18 retained water when all the nearby wetlands had dried. The 2018-19 season saw a repeat of that pattern; the C2 clusters were one of the few wetlands not to dry out in a very hot and dry summer (a situation assisted by topping them up using trucked water in January 2018), They were occupied by large numbers of *L. aurea*, especially during the dry second half of the summer, and including many juveniles who were presumably spawned in the nearby K123 wetland.

All of the nine **HDC wetlands** (K111-114, K117-118, K121-123) continue to be occupied by *L. aurea*. Calling was heard at all except K117 and K118, whilst tadpoles and/or metamorphs were detected at K111, K114, K118, K122, and K123 (Figure 3.6.2). The number of adults detected at K117 and K118 was less than previous years (Figure 3.4.15), but was perhaps affected by the large breeding event in the nearby K105B as has been discussed above (point 3b above). The number of adults detected at K121-123 was much greater than previous year, most likely due to the growth of some vegetation cover around the edge of these wetlands (they were almost devoid of vegetation in the previous season, having only just been constructed).

During October 2018 additional sediment was applied to large parts of the banks of K121, K122, and K123 in order to encourage growth of aquatic reeds around the edges of the wetlands. We anticipate that these will increase the capacity of these to act as refuge wetlands in coming seasons.

With the exception of K117, all of these dried out by the end of February 2019. The lack of large permanent wetlands in both K10 North and K10 South is a conspicuous gap in these habitat

mosaics, and may limit the abundance of adult *L. aurea* if not addressed. Future construction of wetland arrays using the HDC design should incorporate at least one large permanent wetland. Overall, however, the HDC wetlands continue to underlie the increased abundance of adult *L. aurea,* extent of breeding habitat, and wetland connectivity in the Southern region of the Industrial Zone that has been seen from 2015 (Section 3.8; see also discussion in points 4b.iv and 5 above).

In evaluating the management strategies available to increase survival of *L. raniformis* in Central Victoria, Heard et al. (2018) found that the most effective strategy was the addition of new, well-designed constructed wetlands, rather than attempts to improve existing habitat. The experience from *L. aurea* on Kooragang Island would seem to strongly support this guiding principal.

8. **Other issues**: the 2018-19 season was affected by third successive dry summer, which saw many wetlands dry up completely. It was also the second successive season to be affected by fire, although the fire this season was much more serious than experienced previously.

    a. Fire: A grass fire affected a number of wetlands in the Northern Zone in February 2018, destroying some fauna fences and burning out a large amount of terrestrial and aquatic vegetation at NCIG Stage 1, NCIG Stage 2, and K7. Also some species (notably, long-necked turtles (*Chelodina longicollis*) were directly affected, vegetation recovery was rapid and in the 2018-19 many of the burnt wetlands supported at least some numbers of *L. aurea*.

    Another grass fire that started close to K9 (Central Zone) in January 2019 caused more extensive damage. It spread to the BHP CHEMP wetlands in Ramsar Rd West, causing extensive damage to terrestrial and aquatic vegetation, and spread south-east along Bellfrog Way causing similar damage. K22 and K23 were both completely burnt out (both were dry at the time), before the fire jumped the PWCS rail line north of K106A and continued to spread south-east through the *K7 KIWEF* subregion. Vegetation at K106A, K106B, K106C, K29 and C1 was burnt (with damage to the C1 tubs as noted in point 7 above), but K105A appears to have been unaffected. The fire progressed southwards, burning terrestrial vegetation across Area 2 and to the east, and causing damage to K102 and the 'K30' group of wetlands (K30, K30A, K31, K32, K33, K34, K35, K41, K42). The fire did not cross the NCIG rail line, and did not affect K104, but many of the wetlands in the Northern region of the Industrial Zone were affected.

    This fire is known to have directly caused mortality of *L. aurea* at the BHP CHEMP wetlands and at K22/23. Since a large number of frogs had moved towards K105A in the preceding months, there is grounds for hope that a large part of the population normally resident in the *K7 KIWEF* subregion was located at K105A at the time that fire occurred. We were unable (for reasons outlined below) to survey that subregion or K105A after the fire; surveys in spring of the coming 2019-20 season will provide some assessment of impacts on the *L. aurea* population in this region.

    The full extent of the fire was even more serious, however, than burning out a large number of wetlands. In late January we discovered that the grass fire had started a ground fire at the south end of Area 2; that part of the KIWEF had been filled with a variety of materials decades before, including high quantities of coal fines, and that sediment was evidently ignited by the grass fire. This ground reached temperatures of up to 800°C, burnt out almost all of the western half of Area 2, and was active in all of the unfilled cells immediately to the north including K106A, K106B, and K29. It constituted a major safety hazard, preventing any Round 3 surveys in the NW part of the Industrial Zone, and burnt most of the drift fences that had been installed on across Area 2 to study use of the terrestrial habitat by *L. aurea*. It was

finally brought under control in mid to late autumn of 2019, more than three months after it first started.

Fire is of course a natural part of many ecosystems, and even on Kooragang can be part of landscape processes that alter habitat in a way that advantages *L. aurea*; for example, fire can clear vegetation from 'choked' wetlands, resetting the cycle of vegetative succession, and *L. aurea* are though to benefit from landscapes with a certain amount of disturbance. However, the effect of fire is determined by severity and frequency, and two fires in successive years – with one being particularly severe – has the potential to affect *L. aurea* populations in a negative way. Given the likely trends being driven by anthropogenic climate change, it is important to consider what implications increased frequency and severity of fire may have on the Kooragang population of *L. aurea*, and what steps might be taken to mitigate impacts where necessary.

b. Drought & Climate Change: The 2018-19 was the third consecutive year of low summer rainfall and widespread drying of wetlands across Kooragang Island. On a larger scale, it was the hottest Australian summer on record and one of the driest, and was the 13th year in the last 20 where average temperatures were more than 0.5°C greater than long-term averages. These broad scale patterns match closely the long-term climate projections made by numerous agencies including BoM and CSIRO and seem to represent the new normal for the Hunter region; hot summers with lower rainfall, but with more extreme rainfall events when it does rain.

   Although the Kooragang system of wetlands and ground water had been fully charged by spring rainfall, the summer was hot and dry enough to dry out most wetlands by March 2019. The spring rain stimulated a significant breeding event, which has been discussed extensively in this report, but unlike the previous season autumn rainfall was low and evidently did not stimulate late-season breeding. Whether the high recruitment in spring was enough to counteract the effects of a dry hot summer remains to be seen.

   We can expect that current climate change trajectories will continue to bring longer, hotter, drier summers – which will come with increased bush fires and against a background of sea level rise and more extreme weather events. If we are to maximise the probability of *L. aurea* survival on Kooragang in the medium to long term then it behoves us to consider, as early as possible, the likely effects of these climate trends so that required actions can be planned and undertaken. For example:

   - Increased temperatures may reduce the period that many wetlands hold water, but are expected to reduce chytrid load. It is thus possible that there may be a net benefit to *L. aurea*, as long as access to permanent water in some parts of the mosaic can be ensured.

   - Similarly, the drying of wetlands is very effective at removing *Gambusia* from the system (e.g. the last three seasons on Kooragang), with clear benefits for *L. aurea* recruitment – with the proviso that access to permanent water can be provided across the mosaic.

   - Small permanent wetlands that are well shaded by trees appear to provide suitable refuge habitat as the landscape dries; but increased fires will of course affect the tree cover.

   - Extreme weather events may produce large flooding events that can charge ephemeral and semi-permanent wetlands. There is growing evidence that *L. aurea* is capable of explosive breeding events after heavy rain, given access to large wetlands that have

suitable microhabitat and are free of *Gambusia*. On the other hand, extreme flooding often helps spread *Gambusia* across the landscape (e.g. flooding event in April 2015).

- Sea level rise is expected to increase the salinity levels of the upper estuary, including the Northern part of Kooragang Island, and this may provide overall protection against chytrid. Conversely, inundation of salt marsh and salt meadow by king tides during extended periods of low rainfall can lead to hypersaline conditions in wetlands, conditions which are not suitable for *L. aurea*, and this may be a reason behind the decline of *L. aurea* from Bellfrog Way (see Figure 3.2.5 and discussion in point 4bi above).

It is possible that many of the likely negative impacts of climate change could be mitigated by the addition of managed permanent refuge wetlands across the landscape (perhaps using the 'cluster pond' design as a template). It is also possible that the potential benefits largely outweigh the negative impacts and that the population will thrive with minimal intervention. Or it may be the sea level rise and increased drought will doom the Kooragang population, meaning that we should be considering assisted reintroduction of *L. aurea* to areas of its former range upstream. Whatever the most likely outcome, the requirements for action can only be determined if we start to consider future climate change as part of ongoing management of the *L. aurea* population on Kooragang Island.

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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.

APPENDIX 6

CHEMP MONITORING UPDATE REPORTS

Newcastle Coal
INFRASTRUCTURE GROUP

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

AUTHOR	
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INTRODUCTION

This report provides an update of activities relating to the NCIG Compensatory Habitat and Ecological Monitoring Program (CHEMP) since the previous report in June 2018. The aim of this report is 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 second half of 2018 (June-December 2018).

1. Kooragang Island Green and Golden Bell Frog Population Monitoring

1.1. Green and Golden Bell Frog (*Litoria aurea*) Research Program on Kooragang Island (Amphibian Research Group, UoN)

The UoN Amphibian Research Group recommenced monitoring of the Green and Golden Bell Frog on Kooragang Island in late 2018. These surveys, co-funded by NCIG, Port Waratah Coal Service (PWCS) and Hunter Development Corporation (HDC) have been conducted annually since 2010. The aim of this research is to understand the population ecology to help inform best practice habitat creation and management to improve ecological outcomes for the Green and Golden Bell Frog. The final report for the 2017-2018 season was provided during this reporting period.

Overall, the data showed that the population of *Litoria aurea* on Kooragang Island is stable, with no evidence of overall decline since surveys commenced in 2010 (Table 1). The 2017-18 model-estimated population size was approximately 2000-3000 individuals across the surveyed wetlands (Figure 1 and 2). 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.

Table 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.

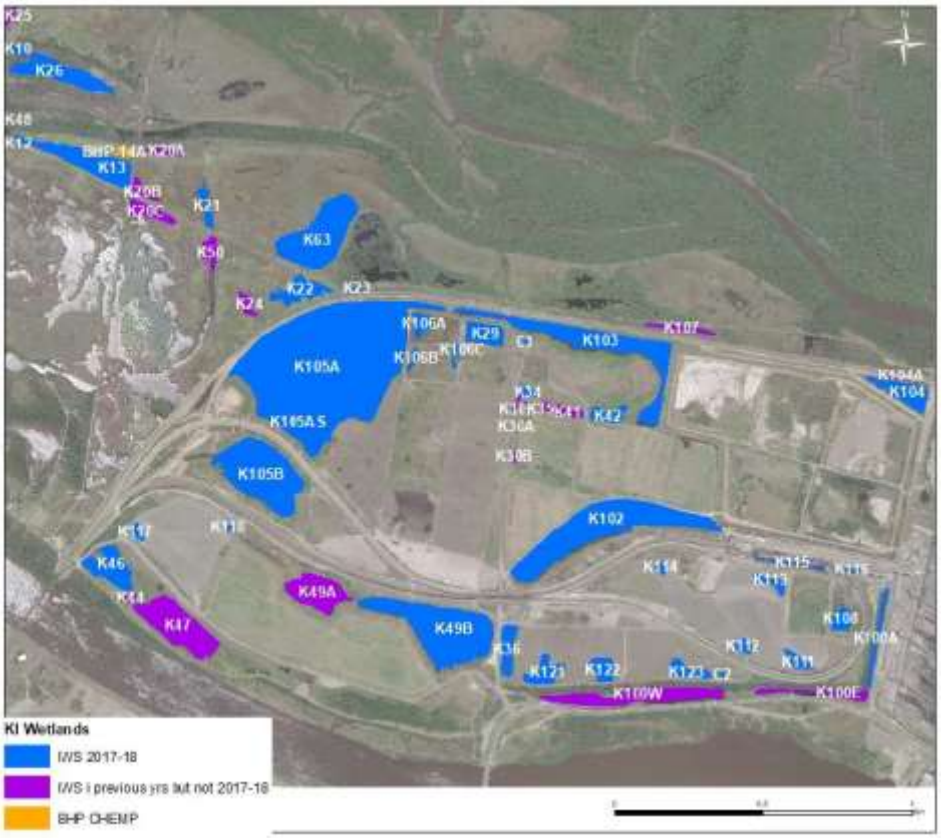

Figure 1. Surveyed wetlands in and around Terminal 4 on southern Kooragang Island for the 2017-18 season.

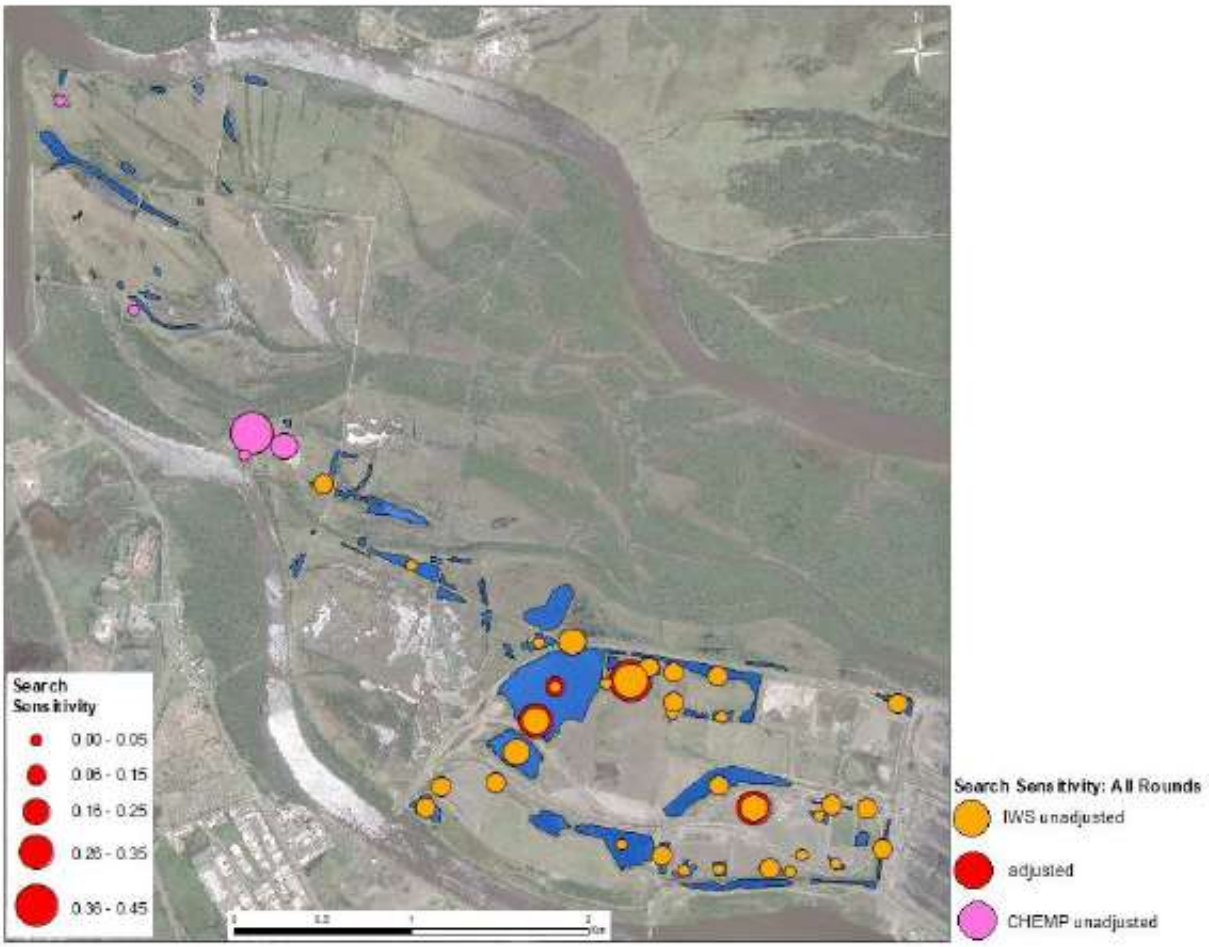

Figure 2: Search sensitivity (frogs detected per person minute) across the 60 wetlands surveyed as part of 'whole island' monitoring in 2017-18, pooled across the principal survey rounds. Note: the CHEMP wetlands shown here are only those included in the Save Our Species (SOS) 2017-18 surveys – they do not include all CHEMP wetlands.

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.

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. In one instance (southern Deep Pond, K105B) the quality of habitat has been greatly improved following the construction of rail infrastructure.

K105B (southern Deep Pond) 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.

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 is considered 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.*

2. NCIG Green and Golden Bell Frog Compensatory Habitat

2.1. Green and Golden Bell Frog Research and Monitoring (Dean Lenga - UoN)

The Green and Golden Bell Frog Research and Monitoring Program on Ash Island was again undertaken by the University of Newcastle (Conservation Biology Group) over the 2018/2019 season. An update report has been provided for the September-December 2018 period. The full report has been provided in Appendix A and a summary provided below.

A total of 59 GGBF were observed across 10 of 44 constructed ponds in the NCIG Compensatory Habitat during the reporting period (Sep-Dec 2018). Breeding was confirmed in two ponds and 19 records of calling males across five ponds (Table 2 and Figure 3). Majority of GGBF observations occurred in *Gambusia* free, ephemeral water bodies.

Above average rainfall occurred early in the season (September and October 2018) likely driving the breeding events within the Compensatory Habitats. The breeding events occurring in ephemeral waterbodies supports the view that high, rapid recharge of ephemeral waterbodies is an important driver of GGBF breeding. It also emphasises the importance of a landscape mosaic that provides permanent refuge ponds for adults during dry periods, combined with presence of ephemeral ponds that form following rainfall.

Table 2: Records of male GGBF calling and confirmed presence of GGBF tadpoles in the NCIG compensatory habitats between the months of September to December 2018. Dates of observations and records shown.

Pond	Calling adult males	GGBF Tadpoles recorded
3.1	0	1 (13/12/2018)
4.8	1 (18/10/2018)	0
4.9	2 (18/10/2018) 5 (20/12/2018)	0
5.1	1 (19/09/2018) 2 (23/10/2018) 3 (11/12/2018)	0
5.2	2 (23/10/2018) 2 (11/12/2018)	3 (21/11/2018)
5.3	1 (23/10/2018)	0
Total	**19**	**4**

Figure 3: Tadpoles found in pond 5.2 on the 21/11/2018 from fyke netting.

2.2. Compensatory Habitat Management

2.2.1. Fox Control

NCIG's annual Fox Baiting program was again undertaken between November 2018 and January 2019, in collaboration with BHP's Compensatory Habitat fox baiting program. During this three-month period, 24 runs were undertaken across 18 bait stations, 10 in NCIG's licence area (Figure 4 and 5) and 8 in BHP's licence area. The baiting was undertaken by CVA in accordance with NCIG's Compensatory Habitat Management Plan and CVA's 2018-19 Ash Island Fox Control Plan, as approved by NPWS.

Preliminary results provided by CVA show that the program has again been very successful, with 89 baits taken across NCIG's and BHP's habitats and evidence of fox activity at majority of stations. Additionally, increased activity was observed following the fire on Ash and Kooragang Island in early January 2019. Further analysis of the results will be provided in the next update report as they become available to NCIG.

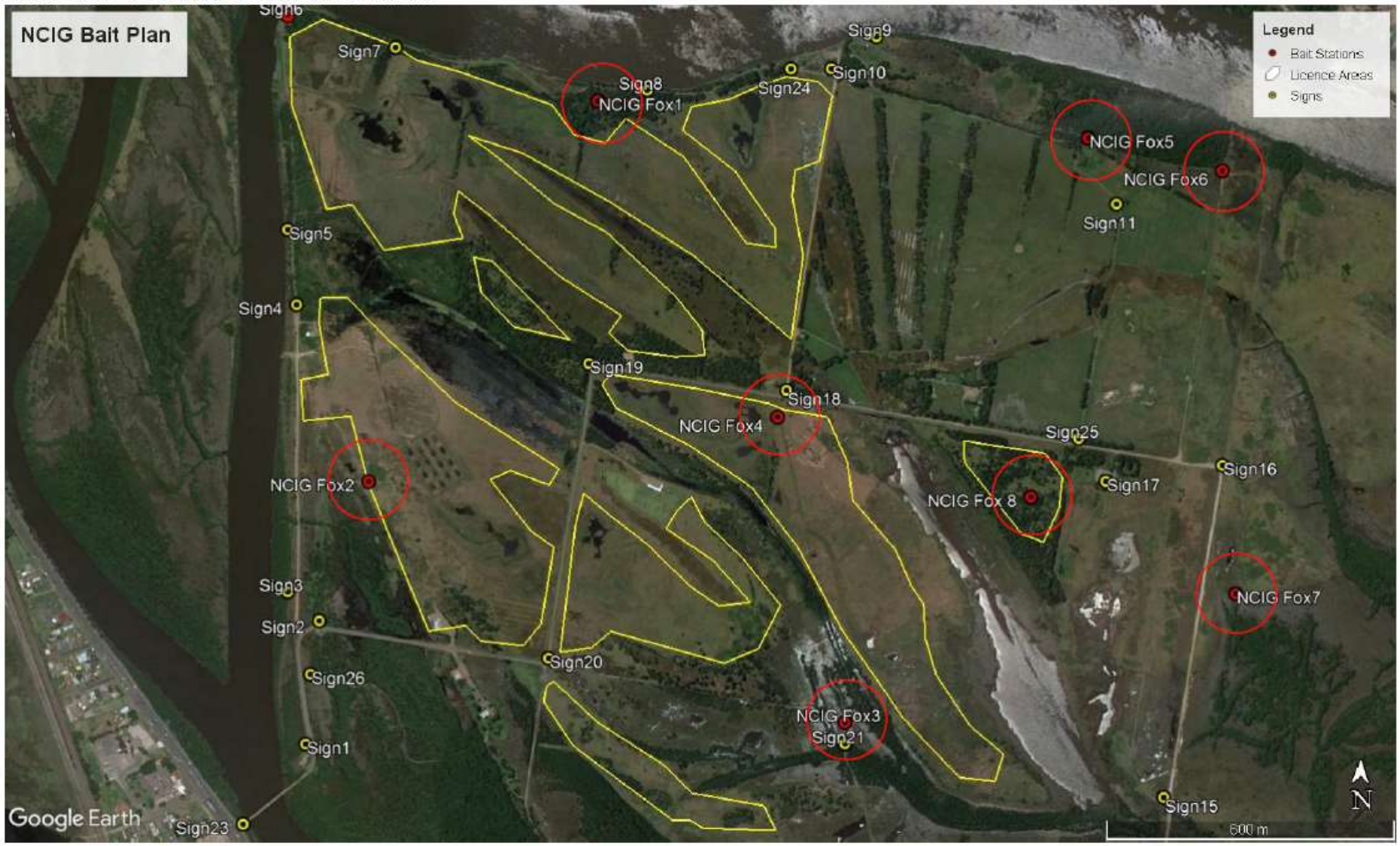

Figure 4: GGBF Compensatory Habitat Fox Baiting Locations

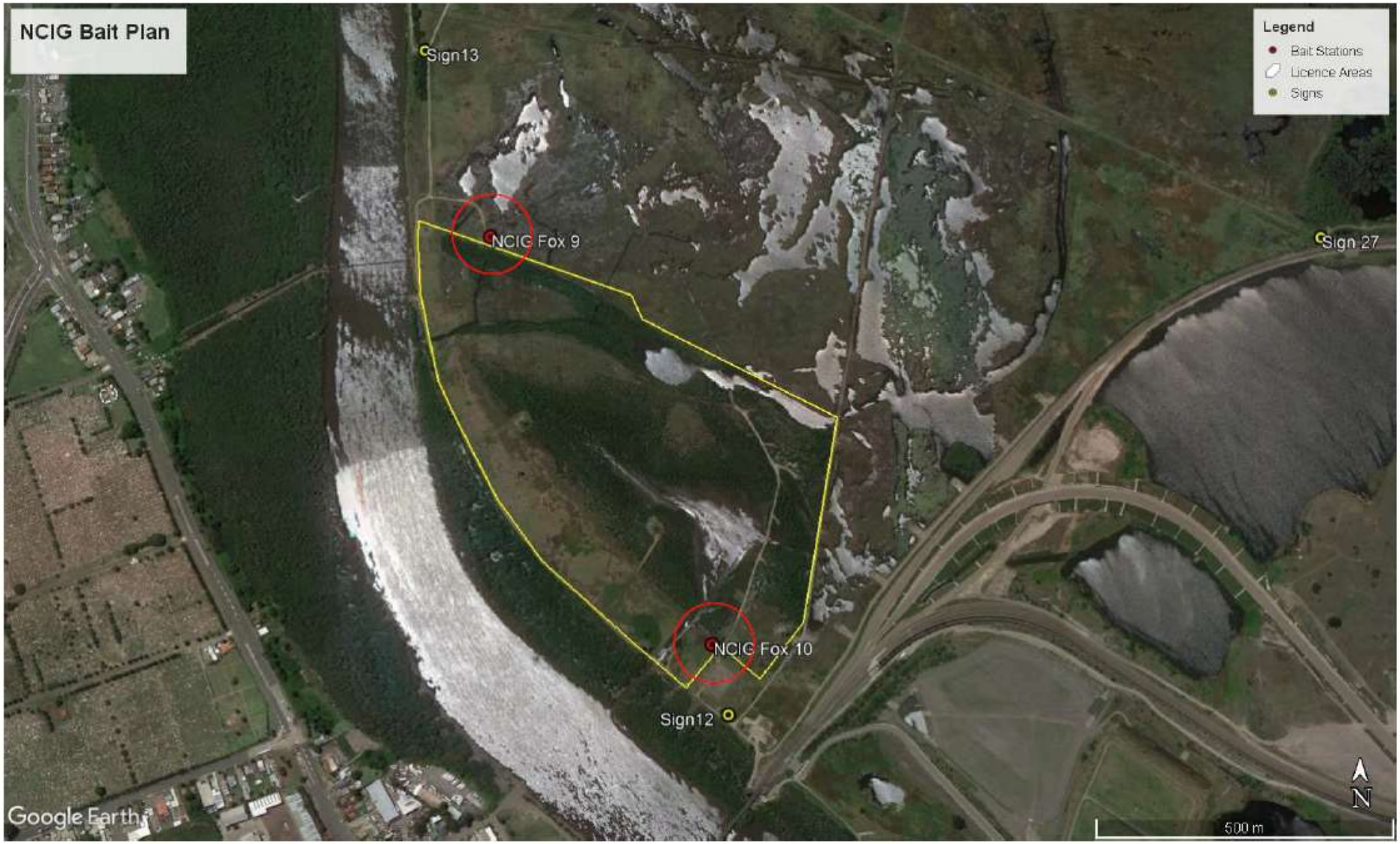

Figure 5: Shorebird Compensatory Habitat Fox Baiting Location

2.2.2. Fence Repairs and Bunding

As mentioned in the previous report, the deliberately lit fire in February 2018 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 were completed at the start of October 2018 (Figure 6).

Prior to the Frog Fence repairs, bunding was able to be undertaken in Stage 1. As previously reported, the bunding works were completed in June, however, a couple of areas slumped during heavy rain. This was rectified in September 2018 once the water levels reduced. Additionally, bunding has also been completed in Stage 2 (Figure 7). This bunding will help prevent water bodies connecting during periods of high rainfall, reducing the spread of *Gambusia.*

Figure 6: New frog fence after Feb 2018 fires

Figure 7: New Bunding in Stage 2

2.2.3. Weed Control

Weed control was undertaken by CVA throughout NCIG's Compensatory Habitat during this reporting period. Priority weeds were targeted including Alligator Weed, Blackberry, Groundsel Bush, *Juncus acutus*, Bitou Bush, Lantana and Pampas. CVA provided updated Weed Mapping in September (Figure 8). These weeds, and a few additional locations have been targeted in recent months.

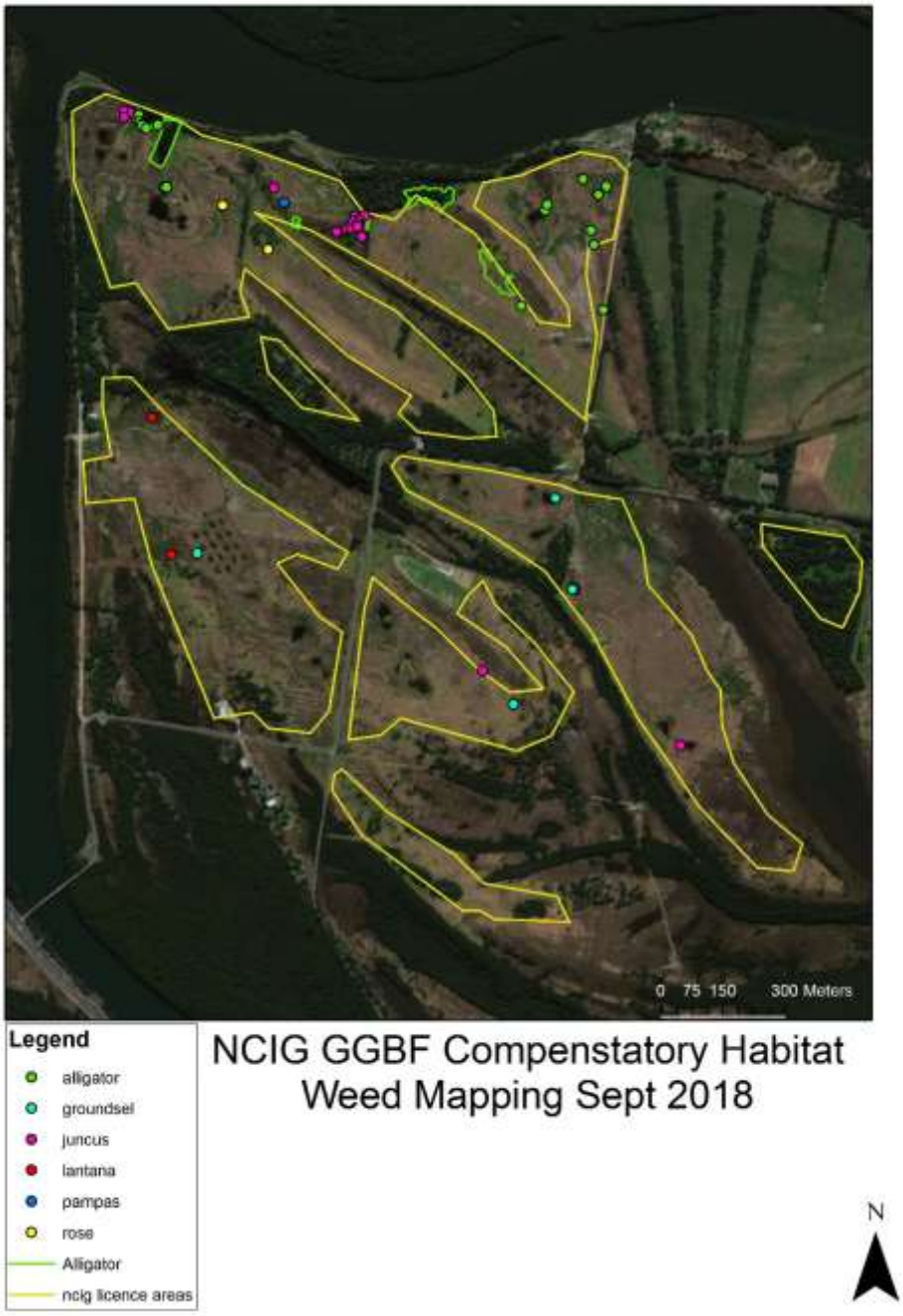

Figure 8: Weed Mapping in NCIG GGBF Compensatory Habitat

3. NCIG Green and Golden Bell Frog Compensatory Habitat

3.1. Green and Golden Bell Frog Research and Monitoring (Dean Lenga - UoN)

3.1.1. Area E Shorebird Monitoring (General Flora and Fauna)

In accordance with the Shorebird Monitoring Evaluation Reporting and Improvement (MERI) Plan, General Flora and Fauna have undertaken regular surveying of shorebird usage at Fish Fry Flats, North West Pond, Swan Pond South, Swan Pond North and Wader Pond (Figure 9). 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 2018 Area E Shorebird Monitoring Report was provided to NCIG during this reporting period.

Figure 9: Shorebird Survey Locations

In the 2018 survey period, 37 shorebird species were recorded from all survey locations including 11 migratory shorebirds. Specifically, 27 shorebird species including 6 migratory shorebirds were observed at Fish Fry Flats during the 2018 surveys, increasing the count to 8 migratory shorebirds in total at Fish Fry Flats since the removal of mangroves (Table 2). The results show that migratory shorebirds are using Fish Fry Flats during the day and night, on high and low tides, with no obvious preference observed (Appendix C). Additionally, White-fronted Chats were observed on three occasions in 2018, this is the first time they have been observed at Fish Fry Flats since mangrove removal.

Table 2. Migratory Shorebird Species Recorded in Area E in 2017/18

All sites Area E	2017	2018	**Fish Fry Flat**	2017	2018
Curlew, Eastern	p	p	Curlew, Eastern	p	p
Godwit, Bar-tailed	p				
Greenshank, Common	p		Greenshank, Common	p	
Knot, Red	p				
Plover, Double-banded	p	p	Plover, Double-banded	p	
Plover, Pacific Golden	p	p	Plover, Pacific Golden	p	p
Sandpiper, Curlew	p	p	Sandpiper, Curlew		p
Sandpiper, Marsh		p			
Sandpiper, Sharp-tailed	p	p	Sandpiper, Sharp-tailed	p	p
Snipe, Lathams		p	Snipe, Lathams		p
Stint, Red-necked	p	p	Stint, Red-necked	p	p
11	9	8	8	6	6

Activity and habitat use by migratory shorebirds has been noted at Fish Fry Flats during the surveys (Table 3). The results thus far indicate that Fish Fry Flats is primarily used as foraging habitat for migratory shorebirds, particularly the mudflat portion of the habitat. In future surveys, the habitat will be further divided to allow better comparison between UoN's vegetation sampling zones. To allow comparison with UoN's vegetation survey zones, whist still being practical for shorebird count surveys, the new habitat zones will be categorized as (1) above saltmarsh, (2) saltmarsh, (3) mud with old pneumatophores, (4) mud with no pneumatophores and exposed by daily tides and (5) water. These results are expected to determine the preferred habitat for shorebirds in Area E.

Table 3: Migratory shorebird activity and habitat use in Fish Fry Flats (2017-18)

Fish Fry Flat 2017 - 2018	No of Records	Day												Night											
		High Tide						Low Tide						High Tide						Low Tide					
		Foraging			Roosting			Foraging			Roosting			Foraging			Roosting			Foraging			Roosting		
		Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water
Curlew, Eastern	13	1	4						5						2						1				
Greenshank, Common	1																					1			
Plover, Double-banded	1								1																
Plover, Pacific Golden	8													1	1	1				1	4				
Sandpiper, Curlew	1								1																
Sandpiper, Sharp-tailed	23		4	1					4	2					2	4				1	5				
Snipe, Lathams	2														1						1				
Stint, Red-necked	13		2	1	1	1			3	1		1				1					2				

Results of the 2017 and 2018 survey suggest that shorebird species richness has a rising trend throughout the year (Figure 10 and 11), peaking in spring. However, as the reference sites begin to dry out in summer, species richness appears to decrease at these sites while Fish Fry Flats species richness remains relatively stable, most likely due to the regular tidal flows in Fish Fry Creek and Wader Creek.

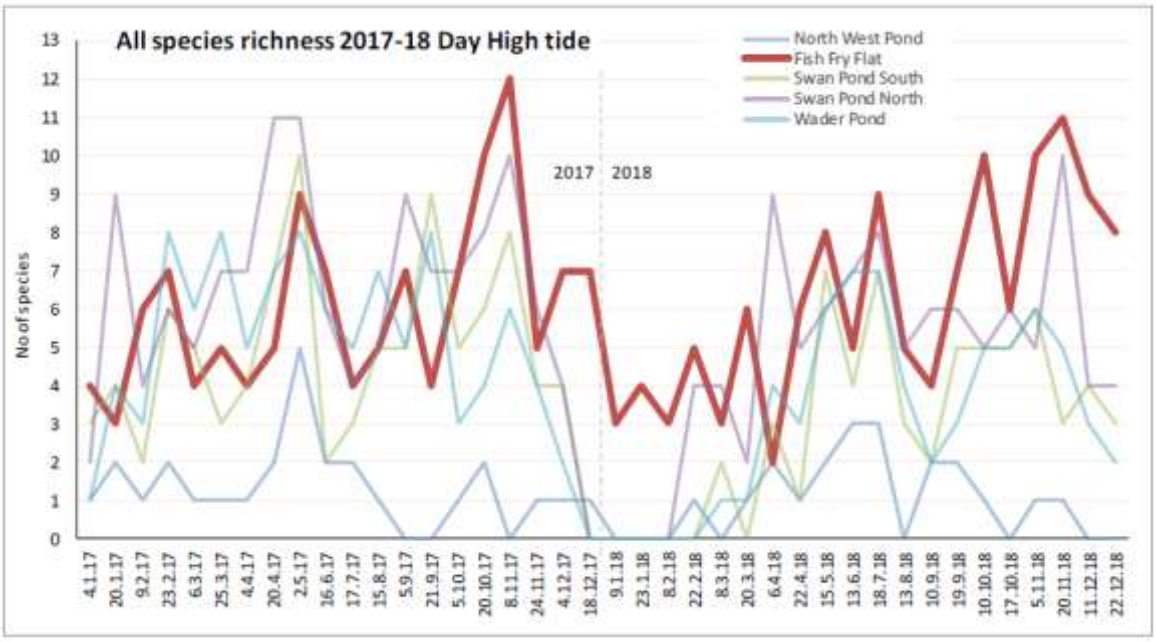

Figure 10: Fish Fry Flats species richness trend observed in 2017-18 (high tide)

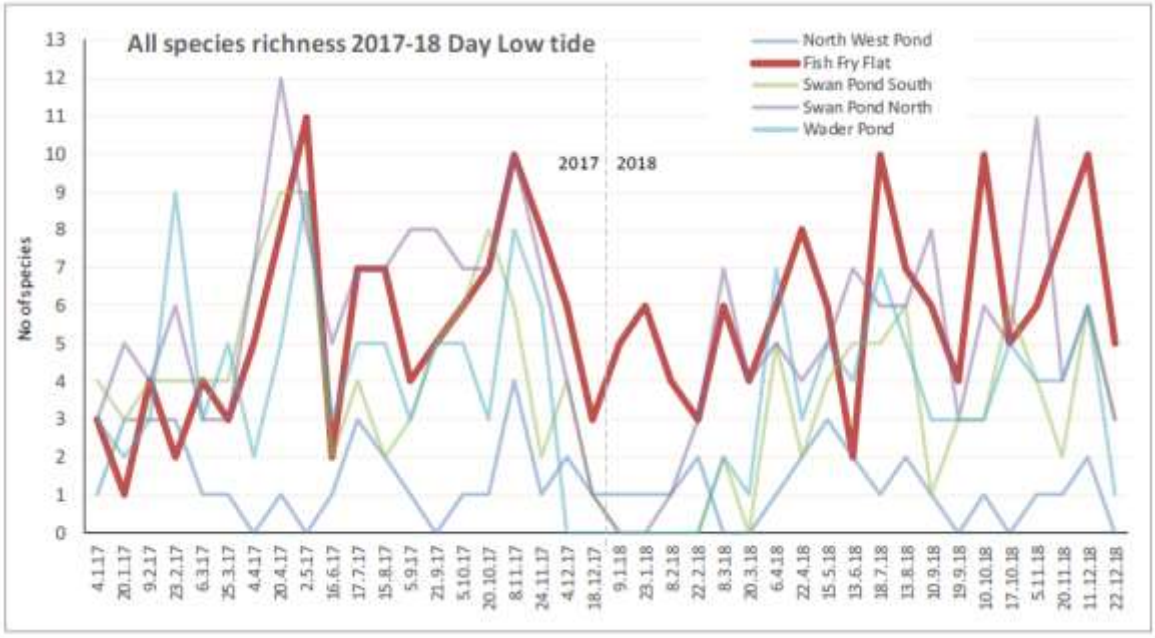

Figure 11: Fish Fry Flats species richness trend observed in 2017-18 (low tide)

3.1.2 Area E Wetland Hydrology Monitoring (Water Research Laboratories UNSW)

Trigger Levels for 2019

Based on existing plans and Hunter River tidal levels near Area E, UNSW Water Research Laboratories provided NCIG additional SmartGate Trigger Levels for 2019.Following the stakeholder meeting discussion in September 2018, it was concluded that the existing tidal triggers will remain the same and active monitoring will be undertaken, including water level monitoring before any alterations are made to tidal trigger levels. The 2019 synthetic tide, alongside the natural tide can be seen in Figure 12.

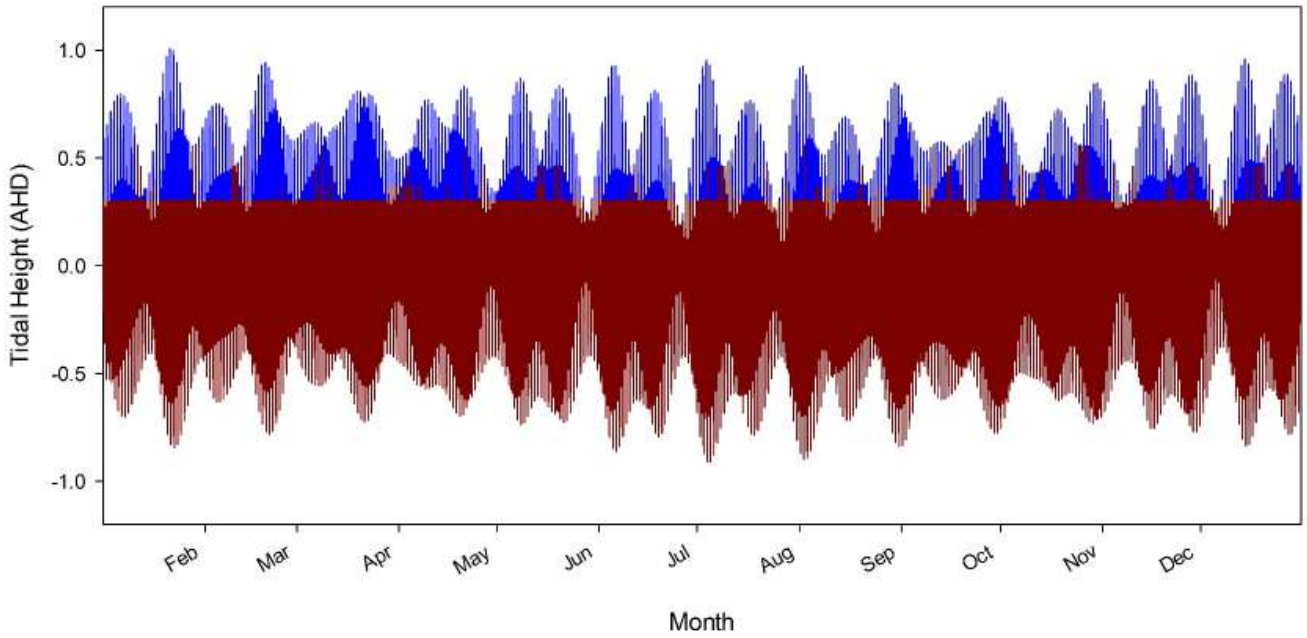

Figure 12: Newcastle Natural and Synthetic Design Tides for 2019

Groundwater Dynamics

The UNSW Water Research Laboratory (WRL) continued with the ongoing hydrological monitoring program in 2018, in particular, investigating the relationship between the surface water and groundwater at Area E. A detailed investigation was conducted in July 2018 to better understand groundwater movement and interactions with surface water under different conditions including 1) wetland in natural tidal conditions, 2) wetland flooded, with flushing restricted by the SmartGate and 3) wetland drained, with the gates preventing inundation. Radon, a naturally occurring groundwater tracer has been used to detect groundwater seepage into Fish Fry Creek and Flats. A continual 24-hour time series dataset of radon and wetland

water levels covering two tidal cycles were collected for each experimental condition.

The surface and groundwater dynamics for each condition can be seen in Figure 13. The results show a peak in radon during both low tide periods under natural conditions, indicating groundwater discharging into Fish Fry Flats. During the flooded conditions, a two-fold increase in radon from the start of the period to the end, indicates that even under flooded conditions, groundwater seepage contributes to the overall surface water volume of the wetland. When the SmartGate was opened to drain the wetland, radon spiked as the water that infiltrated the sediment during the flooded period discharged into Fish Fry Creek. The monitoring indicates that large volumes of groundwater seepage are likely after Area E experiences flooded conditions.

Overall, the results show that groundwater and surface water systems are closely linked, and groundwater seepage occurs under various conditions. This may be an important factor as small amounts of groundwater seepage have the potential to affect the quality of surface water, as groundwater often contains higher concentrations of organic and inorganic substances in comparison to surface waters.

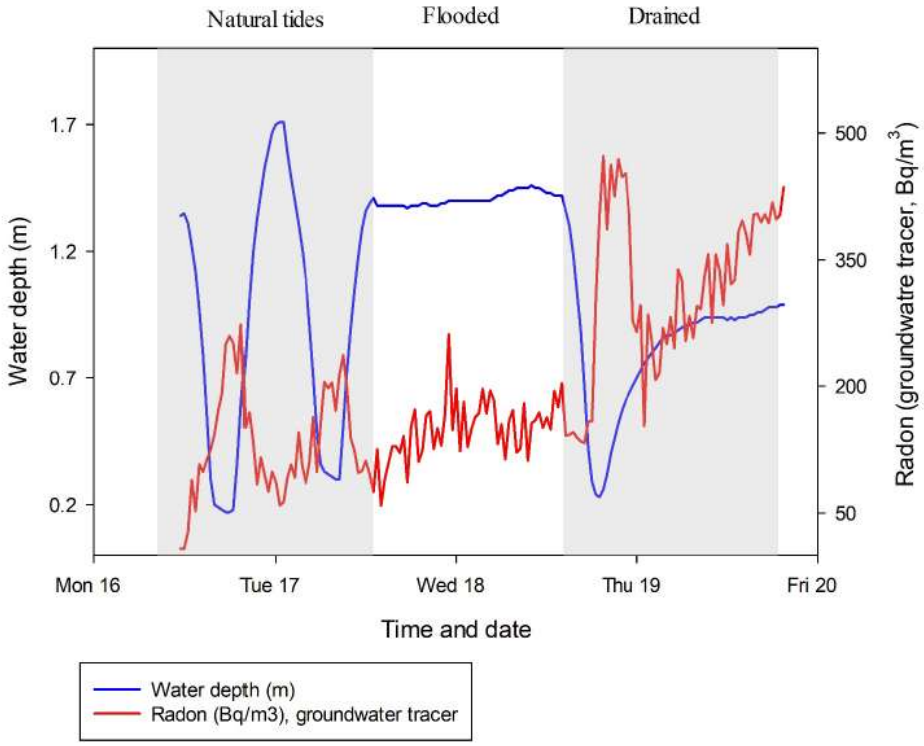

Figure 13: Surface water and groundwater interactions in Fish Fry Creek under different natural tides, flooded and drained conditions.

Surface Water Quality

Surface water quality parameters at Fish Fry Creek were also measured under natural, flooded and drained conditions as described above. During natural conditions, it was clearly observed that tidal variation controlled the water quality and hydrodynamics within Fish Fry Flats (Figure 14). During the flooded conditions, the EC decreased over the 24-hour period, potentially due to groundwater seepage containing lower EC. Chlorophyll showed a similar trend to natural tidal conditions, indicating processes other than tidal variation may be driving chlorophyll dynamics in Fish Fry Flats. A sharp increase for temp, DO, pH and chlorophyll and a decrease for EC was observed after the gate was opened and the water drained from the wetland.

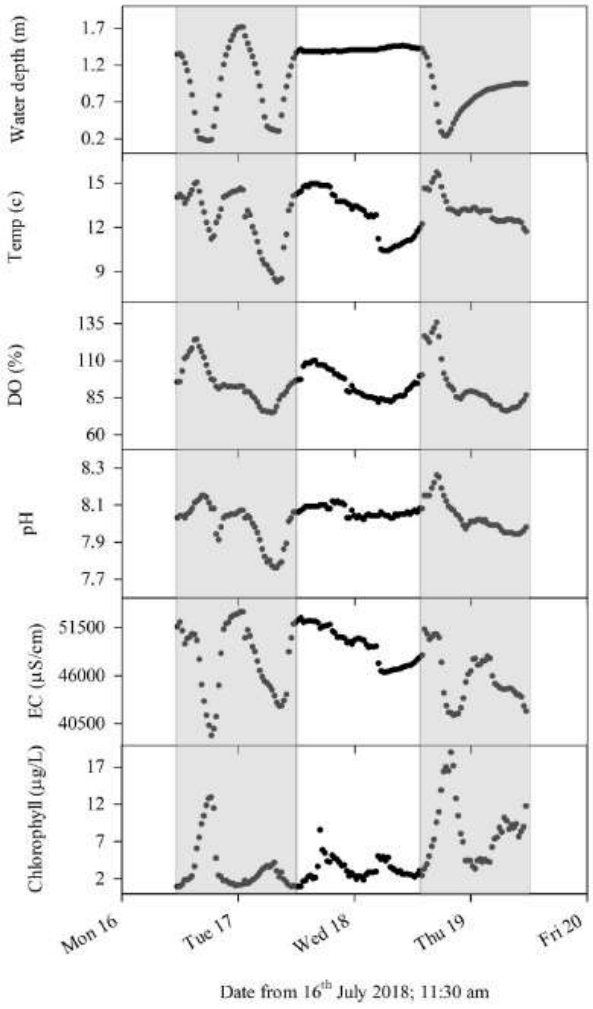

Figure 14: Surface water quality and dynamics time-series measurements at Fish Fry Creek over 72hrs under natural, flood and drained conditions.

Groundwater levels and quality

Groundwater levels at Area E have been continually recording water levels since November 2017 using Solinst pressure transducer loggers placed in piezometers (Figure 15). Data shows that piezometers 4 and 6 located on the South West side of the mud flats have the highest hydraulic head (water level normalised to surface elevation) following the topography of the area, indicating that groundwater flows towards the centre of the mudflats and drains to Fish Fry creek (Figure 16). Piezometers 7 and 11 located on the North side of Fish Fry creek have lower hydraulic heads. Average depth to the shallow groundwater aquifer at Area E was around 1.0 meter which is similar to previous measurements in 2018. In general, groundwater levels at Area E are greatly affected by tides and follow the tidal regime as shown in Figure 15. Groundwater level data for the second half of 2018 did not show any long-term trend and no obvious decline or incline trend was observed in the graph, indicating stable conditions throughout 2018.

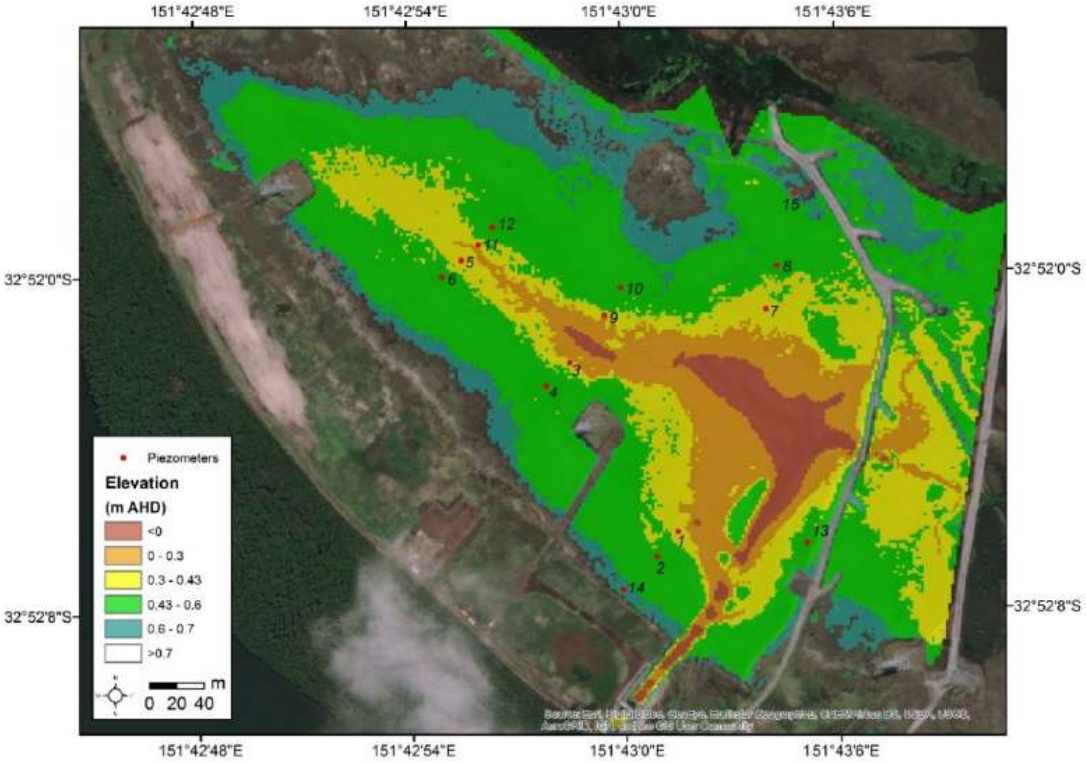

Figure 15: Locations of the piezometers at Area E

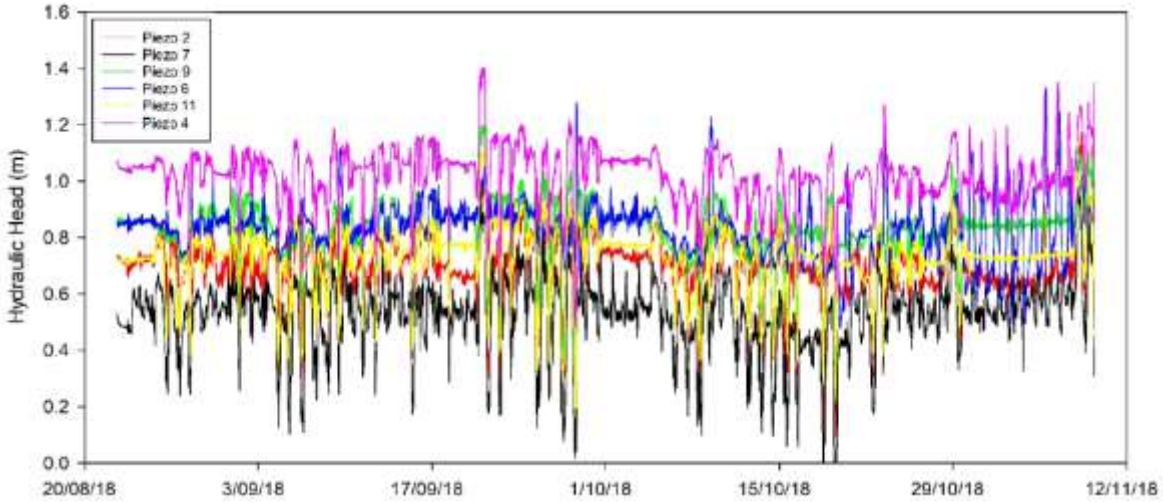

Figure 16: Groundwater level time series data from 22/08/18 to 10/11/18 for shallow bores across Area E

Groundwater data from Area E indicates that groundwater at the site is hypersaline with all piezometers showing a higher EC than seawater (52 mS/cm), indicating high rates of evapotranspiration occurring at Area E (Table 4). The groundwater pH (avg 6.9) was more acidic than the average surface water (8.1) which was measured at the same time as the groundwater sampling. The groundwater also had a lower DO than the surface water (2.8 mg/L compared to 10.5 mg/L). These results imply that groundwater seepage can lower the surface water pH and DO concentrations. The groundwater quality data (Table 4) showed high concentrations of trace metals, including iron (Fe) and manganese (Mn) which could potentially be linked to acid sulphate soils in the area. Additionally, total dissolved nitrogen (TDN) and dissolved inorganic carbon (DIC) concentrations were elevated. However, mangrove sites in Australia and worldwide are known for high dissolved inorganic carbon accumulation in their sediments. Average dissolved organic carbon and total dissolved nitrogen were in the range of wetlands in Australia surrounded by mangrove vegetation.

Table 4: Groundwater quality observations at Area E

Piezo no.	Date	EC (mS/cm)	Temp	pH	DO (mg/L)	Fe (μM)	Mn (μM)	DOC (μM)	DIC (μM)	TC (μM)	TDN (μM)	TDP (μM)
1	19/07/2018	74.9	10.7	7.1	4.8	2148	36.1	645.9	5556.1	6202	142.5	3.1
3	19/07/2018	68	20.4	6.8	2.2	223	15.9	908.9	17664.6	18573.4	171.4	4.9
4	19/07/2018	75.1	12.1	7	2.1	2297	35.7	1010.6	6010.8	7021.3	195.9	3.3
6	19/07/2018	75.3	13.7	6.9	6.4	1216	32.5	925.6	7616.9	8542.5	161.3	3.2
7	19/07/2018	71.2	16.9	6.8	5.7	657	14.3	406.4	5556.8	5963.2	138.7	3.1
9	19/07/2018	62.7	17.9	7.2	0.5	759	11.9	608.3	19121.9	19730.2	125	3.1
10	18/07/2018	78.1	17	7	3.4	798	19.4	864.3	8901.1	9765.4	181.2	3
11	19/07/2018	71.1	19.9	7	2.8	1500	26.2	630.9	7875.6	8506.5	137.2	3
12	18/07/2018	71.3	16	7.3	5.9	92.7	27.1	1130.5	9102.9	10233.4	195.2	3.2
13	17/07/2018	70	17	6.4	0.4	2451	28	1079.6	2792.5	3872.1	188.9	2.8
14	18/07/2018	75.8	16.7	6.5	2.7	3475	43.4	667.9	1568	2235.9	117.8	2.8
15	17/07/2018	72.7	18.3	6.6	1.6	923	48.7	534.8	3154.7	3689.4	86	3
	Average	72.0	17.0	6.9	2.8	1070	27.6	766.1	6813.8	7763.9	151.9	3.1
	Std Error	1.2	0.8	0.1	0.6	294	3.3	67.0	1574.1	1579.8	10.0	0.2

Vegetation Development

Six drone surveys have been conducted to date from 13th February 2017 – 9th November 2018. Distinct vegetation colour and coverage can be observed when comparing the images, however as the images were taken during different times of the year, seasonal and climatic variations of the vegetation need to be considered. The obvious changes in the spatial coverage of vegetation in the images below (Figure 17) suggest that saltmarsh is developing in Area E. The most recent processed drone imagery (August 2018) shows an increase in vegetation along the low tide mark of Fish Fry Flats (Figure 18) this survey was conducted in the same season (winter) and experienced similar climatic conditions to those observed in the July 2017 survey (Figure 17 top right). Hence, climatic and seasonal variations are considered negligible when comparing these two images.

Figure 17: Drone imagery of Area E, top left: Feb-2017; top right: July-2017; bottom left: October-2017 and the bottom right: April-2018).

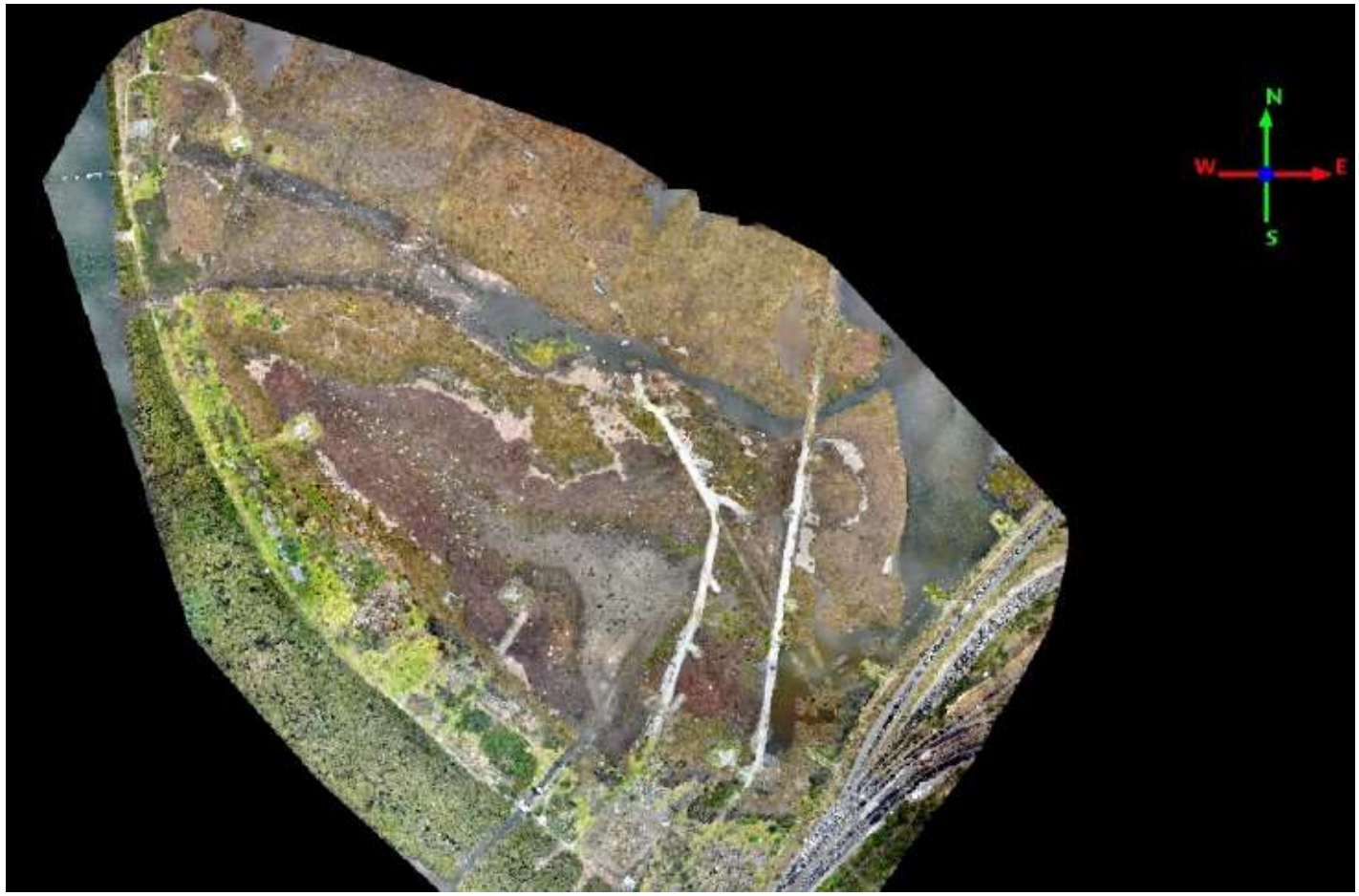

Figure 18: Drone imagery of Area E, taken on the 22nd August 2018

Elevation

The August 2017 drone survey was compared to the drone survey in October 2017 (same season) and to the imagery obtained from the baseline survey in February 2017. The locations of the cross sections can be seen in Figure 19. The cross section 1 elevation profile indicates no major changes in surface elevation in the northern section, however south of Fish Fry Flats shows a slight (up to 10cm) increased compared to the baseline data. Cross section 2 indicates a 5cm decrease in elevation in areas north of Fish Fry Creek in comparison to the baseline data. However, there is no indication of any changes in the elevation profile south of Fish Fry Creek. The elevation variations at Area E are within the uncertainty of the measurement techniques used (0.1±0.1 meter) and are therefore not considered to be significant at this stage. The drone surveys are recommended to be continued at 6-monthly intervals to capture elevation changes as soil and physical properties change overtime.

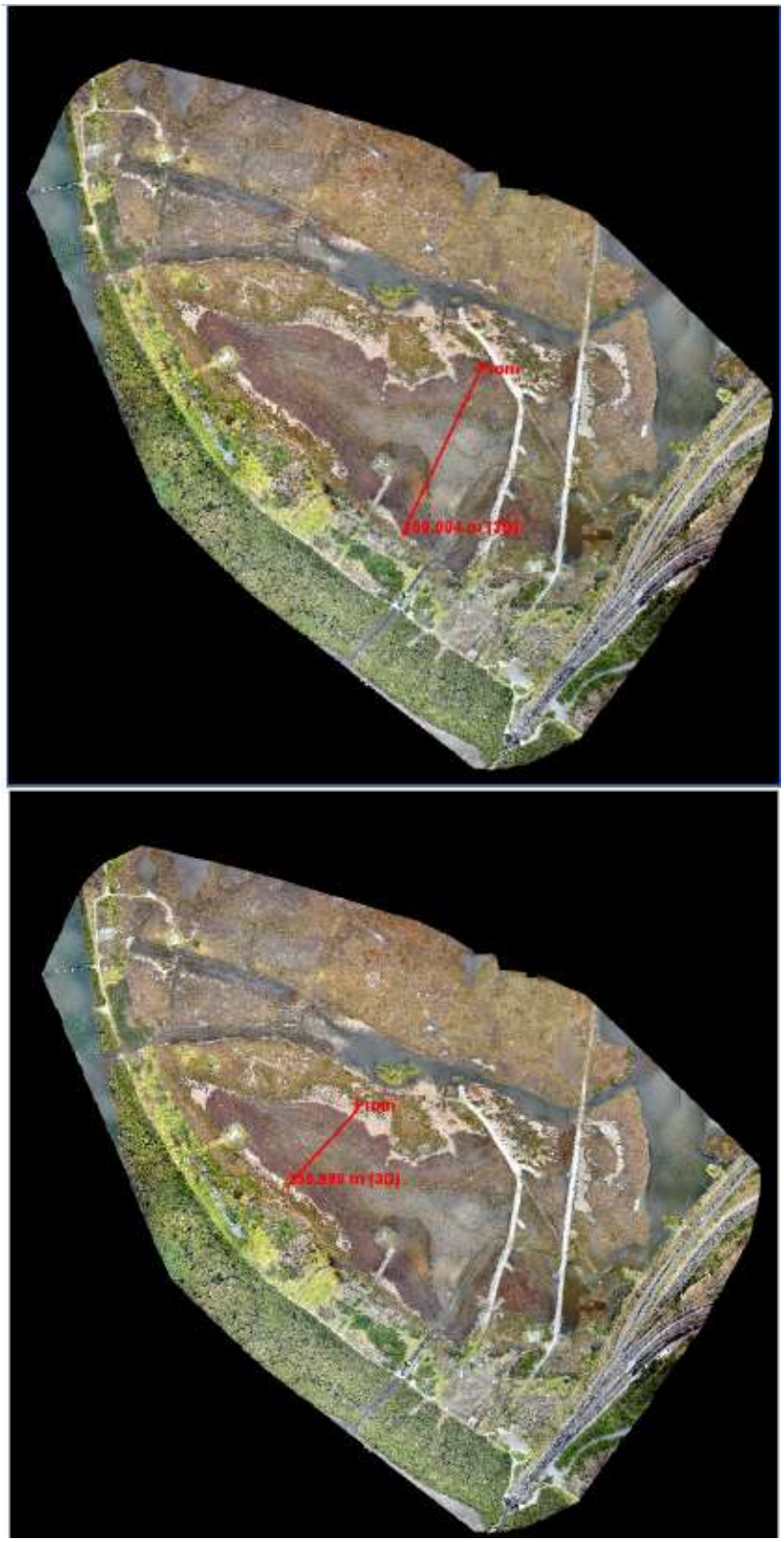

Figure 19: Location of cross section 1 (top) and 2 (bottom)

3.1.3 Fish Fry Flats Vegetation and Benthos Survey- Preliminary Report (Caleb Rankin - UoN)

The University of Newcastle have provided NCIG with an updated preliminary report of the benthos and vegetation monitoring 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, crab holes, and macrofauna.

For each of the ecological indicators measured, stratified random sampling is being undertaken at each site with indicators being measured in each of five zones transitioning from mudflat to saltmarsh Above Highest Tide (AHT, saltmarsh that is not inundated by the highest annual tides) based on tidal flow illustrated in Figure 20. Saltmarsh AHT is only sampled in Area E where the tide has been lowered and existing saltmarsh remains above the highest tide.

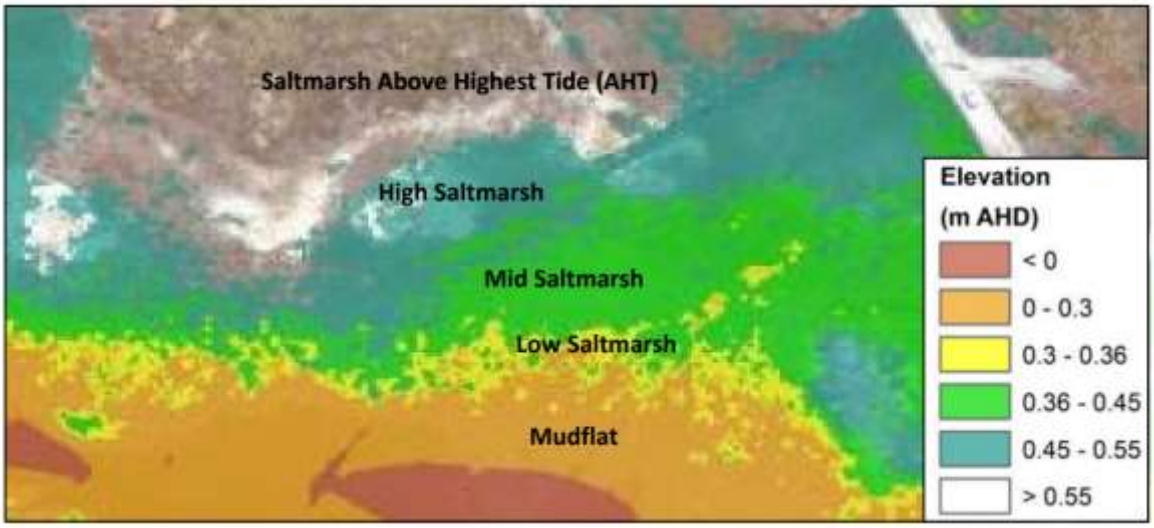

Figure 20: Digital Elevation Map detailing the tidal flow and the zones sampled from mudflat to saltmarsh Above Highest Tide (AHT).

For all sites, 1m^2 quadrats have been placed randomly in each of the five strata present at Area E (Figure 20) to measure vegetation cover, diversity and active crab holes. Each quadrat location has been marked to ensure the same location is used in future sampling. Random sampling using 6cm deep cores extracted by PVC pipes has been used for sampling macrofauna at each site.

In addition to the Area E monitoring, two control and two older restoration sites will be sampled for comparison (Figure 21). The control sites,

Cobbans Creek and Crabhole Flats, were selected due to having a similar characteristics and disturbance history to Area E. These include similar structure, age and direct and indirect disturbances. The older restoration sites, Tomago Wetlands and Hexham Marsh, were selected on the basis of their similar structure to Area E and for their increasing value as shorebird habitat. Each has been undergoing restoration for over 10 years. Each of the control and restoration sites will be sampled twice per year in June (winter) and November (summer) starting in June 2018.

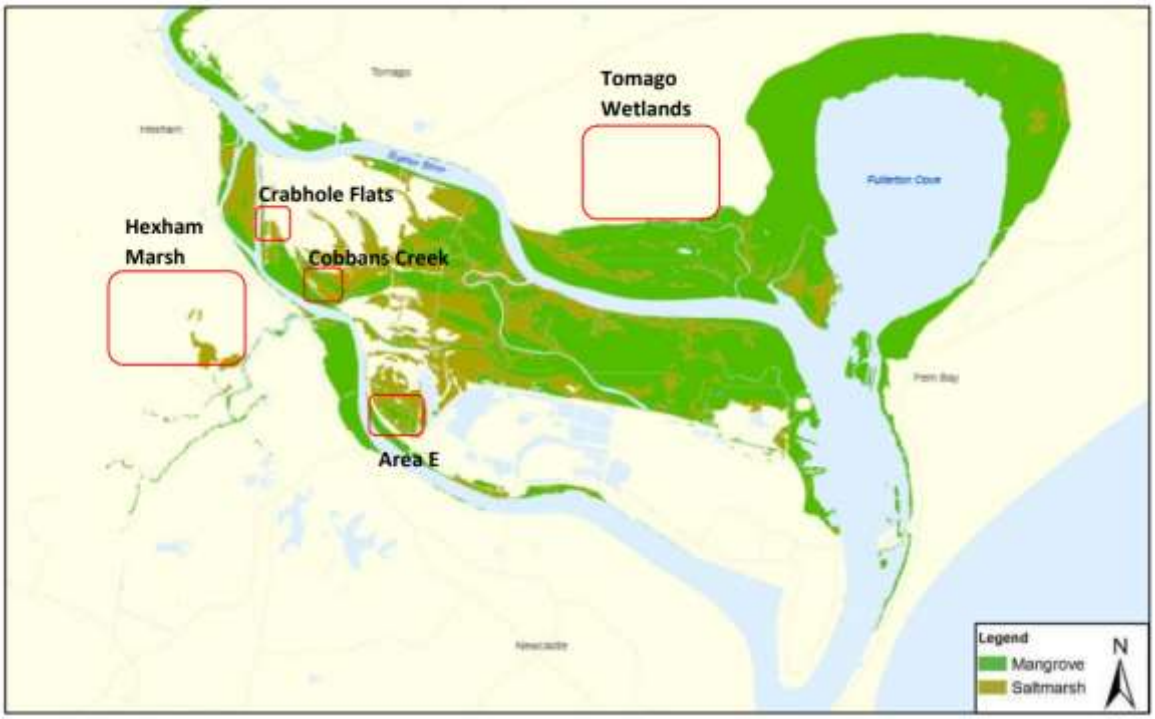

Figure 21 Locations of the study sites

Vegetation and Crabholes

Since the initial surveys in November 2017, there has been an increase in saltmarsh cover and species richness. In June 2018 there was a significant increase in seedling counts (Figure 22C) which translated to the November 2018 increase in vegetation cover and species richness (Figure 22A & B). The most significant increase was in the low marsh zone, where there was previously no vegetation, and the mid marsh, where vegetation cover and species richness more than doubled from the July to November 2018 sampling events (Figure 22A & B). No significant differences were observed in weed cover except for summer die back of perennial weeds in the AHT saltmarsh (Figure 22D).

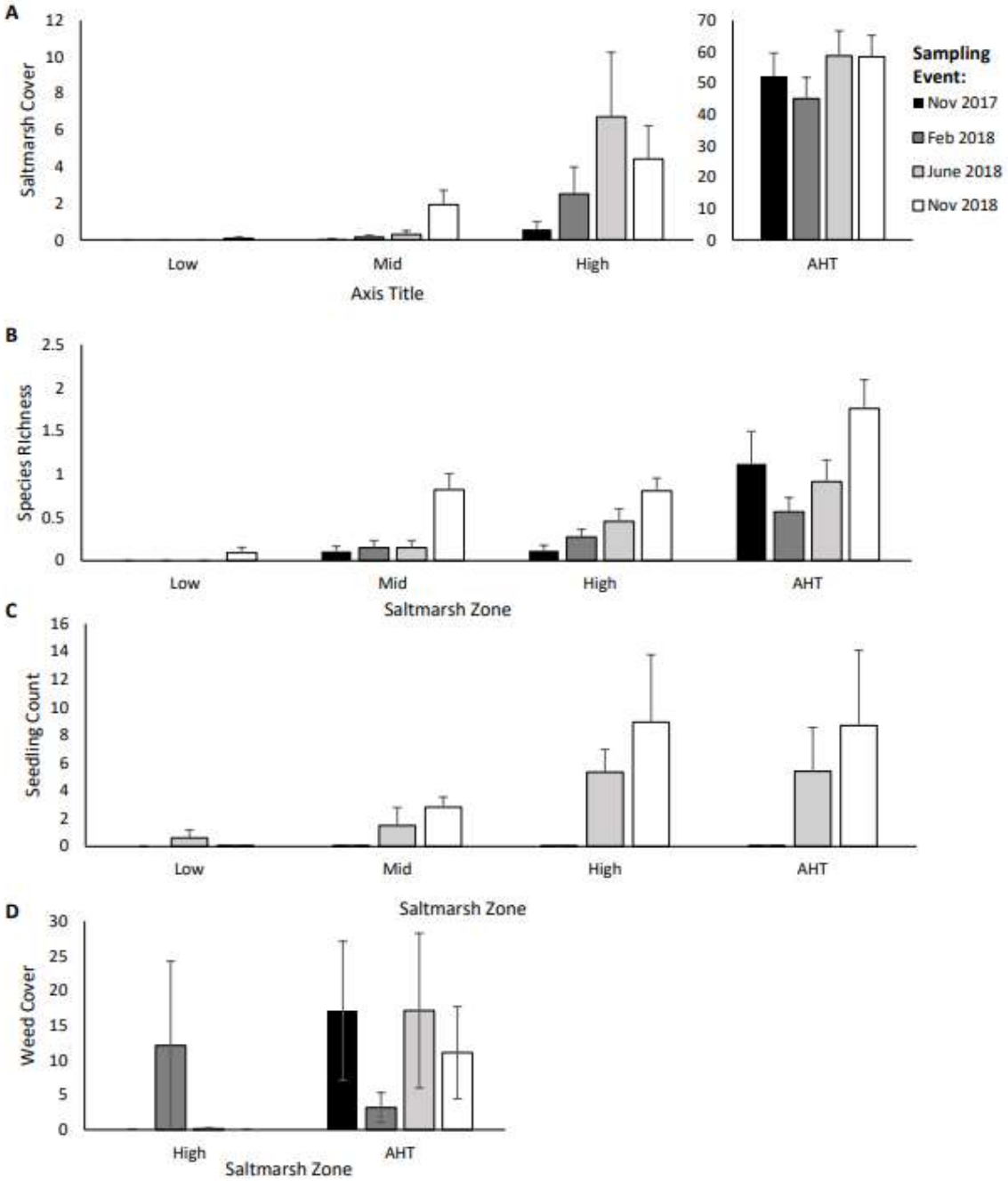

Figure 22: Changes in mean Vegetation Cover (A) Plant Species richness (B) Number of Seedlings (C) and Weed Cover (D) at Area E from November 2017 to November 2018 per m2. Bars are mean ± standard error (se). Measurements are from 25 quadrats for each of the saltmarsh zones on each sampling occasion.

Comparisons between sites showed that while Area E saltmarsh cover is still significantly lower than the control and restoration sites, the plant species diversity has recovered quickly and is now comparable to the other sites (Figure 23A & B). Crabhole Flats and Hexham Marsh had similar weed cover to Area E while Cobbans Creek and Tomago Wetlands had slightly higher saltmarsh cover and lower species diversity overall (Figure 23C).

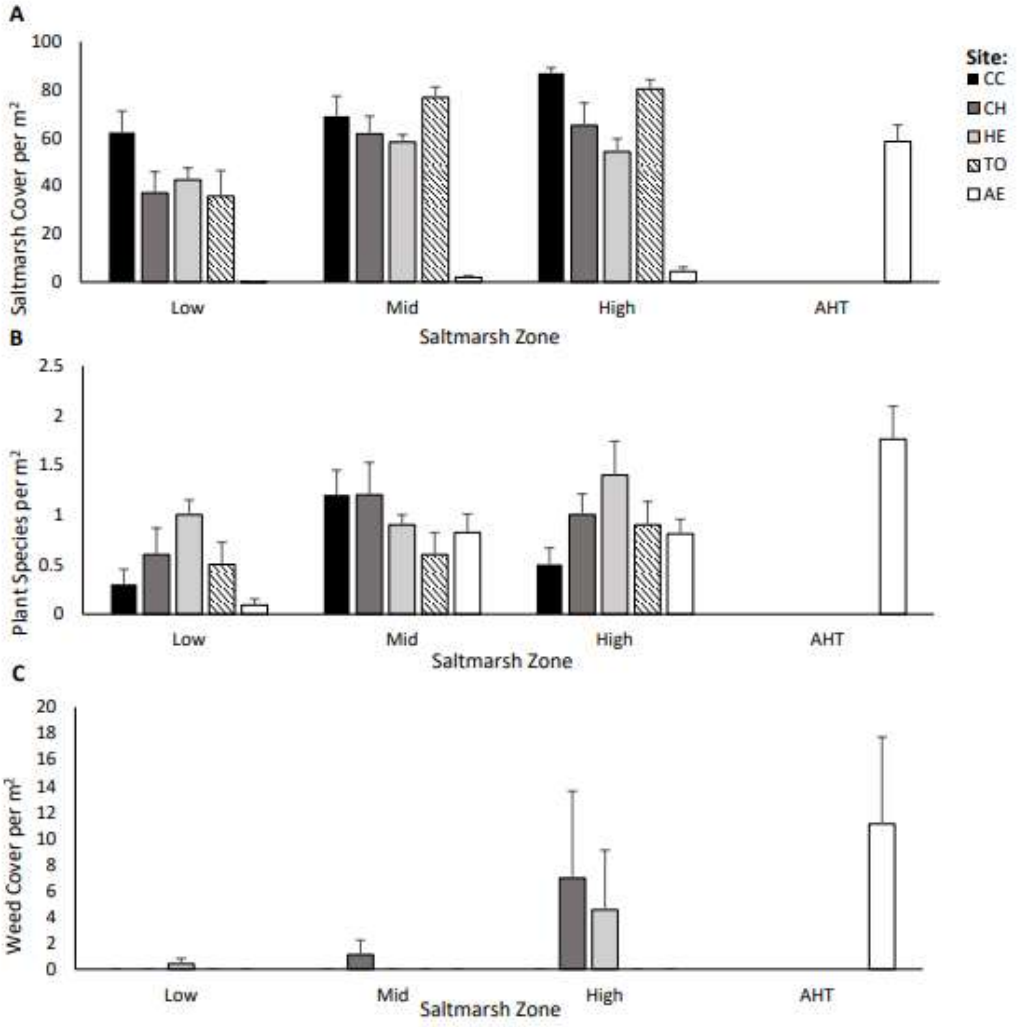

Figure 23: Comparisons for each saltmarsh zone of mean Saltmarsh Cover (A) Plant Species richness (B) and Weed Cover (C) For each of the sites Cobbans Creek (CC), Crabhole Flats (CH), Hexham Marsh (HE), Tomago Wetlands (TO) and Area E (AE), sampled in November 2018. Bars are mean ± standard error (se). Note that the AHT zone was only sampled in AE (see 2.3 Sampling Strategy). Measurements are from 10 quadrats for each of the saltmarsh zones at CC, CH, HE, and TO and from 25 quadrats for each of the saltmarsh zones at AE.

Crabhole counts at Area E decreased significantly from the November 2017 to the June 2018 sampling event but have stabilised from the June to November 2018 sampling events (Figure 11A). GoPro footage is currently being analysed to determine how representative the crabholes are of crab abundance. Comparing between sites, Hexham Marsh and Area E had the highest crabhole count in the low marsh with Cobbans Creek having the highest crabhole count in the high marsh (Figure 11B). There was little apparent relationship between vegetation and crabhole counts.

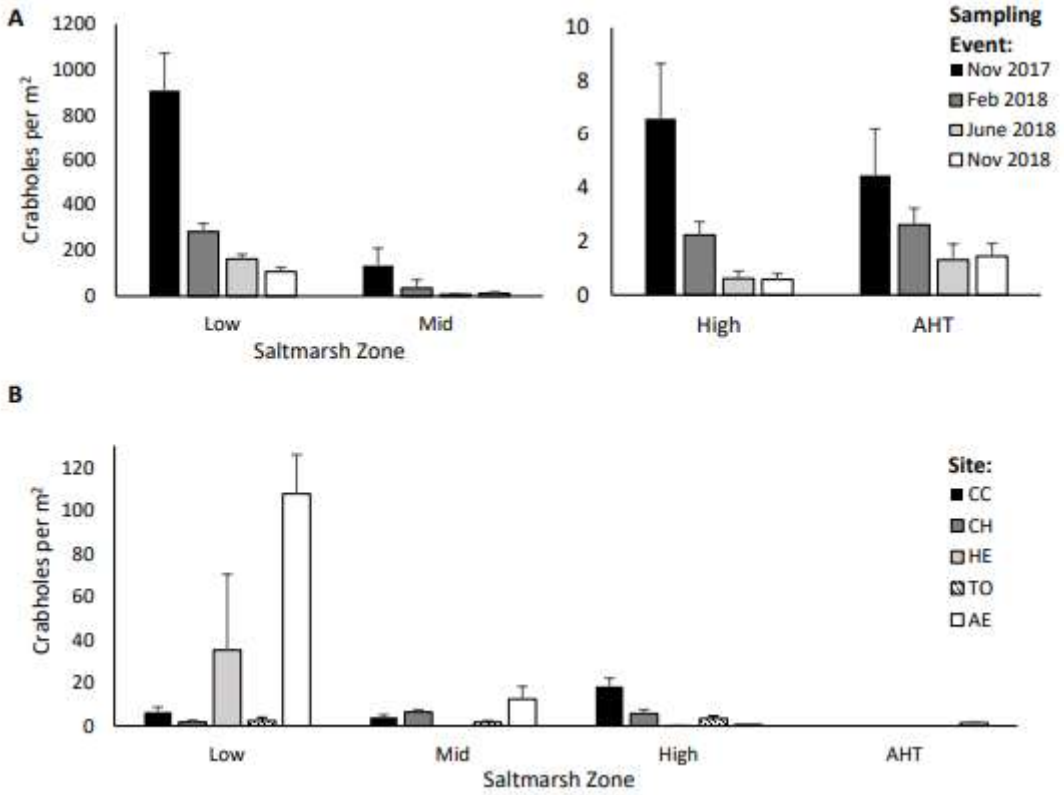

Figure 23: Mean crabhole count from February 2017 to November 2018 in Area E (A) and comparisons between the sites Cobbans Creek (CC), Crabhole Flats (CH), Hexham Marsh (HE), Tomago Wetlands (TO) and Area E (AE) for crabhole counts in each zone on November 2018 (B). Bars are mean ± standard error (se). Note that the AHT zone was only sampled in AE (see 2.3 Sampling Strategy). Measurements are from 10 quadrats for each of the saltmarsh zones at CC, CH, HE, and TO and from 25 quadrats for each of the saltmarsh zones at AE.

Infauna

At Area E, 10 types of macrofauna have been observed and identified to the family level where appropriate (Figure 24). From November 2017 to November 2018 there were significant changes in the abundances of various macrofauna at Area E. Most significantly, the 2018 abundance of bivalves decreased to about 10% of the November 2017 abundance, while amphipods and crabs in the edge marsh were absent (Figure 24B). Conversely, abundances of nereididae polychaetes (bristle worms) and oligochaetes (segmented worms) doubled. The increase in nereididae polychaetes is promising for Area E given their importance in shorebird diets. However, the reduction in bivalves and amphipods reduces the variety of foods available to the shorebirds.

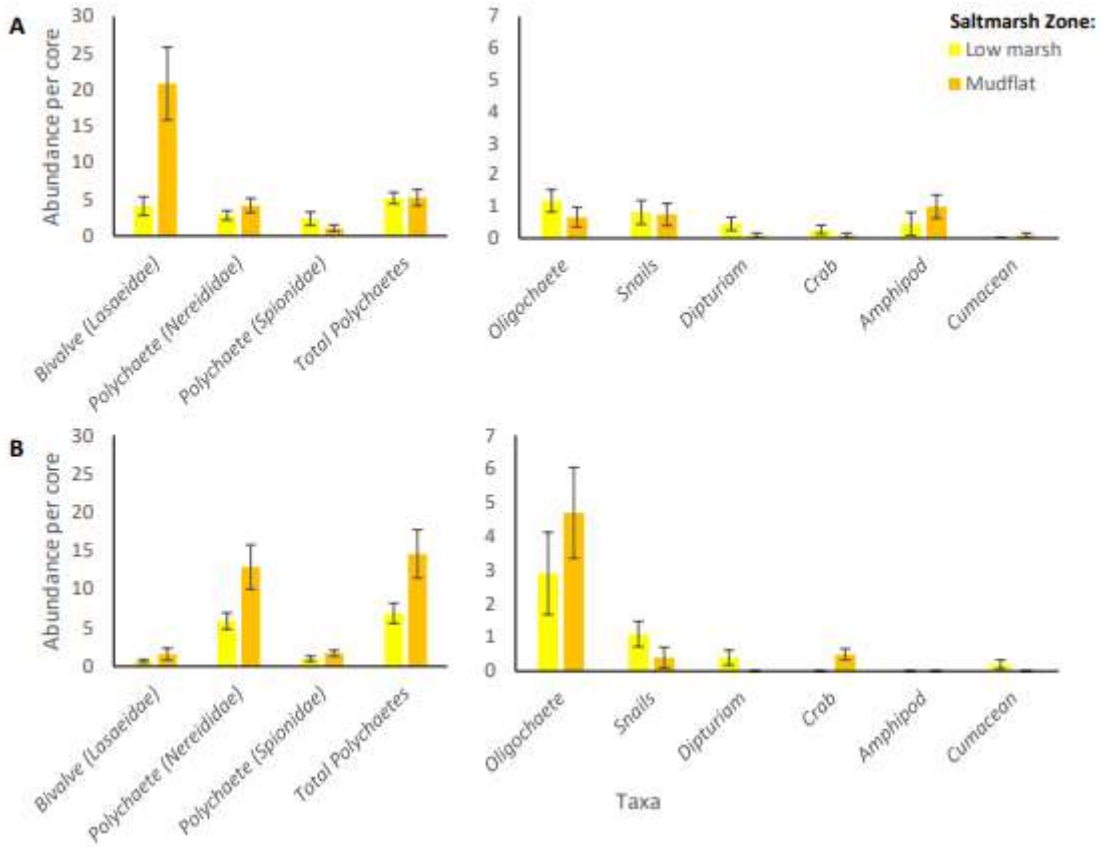

Figure 24: Mean abundance of the macrofauna taxa identified at Area E per core (181cm3) between November 2017 (A) and November 2018 (B). Standard error (se) bars indicate where there are significant differences. Measurements are from 10 sediment cores for each of the saltmarsh zones

3.2 Compensatory Habitat Management

Mangrove Removal

Mangrove removal was undertaken by Conservation Volunteers Australia (CVA) in November 2018. This was the second removal event since the mangroves were initially removed from Area E in late 2016. Mangrove regrowth density and distribution was mapped prior to removal to allow comparison with the 2017 removal data (Figure 25). The 2018 results show a reduction of more than 85% mangrove seedlings/propagules/regrowth in comparison to the 2017 data. The 2018 removal data can be seen in Table 5.

Table 5: NCIG Mangrove Removal Data 2018

Zones 2017	Consolidated Zones 2018	Seedlings	Propagules	Regrowth	Total
1 2 3 4	1	86	33	0	119
5	2	70	304	0	374
6	3	30	298	0	328
7 8 9 10	-	No mangroves present			0
11	4	54	505	0	559
12	5	25	179	0	204
13					
14 15	-	No mangroves present			0
16	6	58	230	0	288
17	7	104	84	0	188
	Total	**427**	**1,633**	**0**	**2,060**

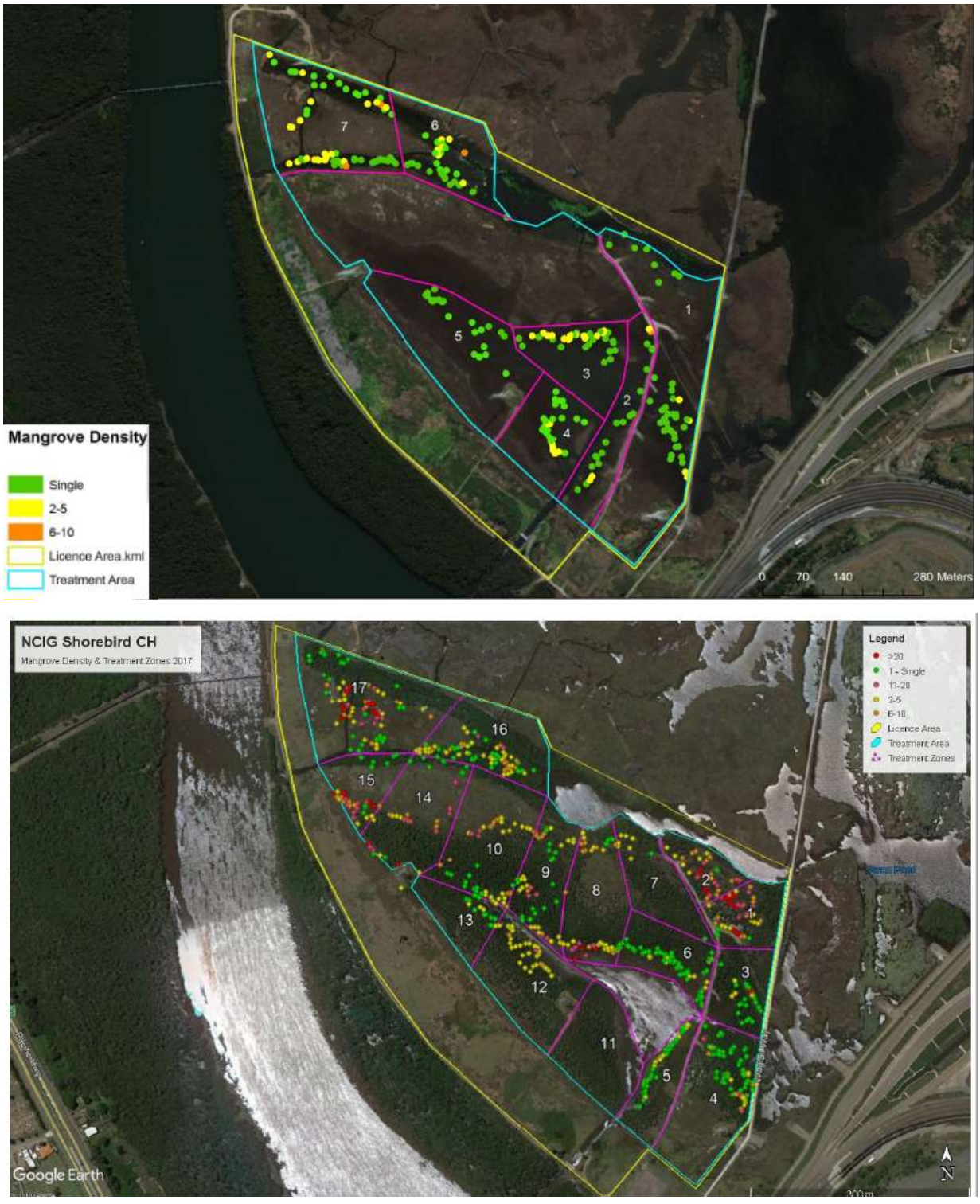

Figure 25: Comparison of mangrove removal intensity in November 2018 (top) and November 2017 (bottom)

Appendix A – Green and Golden Bell Frog Research and Monitoring Program on Ash Island 2018/2019 Season (UoN)

Green and Golden Bell Frog Research and Monitoring Program on Ash Island, Hunter Estuary.

Report for Sept-December 2018 (2018/2019 Summer Season)

Prepared for Newcastle Coal Infrastructure Group

Prepared: Dean Lenga, Assoc Prof. John Clulow

Reviewed: Prof. Michael Mahony, Dr Simon Clulow

February, 2019

Executive Summary

Key findings:

- Above average rainfall in September and October, 2018 filled ephemeral and permanent waterbodies (reversed with below average rainfall in November, December, 2018, resulting in drying of ephemeral habitats).
- 59 GGBF were observed across 10 of 44 constructed wetland habitats (Sept-Dec, 2018). These records were all in ephemeral waterbodies.
- Elevated early summer rainfall was associated with GGBF breeding events, and it is considered that the high rainfall events were the likely triggers of these breeding events.
- Breeding events were confirmed by the presence of GGBF tadpoles in 2 constructed ephemeral waterbodies.
- It is noted that the record of breeding in constructed habitats in the survey period (Sept-December 2018) within the 2018/2019 season contrasts with the absence of recorded breeding the constructed habitat in the previous 2017/2018 summer.

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 September and December, 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 standard methods for surveys of Green and Golden Bell frogs on Ash/Kooragang Islands over multiple seasons. Techniques include are described below:

- Visual Encounter Surveys: timed counts, adjusted for observer number, of GGBF in and around wetland habitats used to generate estimates of relative population densities.
- Capture Mark Release Surveys in GGBF occupied waterbodies:
    - Recording sex, 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 biopsies of captured frogs 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.

- Data on 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 September to December, 2018.

Results

Temperature and Rainfall (Sept – December, 2018)

Air temperatures were lower, and monthly rainfall higher than long-term (76 year) averages for the months of September & October, 2018. This situation was reversed for November and December, 2018 with average air temperatures higher, and rainfall lower than long-term averages (Table 1; Figs 1, 2). Rainfall in September (111 mm) and October (137 mm) were close to double long-term averages (Table 1). This pattern of high early summer rainfall resulted in permanent and ephemeral waterbodies filling, and was likely the driver of summer breeding events of GGBF in the system within compensatory habitat waterbodies (see below). Nevertheless, the majority of ephemeral ponds were found to have dried by January, 2019 as a result of below average rainfall and above average temperatures in Nov/Dec, 2018, that continued into January.

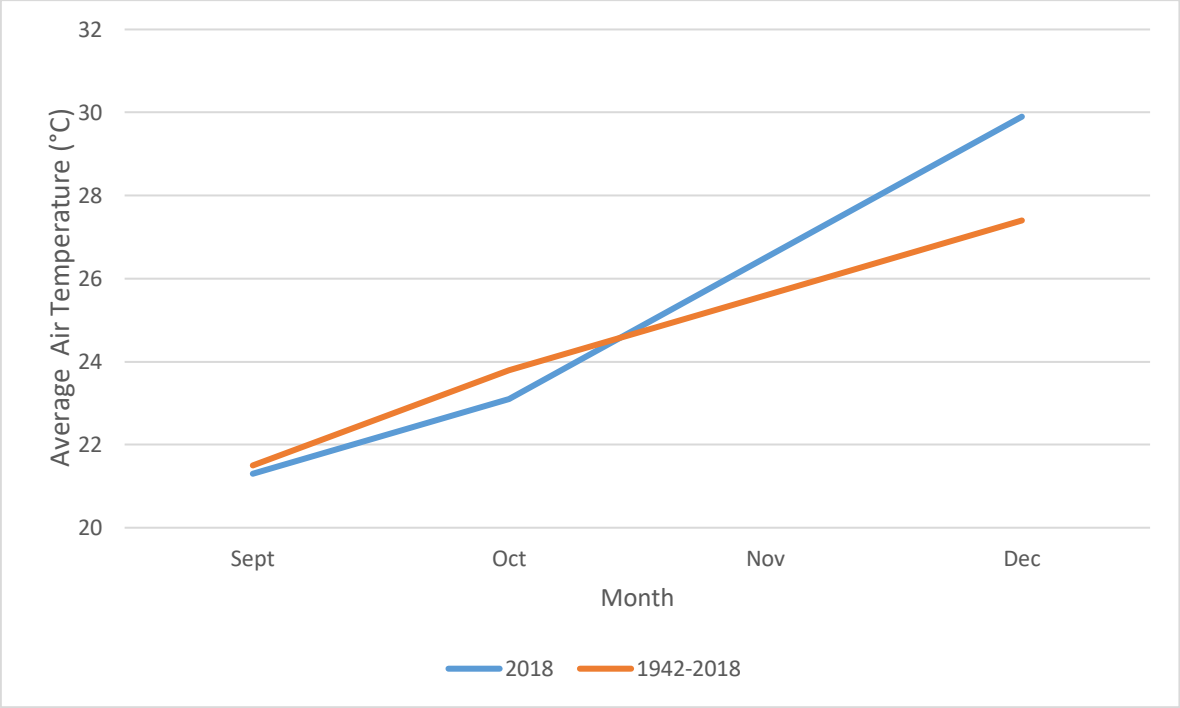

Figure 1. Average monthly air temperatures September to December 2018 and long-term average air temperatures for 1942-2018 from the Williamstown weather station (061078).

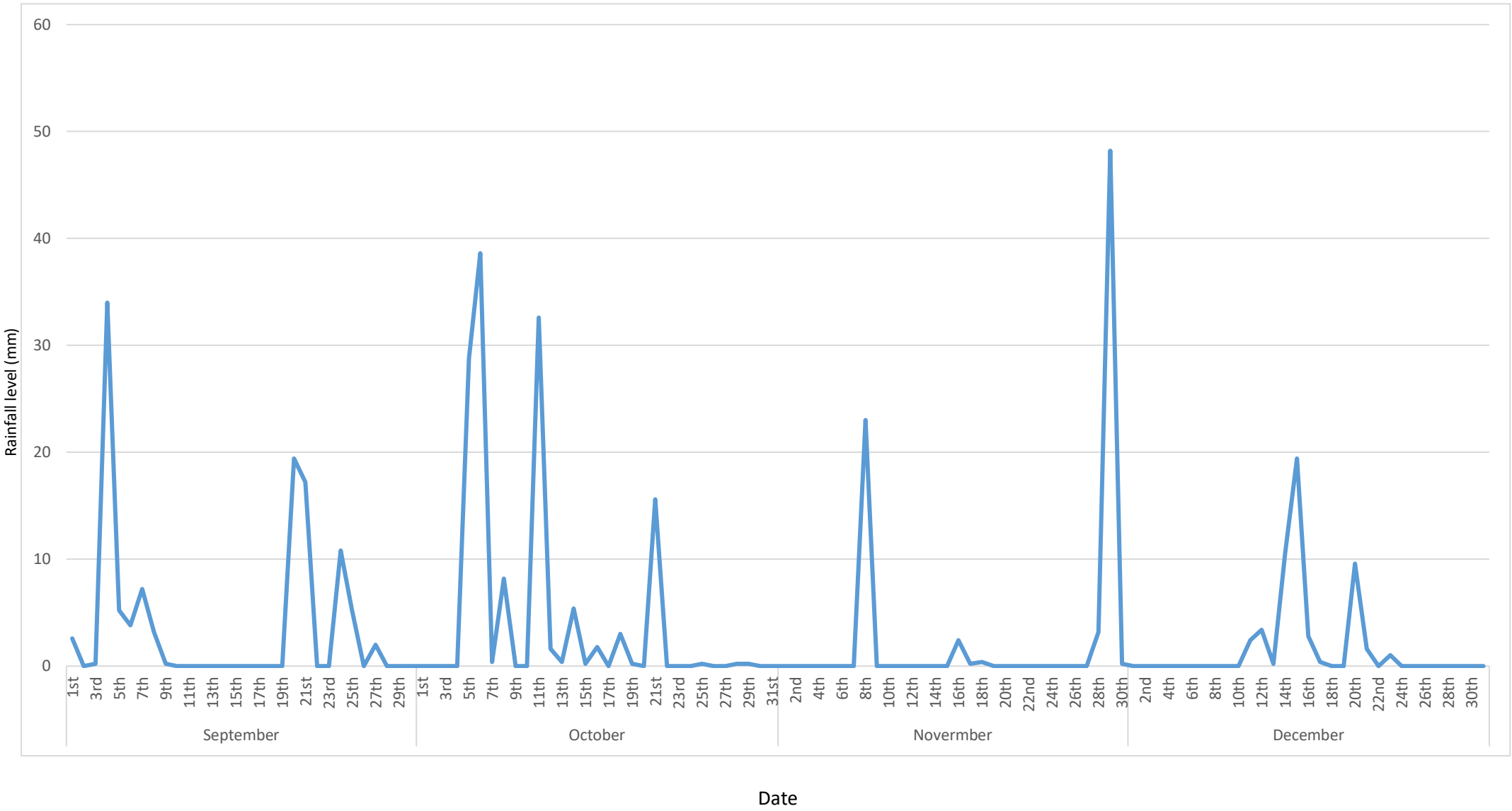

Figure 2. Daily rainfall (mm) for each day of the months of September to December 2018 from the Williamstown weather station (061078)

Table 1. The total amount of rainfall (mm) for months September to December 2018 compared to the average long-term rainfall (mm) for the months September to December from 1942 to 2018. Recorded from the Williamstown weather station (061078)

	Sept	**Oct**	**Nov**	**Dec**
Total Rainfall in 2018 (mm)	111.0	137.4	77.6	51.4
Average Rainfall for 1942-2018 (mm)	60.4	73.9	82.3	78.6

GGBF numbers recorded within survey period September to December, 2018.

GGBF (metamorphs, juveniles or adults) were found in 10 of the 44 ponds in NCIG constructed habitats. Ponds 4.9, 5.2, and 7.2 recorded the largest numbers of GGBF, each with 11 or more observations. Significantly, these three ponds were all ephemeral and were *Gambusia* free at the time of surveys (Appendix 1, Table 1). Gambusia were surveyed through either fyke or funnel netting in the ponds.

At total of 59 GGBF were recorded in the constructed wetlands between the months of September and December, 2018. Age and sex classes of GGBF recorded were:

- 18 adult male
- 10 adult female
- 10 unsexed juveniles
- 21 miss captures

Breeding behaviours & confirmed breeding events

There were 19 records of males calling in the 4 month survey period.

Breeding was confirmed in two constructed habitat waterbodies during the survey period (5.2 & 3.1). This is an observation of considerable significance for understanding the ongoing dynamics of the system, particularly given the absence of breeding records in the previous 2017/2018 summer.

Table 2. Records of male Green and Golden Bell frogs calling and confirmed presence of GGBF tadpoles in the NCIG compensatory habitats between the months of September to December 2018. Dates of observations and records shown.

Pond	**Calling adult males**	**GGBF Tadpoles recorded**
3.1	0	1 (13/12/2018)
4.8	1 (18/10/2018)	0
4.9	2 (18/10/2018) 5 (20/12/2018)	0
5.1	1 (19/09/2018) 2 (23/10/2018) 3 (11/12/2018)	0
5.2	2 (23/10/2018) 2 (11/12/2018)	3 (21/11/2018)
5.3	1 (23/10/2018)	0
Total	**19**	**4**

Figure 3. Tadpoles with back legs found in pond 5.2 on the 21/11/2018, from fyke netting.

Other frog species observed within the NCIG constructed 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.

23 of the 43 NCIG compensatory habitat ponds on Kooragang Island were found to have *Gambusia holbrooki* present during the survey period ranging in abundance levels (low, medium, high). *Gambusia* were not found in 20 of the habitat ponds during the survey period. Although ponds 1.3, 1.5, 3.4 & 3.5 had Gambusia during the early surveys, they had dried out by the end of the survey period causing the Gambusia populations within them to die. 18 of the 20 ponds that were free of *Gambusia* were ephemeral. In comparison, 15 of the 23 ponds that were found to have *Gambusia* were classified as permanent ponds, emphasizing the concept that there is a strong bias in the occurrence of *Gambusia* towards permanent ponds.

Other fish species caught in fyke nets in NCIG wetlands were recorded and counted. 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 September to December spring/summer period of the 2018/2019 breeding season was characterised by above average rainfall in the first two months, and below average for the second two months of the survey period (despite one elevated spike in rainfall in November). This resulted in all constructed ponds of the system holding elevated levels of water. These levels declined following persisting below average rainfall in November and December, continuing into January, 2019, a process exacerbated by heat wave conditions towards the end of December, also persisting into January, 2019.

Habitat ponds in Stages 1 and 2 received additional bunding during 2018, and this has improved the capacity of those waterbodies to exclude Gambusia once they have completed a full drying cycle, although it will shorten hydroperiod within those ponds under drying and/or heat wave conditions.

The demonstration of breeding events in two of the established habitat stages, and the record of GGBF in about 25% of the constructed habitat ponds is encouraging evidence of the persistence of GGBF throughout the NCIG constructed habitat system. This is particularly encouraging given the absence of breeding records in the system during 2017/2018 summer. It is highly probable that the key driver of the breeding events was the elevated, early summer rainfall events, and it is noted that both breeding events were in ephemeral ponds within the two stages (3 and 5) where they occurred. This supports our view that high, rapid recharge of ephemeral waterbodies is an important driver of GGBF breeding, and emphasizes the importance of a landscape mosaic that provides permanent, refuge ponds for persistence of adults during dry periods, combined with presence of ephemeral pondages that form following rainfall that support breeding after rainfall events (as frogs disperse across the landscape). This view of the importance of ephemeral pondages in the system is further reinforced by the observation that all records of GGBF (juveniles, adults) in the current survey period were within ephemeral waterbodies across the constructed habitat system.

Table 1. Pond structure and water chemistry. Summary of data collected for all NCIG compensatory habitat ponds surveyed between the months of September 2018 to December 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 4 month of data collection are shown. Water quality data for each pond is shown as means 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 Temp °C	Standard Dev (+/-)	Average pH	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	0	high	21.24	6.47	6.41	0.34	0.63	0.07	0.74	0.99	266.00	50.00
1.2	ephemeral	1	none	14.60		6.88	0.74	0.39	0.04	2.71	3.47	40.00	0.00
1.3	ephemeral	0	none	17.57	6.44	5.99	0.80	0.44	0.08	1.25	1.17	112.00	50.00
1.4	ephemeral	0	medium	18.07	4.81	6.23	0.65	23.38	39.51	1.17	1.50	166.00	88.00
1.5	ephemeral	0	none	16.65	6.15	6.48	0.33	0.52	0.04	1.87	2.02	20.00	0.00
2.1	permanent	0	low	18.80	6.36	7.68	0.93	2.58	0.66	3.73	1.03	100.00	80.00
2.2	ephemeral	0	none	14.75	6.86	6.66	0.58	1.19	0.26	1.94	1.64	66.00	66.00
2.3	permanent	0	none	18.65	5.44	7.49	1.16	1.50	0.32	1.88	1.31	70.00	70.00
2.4	ephemeral	0	low	17.00	9.05	6.81	0.35	1.39	0.46	1.50	1.85	70.00	30.00
2.5	ephemeral	0	low	21.60		6.95		1.71		0.78		140.00	140.00
3.1	ephemeral	0	none	21.35	4.45	7.81	1.17	0.26	0.03	2.61	0.44	30.00	0.00
3.2	ephemeral	0	none	20.55	4.60	7.49	1.02	0.28	0.04	2.30	1.41	48.00	10.00
3.3	permanent	0	medium	20.87	5.91	6.84	1.26	0.92	0.11	0.96	0.29	175.00	8.00
3.4	ephemeral	1	none	18.55	4.17	7.13	1.22	0.93	0.09	1.24	0.90	5.00	0.00
3.5	ephemeral	0	none	19.00	4.81	7.12	0.97	0.62	0.26	1.98	0.25	10.00	5.00
4.1	permanent	0	medium	17.85	10.54	6.15	0.29	0.19	0.02	1.60	0.92	150.00	150.00
4.2	permanent	0	none	18.00	9.33	6.05	0.55	0.23	0.04	1.53	0.06	135.00	135.00
4.3	permanent	0	medium	19.90	10.75	6.42	0.04	0.20	0.01	1.06	0.45	210.00	210.00
4.4	permanent	0	high	19.05	9.12	6.61	0.34	0.29	0.03	1.52	0.37	140.00	140.00
4.5	ephemeral	1	none	17.45	10.39	6.68	0.17	0.19	0.06	1.96	2.02	40.00	40.00

4.6	ephemeral	0	none	17.65	11.24	6.46	0.02	0.15	0.04	1.53	0.86	60.00	60.00
4.7	permanent	0	medium	19.40	9.48	7.00	0.93	0.13	0.01	2.61	2.49	140.00	140.00
4.8	permanent	0	high	19.50	9.33	7.26	0.17	0.28	0.10	3.88	4.15	100.00	100.00
4.9	ephemeral	15	none	20.55	10.39	7.24	0.52	1.30	0.47	3.60	4.63	100.00	100.00
4.10	permanent	0	high	21.20	9.33	6.99	0.09	2.66	0.54	0.34	0.04	94.00	40.00
4.11	permanent	0	low	22.95	9.83	7.11	0.30	18.26	4.32	0.48	0.03	140.00	110.00
5.1	ephemeral	11	none	18.90	12.45	7.19	1.20	0.14	0.04	2.37	0.85	15.00	15.00
5.2	ephemeral	1	none	18.95	11.53	7.37	1.43	0.15	0.02	2.74	1.28	60.00	60.00
5.3	ephemeral	0	none	17.75	9.97	6.33	2.01	0.13	0.03	1.62	1.12	40.00	40.00
5.4	ephemeral	0	none	18.80	10.75	6.32	1.94	0.15	0.01	1.56	1.96	100.00	100.00
5.5	ephemeral	0	none	16.60	11.03	5.72	1.90	0.13	0.04	1.49	1.63	70.00	70.00
5.6	ephemeral	0	none	16.40	8.77	5.41	2.21	0.14	0.01	1.91	2.14	100.00	25.00
5.7	permanent	0	low	17.20	12.02	5.73	1.77	0.14	0.01	1.52	1.35	120.00	120.00
5.8	permanent	0	high	27.30		4.68		0.13		1.49			
6.1	ephemeral	0	low	13.60		8.42		0.33		6.60		31.00	31.00
6.2	ephemeral	0	low	9.20		7.15		0.13		3.10			
6.3	permanent	0	high	10.60		7.11		0.14		6.40			
6.4	ephemeral	0	high	11.00		6.71		0.19		3.86		58.00	58.00
6.5	ephemeral	0	high	-	-	-	-	-	-	-	-	-	-
6.6	permanent	0	low	14.30		6.88		0.10		21.80			
7.1	permanent	9	high	21.10	7.80	6.67	0.41	2.16	0.34	3.66	5.26	90.00	122.00
7.2	ephemeral	17	none	19.40	7.69	6.62	0.48	0.54	0.07	2.69	3.34	30.00	15.00
7.3	ephemeral	3	medium	18.13	8.59	6.27	0.33	2.45	1.02	3.11	3.37	15.00	5.00

Appendix B – Area E Shorebird Monitoring Report 2018

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30th January 2019

Philip Reid
Environmental Advisor
Newcastle Coal Infrastructure Group
30 Raven Street
Kooragang, NSW, 2304

Re: Final report for 2018 Area E shorebird monitoring

Philip

Please find below the final report for shorebird monitoring surveys conducted during 2018 over sites at Area E of Kooragang Island.

Please note that much of the reporting covers both the 2017 and 2018 periods.

GFF Reference - GFF 19583

Thanking you

Greg Little
General Flora and Fauna

Introduction

This report documents the 2018 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).

During the 2017 and 2018 surveys 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, waders etc. A number of shorebirds recorded in Area E are "migratory" shorebirds. These are shorebird species most of which leave Australia 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

During 2018, as per 2017, 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 2018 survey plus the 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

37 shorebird species were recorded during 2018 from all sites in Area E, as presented in **Appendix-A**. **Figs-2 & 3** below are taken from **Graphs 1 & 3** in **Appendix E**. A total of 46 shorebird species have been recorded during the 2017 (39sp) and 2018 (37sp) surveys. A list at the bottom of **Appendix A** shows those species recorded and not recorded in each year. Seven new species were recorded for Area E in 2018.

Results of the 2018 survey suggest that all shorebird species richness had rising trends through the year for the reference sites (**App-E**). At Fish Fry Flat the "all shorebird" species richness can be seen to increase through 2018 for Day High Tide surveys (**Fig-2**). While the reference sites were drying out in the latter part of 2018 Fish Fry Flat retained regular tidal flows in Fish Fry Creek and Wader Creek. This may have influenced the increase in species richness through the year for Fish Fry Flat. Similar species richness results are observed (**App-E**) for the Day Low Tide.

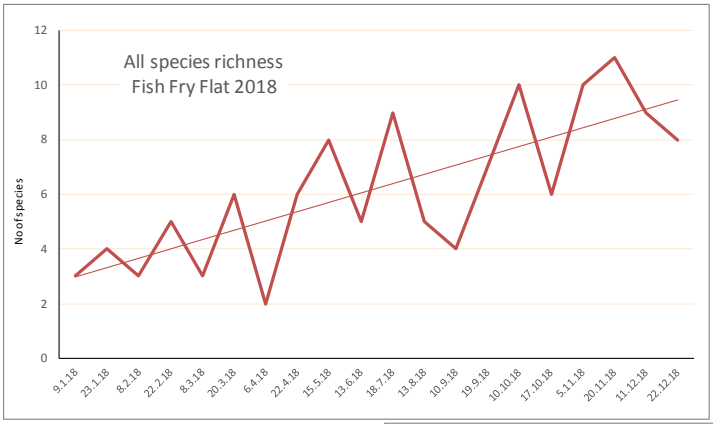


Figure – 2
In 2018 Fish Fry Flat had a rising trend in species richness of all shorebird species through the year. The same trend was observed in 2017.

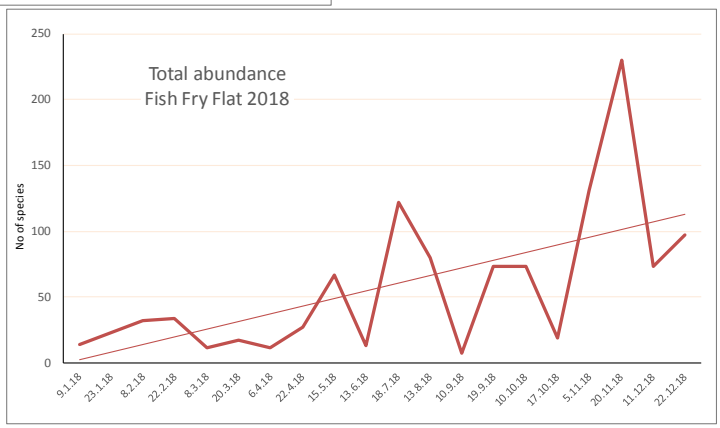


Figure – 3
Total abundance of all shorebird species at Fish Fry Flat show a rising trend through 2018.

Total abundance of all shorebird species at Fish Fry Flat appeared to rise slightly through 2018 (**Fig-3**) but this is minimal compared to the Swan Pond North site (**Graphs-3 & 4** in **App-E**). Similar total abundance results are observed (**App-E**) for the Day Low Tide. Total abundance at Swan Pond North increased significantly through the year (**App-E**), a similar observation to

2017. By the end of December 2018, and as per 2017, the abundance of all shorebirds declined dramatically, even at Swan Pond North, probably because the ponds had almost completely dried out.

Of interest is that the same rising trend of all shorebird species through 2018 also occurred in 2017, see **Graph-1** in **App E**. However, the portion of Graph-1 (**App-E**) showing all shorebird species from about mid 2017 to mid 2018 is better reflective of the all shorebird species trends through the year at Area E. This is also shown in Graph-3 for all shorebird total abundance. The trend suggests that species numbers and abundance increase from mid year, possibly bolstered by migratory shorebirds, then crash when ponds dry out about December/January. From about February after rain the numbers start increasing again.

Migratory Shorebirds

Eight (8) migratory shorebird species were recorded at all sites in Area E during the 2018 survey. During the 2017 survey 9 migratory shorebird species were recorded at all sites. **Table-1** below presents a summary of presence of migratory shorebird species at all sites and Fish Fry Flat during 2017 and 2018. Three species, the Bar-tailed Godwit, Red Knot and Marsh Sandpiper, have not been recorded at Fish Fry Flat during these surveys.

Table - 1 Migratory shorebird presence (p) at all sites and Fish Fry Flat during 2017 & 2018

All sites Area E	2017	2018	**Fish Fry Flat**	2017	2018
Curlew, Eastern	p	p	Curlew, Eastern	p	p
Godwit, Bar-tailed	p				
Greenshank, Common	p		Greenshank, Common	p	
Knot, Red	p				
Plover, Double-banded	p	p	Plover, Double-banded	p	
Plover, Pacific Golden	p	p	Plover, Pacific Golden	p	p
Sandpiper, Curlew	p	p	Sandpiper, Curlew		p
Sandpiper, Marsh		p			
Sandpiper, Sharp-tailed	p	p	Sandpiper, Sharp-tailed	p	p
Snipe, Lathams		p	Snipe, Lathams		p
Stint, Red-necked	p	p	Stint, Red-necked	p	p
11	9	8	8	6	6

Six (6) migratory shorebird species were recorded at Fish Fry Flat during 2018 (**Table-1**). This is the same number of species as for 2017, however, 2 additional species were recorded and 2 species were not recorded at Fish Fry Flat in 2018. Clearing of the heavy cover of mangroves from Fish Fry Flat has provided habitat for these migratory shorebirds.

Appendix B shows migratory shorebird species presence and count at each of the Area E sites through the year, 2018. Few birds were present during winter months. The results are rearranged in Appendix C to show easily the presence of migratory shorebirds during day and night tide surveys. Migratory shorebirds are clearly using Fish Fry Flat during day and night and on both high and low tides.

Activity and habitat use by migratory shorebirds at Fish Fry Flat during 2017 and 2018 is presented in **Appendix F**. There were no migratory shorebirds recorded roosting at night at Fish

Fry Flat. Only one species, the Red-necked Stint, was recorded on three occasions apparently roosting during the day at Fish Fry Flat. Results show that migratory shorebirds at Fish Fry Flat were mainly foraging, day and night, on the mud at high and low tide. It appears that Fish Fry Flat is not an important high tide roost location for migratory shorebirds.

The following observations are made of records of migratory shorebirds at Fish Fry Flat.

- Eastern Curlews - small numbers were recorded foraging during day and night surveys, on both high and low tides.
- Pacific Golden Plover – small numbers were recorded foraging on both high and low tides but only at night, same as per 2017
- Curlew Sandpiper – a single bird was recorded foraging during day low tide in September
- Sharp-tailed Sandpiper - were not recorded at Fish Fry Flat during April to August, outside of these winter months up to 125 birds were recorded foraging at a single visit, during both day and night on both the high and low tides.
- Latham Snipe – a single bird was recorded in February on two occasions at night only, once on the low tide and once on the high tide
- Red-necked Stint - small numbers recorded through the year, mainly outside of colder months, during both day and night high and low tides. Were recorded apparently roosting during the day high and low tides but were not recorded roosting at night.

White-fronted Chats

In 2018 White-fronted Chats were recorded at Fish Fry Flat and Swan Pond North during the Area E survey. They were usually recorded, in pairs or small groups, flying over or foraging in and around the Saltmarsh vegetation.

White-fronted Chats were not recorded at the Area E sites during the hotter summer months. In 2017 White-fronted Chat were recorded in Area E outside of the general breeding season for this species. However, in 2018 White-fronted Chats were observed, in pairs, at Fish Fry Flat and Swan Pond North during September and October, within the breeding period for this species. The Chats are usually observed in saltmarsh but some records are of birds on mud or an artificial structure such as Wagtail Way track.

Table – 2 White-fronted Chat sightings, showing date, location and number of individuals.

Year	**2017**													**2018**											
Date/Month	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	Jan	Feb	Mar	Apr	May	13.6.18	Jul	Aug	10.9.18	10.10.18	Nov	Dec
Fish Fry Flat																			4			1	2		
Swan Pond North					2		4															2			
Wader Pond			2	2			8	3		2															

Note – on 10.10.18 two White-fronted Chats were observed on the same day at Fish Fry Flat during separate high and low tide surveys. It is reported in Table-2 as two birds and not 4 as it is assumed they were the same pair.

Discussion

For migratory shorebirds, from either the Northern Hemisphere or New Zealand, the Hunter Estuary, including Area E and Fish Fry Flat, is used mainly 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 migratory shorebirds were observed using Fish Fry Flat as a high tide roost. However, a small number of Red-necked Stints were observed apparently roosting at Fish Fry Flat but only during the day.

Most records of migratory shorebirds at Fish Fry Flat (**Fig-1**) were from the centre-north portion between Fish Fry Creek and Wader Creek and around the broad shallow section of Wader Creek.

The habitat for recording purposes during most of the 2017-18 surveys was divided broadly into saltmarsh, mud and water. In hindsight it may have been better to divide the habitat further into still easily recognized zones such as (1) above saltmarsh, (2) saltmarsh (which is expanding), (3) mud with old pneumatophores, (4) mud with no pneumatophores and exposed by daily tides and (5) water. Fish Fry Creek has regular tidal fluctuations exposing soft mud without pneumatophores, but these are not so obvious on Wader Creek where there is always shallow water present albeit topped up by tidal influences. On other ponds in Area E the water surface appears to expand and contract mainly under the influence of rain and drying.

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?
Shorebird abundance of all species was not negatively affected at Area E or elsewhere in the Hunter Estuary by mangrove removal from Fish Fry Flat. Through 2018 all shorebird abundance increased slightly at Fish Fry Flat (the Activity Area) and increased significantly at Swan Pond North. However, all shorebird abundance declined dramatically at the reference sites by December 2018 because the ponds had almost completely dried out. This also occurred at the end of 2017. Abundance rises through the year probably due to the ponds being filled with water during the cooler months.

Did shorebird species diversity change?
Species diversity/richness of all shorebirds increased through 2018 at Fish Fry Flat. However, the rising trend in species diversity through the 2018 year also occurred in 2017 (see **Graph-1**, **App-E**). While mangrove removal from Fish Fry Flat appears to have allowed use of this area by

shorebird species there may be some other unobserved factor causing this rising trend through each year other than mangrove removal. All shorebird species diversity appears to rise through the year at the reference sites in 2018. This also occurred in 2017. Species diversity increases through the year are probably due to the ponds being filled with water during the cooler months. Compared to data from 2015 surveys there was an increase in migratory species diversity at Fish Fry Flat during 2017-18.

Did shorebird behavior change?
Most recorded observations of migratory shorebirds at Fish Fry Flat were of birds foraging. There was no obvious large, mixed species, roosting aggregation of migratory shorebirds during day or night high tides. Fish Fry Flat does not appear to support an important high tide roost habitat for migratory shorebirds. However, three records (**App-F**) show Red-necked Stints roosting on both the high and low tide during the day at Fish Fry Flat, but not at night. During 2018 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?
There was no change in habitat for White-fronted Chats outside of the Fish Fry Flat area after removal of mangroves in 2016 from Fish Fry Flat. There appears to have been an increase in the extent of saltmarsh habitat in parts of Fish Fry Flat through 2017-18, however, this is addressed by a separate vegetation survey. White-fronted Chats were not recorded at Fish Fry Flat during 2017. Small numbers of White-fronted Chats were recorded at both Fish Fry Flat and Swan Pond North during the 2018 survey.

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 seven (37) shorebird species, including eight (8) migratory shorebird species, were recorded from all sites in Area E during this 2018 survey. Total abundance of all shorebirds rose slightly at Fish Fry Flat but rose significantly at Swan Pond North during 2018. Six (6) migratory shorebird species were recorded at Fish Fry Flat during 2018. A small number of Red-necked Stints were observed to be roosting during a few visits to Fish Fry Flat in 2018. However, there was no mixed species aggregation of roosting migratory shorebirds recorded at Fish Fry Flat during the 2018 or 2017 surveys.

Trends suggest (see graphs in **App-E**) from the 2017 and 2018 data that all shorebird species richness and total abundance increase from mid year, possibly bolstered by migratory shorebirds, then crash when ponds dry out about December/January. From about February after rain the numbers start increasing again.

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 the Fish Fry Flat area is not being used as high tide roost habitat by large aggregations of 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 large aggregations of 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 reference sites of Area E. White-fronted Chats were recorded in Fish Fry Flat during this 2018 survey (not in 2017). The expanding extent of saltmarsh through parts of the Fish Fry Flat area may have been attracted White-fronted Chats.

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 2018 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*	P	Mar	Y	Y	Y	Y	Y
Little Black Cormorant	*Phalacrocorax sulcirostris*	P			Y			
Little Pied Cormorant	*Microcarbo melanoleucos*	P			Y	Y		
Eastern Curlew	*Numenius madagascariensis*	P	Mig,CE,C,J,K		Y			Y
Black-fronted Dotterel	*Elseyornis melanops*	P			Y	Y	Y	Y
Red-kneed Dotterel	*Erythrogonys cinctus*	P			Y	Y	Y	Y
Pacific Black Duck	*Anas superciliosa*	P					Y	Y
Pink-eared Duck	*Malacorhynchus membranaceus*	P					Y	
Wood Duck	*Chenonetta jubata*	P					Y	
Eastern Great Egret	*Ardea modesta*	P	Mar,C,J,	Y	Y	Y	Y	
Little Egret	*Egretta garzetta*	P			Y		Y	Y
Cattle Egret	*Ardea ibis*	P	C,J			Y		
Australasian Grebe	*Tachybaptus novaehollandiae*	P					Y	
Silver Gull	*Chroicocephalus novaehollandiae*	P			Y		Y	
White-faced Heron	*Egretta novaehollandiae*	P		Y	Y	Y	Y	Y
Australian White Ibis	*Threskiornis molucca*	P		Y	Y	Y		
Straw-necked Ibis	*Threskiornis spinicollis*	P					Y	
Masked Lapwing	*Vanellus miles*	P		Y	Y	Y	Y	Y
Nankeen Night Heron	*Nycticorax caledonicus*	P			Y	Y		
Australian Pelican	*Pelecanus conspicillatus*	P			Y		Y	
Double-banded Plover	*Charadrius bicinctus*	P	Mig				Y	
Pacific Golden Plover	*Pluvialis fulva*	P	Mig,C,J,K		Y			
Red-capped Plover	*Charadrius ruficapillus*	P	Mar	Y	Y		Y	Y
Curlew Sandpiper	*Calidris ferruginea*	E1	Mig,CE,C,J,K		Y			
Marsh Sandpiper	*Tringa stagnatilis*	P	Mig,C,J,K				Y	

Sharp-tailed Sandpiper	*Calidris acuminata*	P	Mig,C,J,K	Y	Y	Y	Y	Y
Lathams Snipe	*Gallinago hardwickii*	P	Mig,C,J,K		Y			
Australasian Shoveler	*Anas rhynchotis*	P					Y	Y
Royal Spoonbill	*Platalea regia*	P			Y			
Black-winged Stilt	*Himantopus himantopus*	P	Mar	Y	Y	Y	Y	Y
Red-necked Stint	*Calidris ruficollis*	P	Mig,C,J,K		Y		Y	
Black Swan	*Cygnus atratus*	P			Y	Y	Y	Y
Chestnut Teal	*Anas castanea*	P		Y	Y	Y	Y	Y
Grey Teal	*Anas gracilis*	P		Y	Y	Y	Y	Y
Caspian Tern	*Hydroprogne caspia*	P	C		Y		Y	
Whiskered Tern	*Chlidonias hybrida*	P					Y	
Wandering Whistling-duck	*Dendrocygna arcuata*	P					Y	
White-fronted Chat	*Epthianura albifrons*	V			Y		Y	
Totals -								
Shore/wetland birds -	37			10	26	15	27	15
Bush birds -	1				1		1	

Y = Yes, recorded at that location

P = Protected under the BC Act

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

recorded 2017 not 2018

Great Cormorant	*Phalacrocorax carbo*
Intermediate Egret	*Ardea intermedia*
Bar-tailed Godwit	*Limosa lapponica*
Common Greenshank	*Tringa nebularia*
Striated Heron	*Butorides striatus*
Red Knot	*Calidris canutus*
Buff-banded Rail	*Gallirallus philippensis*
Black-necked Stork	*Ephippiorhynchus asiaticus*
Gull-billed Tern	*Gelochelidon nilotica*

recorded 2018 not 2017

Pink-eared Duck	*Malacorhynchus membranaceus*
Wood Duck	*Chenonetta jubata*
Cattle Egret	*Ardea ibis*
Australasian Grebe	*Tachybaptus novaehollandiae*
Marsh Sandpiper	*Tringa stagnatilis*
Lathams Snipe	*Gallinago hardwickii*
Wandering Whistling-duck	*Dendrocygna arcuata*

APPENDIX - B

Migratory shorebirds, species and abundance - 2018

Date	8.1.18	9.1.18	23.1.18	8.2.18	8.2.18	15.2.18	22.2.18	22.2.18	9.3.18	15.3.18	6.4.18	6.4.18	14.4.18	22.4.18	22.4.18	24.4.18	May	Jun	18.7.18	Aug	10.9.18	10.9.18	17.9.18	7.10.18	10.10.18	10.10.18	17.10.18	17.10.18	5.11.18	5.11.18	15.11.18	20.11.18	20.11.18	22.11.18	11.12.18	11.12.18	14.12.18	22.12.18	22.12.18	22.12.18
Day/Night	Night	Day	Day	Day	Night	Night	Day	Day	Night	Night	Day	Day	Night	Day	Day	Night			Day		Day	Night	Night	Night	Day	Day	Day	Day	Day	Day	Night	Day	Day	Night	Day	Day	Night	Day	Day	Night
Tide - High/Low	Low	Low	Low	Low	Low	High	Low	High	Low	High	Low	High	High	Low	High	Low			Low		Low	High	Low	High	High	Low	Low	High	High	Low	Low	High	Low	High	Low	High	Low	Low	High	Low	High
North West Pond																																							
Sandpiper, Sharp-tailed																													63										
Fish Fry Flat																																							
Curlew, Eastern		1	1			1																		1						1						1			
Plover, Pacific Golden					3				1	2																				1									
Sandpiper, Curlew																					1																		
Sandpiper, Sharp-tailed	6									12											7	4	6		2	10			24	7		61	1	30	32	46	125	21	24	52
Snipe, Lathams					1	1																																	
Stint, Red-necked			3	1	1			17		10									2										1	2					7	6	2	1		
Swan Pond South																																							
Sandpiper, Sharp-tailed																											2		12	34		16			16	23		6	32	1
Swan Pond North																																							
Sandpiper, Marsh																														2		14							
Sandpiper, Sharp-tailed																													35	170		36			16	32		31		
Stint, Red-necked							17	16																																
Wader Pond																																							
Curlew, Eastern																									1															
Sandpiper, Sharp-tailed											12	2															4	3	34	85		8	1		2	25		1		6

APPENDIX - C Migratory shorebirds, species and abundance - arranged by Day, Night & Tide - 2018

	Date	22.2.18	6.4.18	22.4.18	10.10.18	17.10.18	5.11.18	20.11.18	11.12.18	22.12.18	9.1.18	23.1.18	8.2.18	22.2.18	6.4.18	22.4.18	18.7.18	10.9.18	10.10.18	17.10.18	5.11.18	20.11.18	11.12.18	22.12.18	15.2.18	15.3.18	14.4.18	10.9.18	7.10.18	22.11.18	22.12.18	8.1.18	8.2.18	9.3.18	24.4.18	17.9.18	15.11.18	14.12.18
	Day/Night	Day	Day	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	Night	Night	Night	Night
	Tide	High	High	High	High	High	High	High	High	High	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	High	High	High	High	High	High	Low	Low	Low	Low	Low	Low	Low
North West Pond																																					
Sandpiper, Sharp-tailed																				63																	
Fish Fry Flat																																					
Curlew, Eastern									1	1	1													1				1							1		
Plover, Pacific Golden																									2							3	1			1	
Sandpiper, Curlew																		1																			
Sandpiper, Sharp-tailed				2		24	61	32	21								7	10		7	1	46	24		12		4		30	52	6				6		125
Snipe, Lathams																								1								1					
Stint, Red-necked	17					1		7	1		3	1				2				2		6			10							1				2
Swan Pond South																																					
Sandpiper, Sharp-tailed						12	16	16	6										2	34		23	32							1						
Swan Pond North																																					
Sandpiper, Marsh							14													2																	
Sandpiper, Sharp-tailed						35	36	16	31											170		32															
Stint, Red-necked	16												17																								
Wader Pond																																					
Curlew, Eastern				1																																	
Sandpiper, Sharp-tailed		2			3	34	8	2	1						12				4	85	1	25								6							

APPENDIX - D

Migratory shorebird species account 2017-18

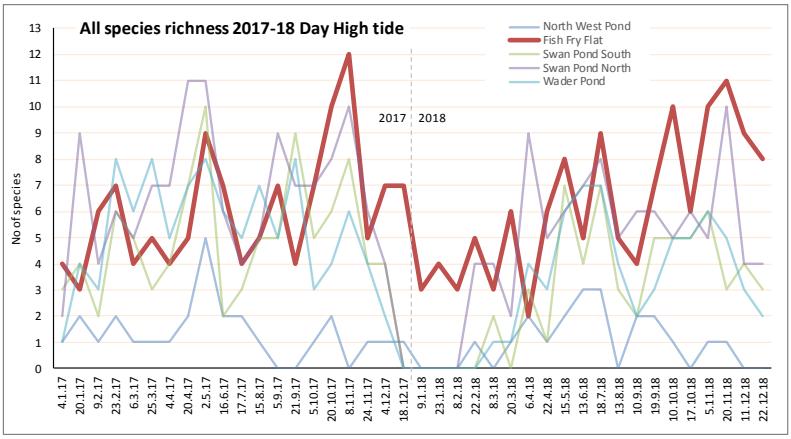
	Date	4.1.17	14.1.17	20.1.17	6.2.17	9.2.17	9.2.17	23.2.17	23.2.17	5.3.17	6.3.17	25.3.17	25.3.17	25.3.17	4.4.17	4.4.17	6.4.17	12.4.17	2.5.17	14.9.17	21.9.17	21.9.17	5.10.17	5.10.17	5.10.17	20.10.17	8.11.17	8.11.17	9.12.17	17.12.17	18.12.17	8.1.18	9.1.18	23.1.18	8.2.18	8.2.18	15.2.18	22.2.18	22.2.18	9.3.18	15.3.18	6.4.18	6.4.18	18.7.18	10.9.18	10.9.18	17.9.18	7.10.18	10.10.18	10.10.18	17.10.18	17.10.18	5.11.18	5.11.18	15.11.18	20.11.18	20.11.18	22.11.18	11.12.18	11.12.18	14.12.18	22.12.18	22.12.18	22.12.18
	Day/Night	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	Night	Day	Day	Day	Night	Night	Day	Night	Night	Day	Day	Day	Night	Night	Night	Day	Night	Night	Day	Day	Night	Day	Day	Night	Day	Day	Night	Day	Day	Night	Day	Night	Night
	Tide - High/Low	Low	High	High	Low	High	Low	High	Low	Low	High	High	Low	High	Low	High	Low	High	High	Low	Low	High	Low	High	Low	High	Low	High	High	High	Low	Low	Low	Low	Low	High	Low	High	Low	Low	High	Low	Low	High	Low	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low	High	High	Low	High
Eastern Curlew																																																																																			
Fish Fry Flat						2		2	3		2	1	1		1																							1	1			1								1							1							1															
Wader Pond							1																																																																													
Godwit, Bar-tailed																																																																																										
North West Pond					45																																																																																		
Swan Pond North																						6																																																																					
Common Greenshank																		

	Date	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	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	8.1.18	9.1.18	23.1.18	8.2.18	8.2.18	15.2.18	22.2.18	22.2.18	9.3.18	15.3.18	6.4.18	6.4.18	18.7.18	10.9.18	10.9.18	17.9.18	7.10.18	10.10.18	10.10.18	17.10.18	17.10.18	5.11.18	5.11.18	15.11.18	20.11.18	20.11.18	22.11.18	11.12.18	11.12.18	14.12.18	22.12.18	22.12.18	22.12.18
	Day/Night	Day	Night	Day	Night	Day	Day	Day	Day	Night	Day	Day	Day	Night	Day	Day	Night	Night	Day	Night	Day	Day	Day	Night	Night	Day	Day	Day	Night	Night	Day	Night	Day	Day	Day	Night	Night	Day	Night	Night	Day	Day	Night	Night	Night	Night	Day	Day	Night	Day	Day	Night	Night	Day	Day	Night	Night	Day	Day	Night	Day	Day	Night
	Tide - High/Low	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	High	High	Low	Low	Low	Low	Low	High	Low	High	High	Low	High	Low	Low	High	High	High	High	High	High	Low	Low	High	Low	High	High	Low	Low	High	Low	High	High
Marsh Sandpiper																																																																	
Swan Pond North																																																																					
Sharp-tailed Sandpiper																																																																					
North West Pond																																																																					
Fish Fry Flat									8							13	9										15	15		6									12			7	4	6		2	10			24	7		61	1	30	32	46	125	21	24	52			
Swan Pond South																6			1		12																													2		12	34		16			16	23		6	32	1			
Swan Pond North				20											5					8	60	3	25	12	7	1	15																							35	170		36			16	32		31					
Wader Pond											6				2		1	1	4							6	3																						4	3	34	85		8	1		2	25		1		6			
Lathams Snipe																																																																					
Fish Fry Flat																																			1	1																																	
Red-necked Stint																																																																					
Fish Fry Flat																													4			3	1	1			17		10			2										1	2				7	6	2	1					
Swan Pond North																										3										17	16																																	

APPENDIX – E Graphs 2017-18

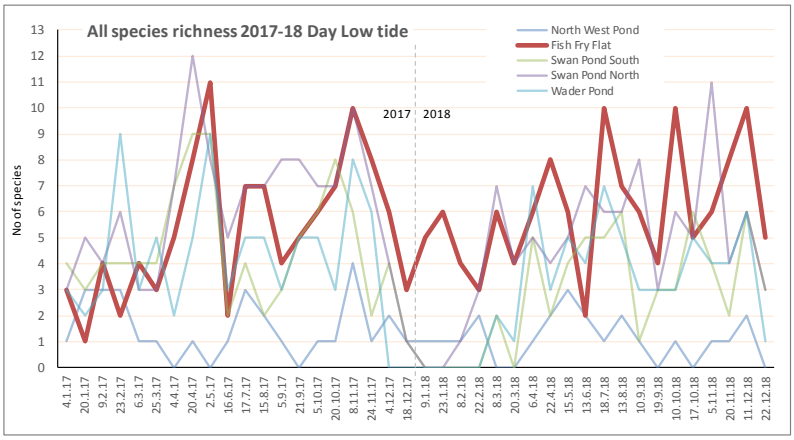
Graph – 1

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.



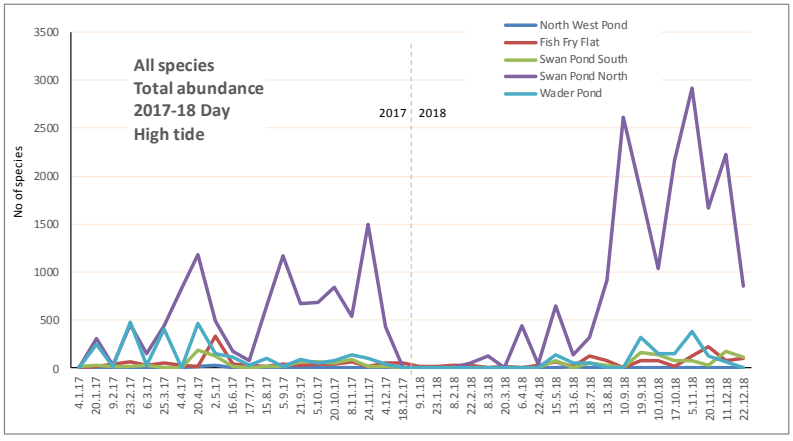
Graph – 2

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.



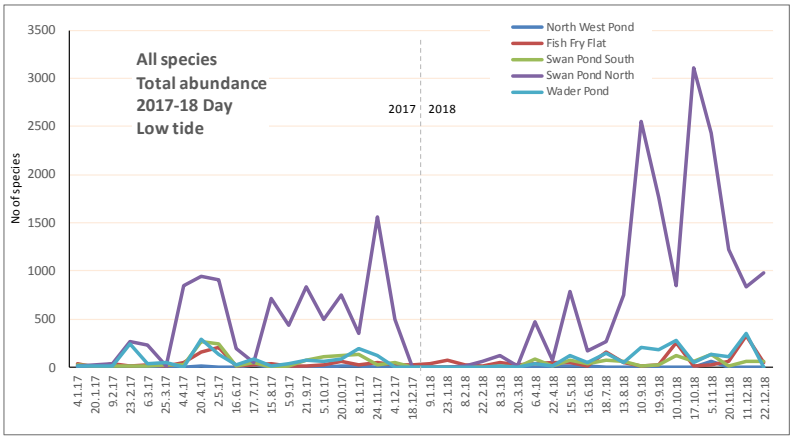
Graph – 3

All shorebird total abundance at all sites in Area E during day high tide.



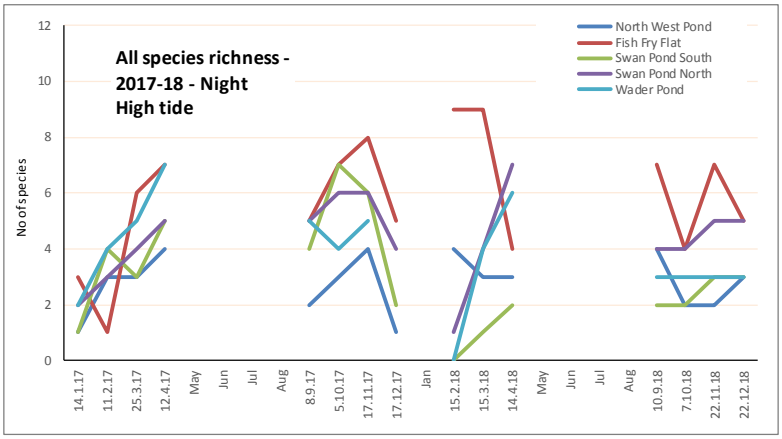
Graph – 4

All shorebird total abundance at all sites in Area E during day low tide.



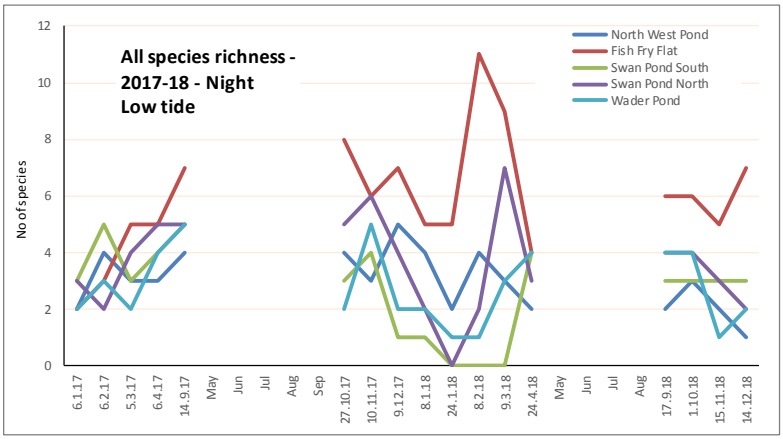
Graph – 5

All shorebird species richness at all sites in Area E during night high tide.



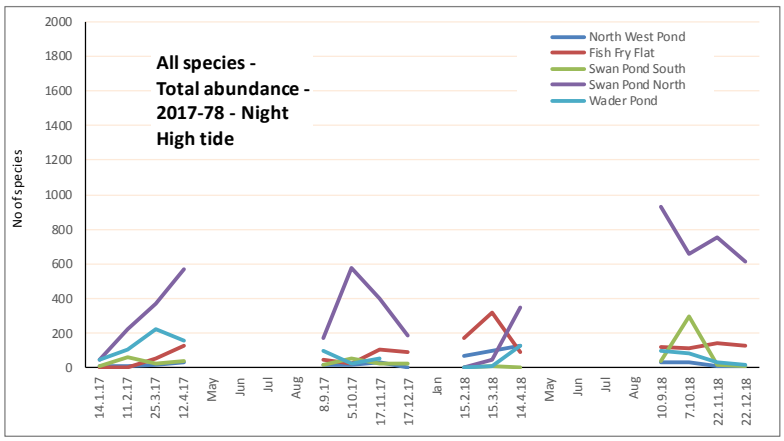
Graph – 6

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.

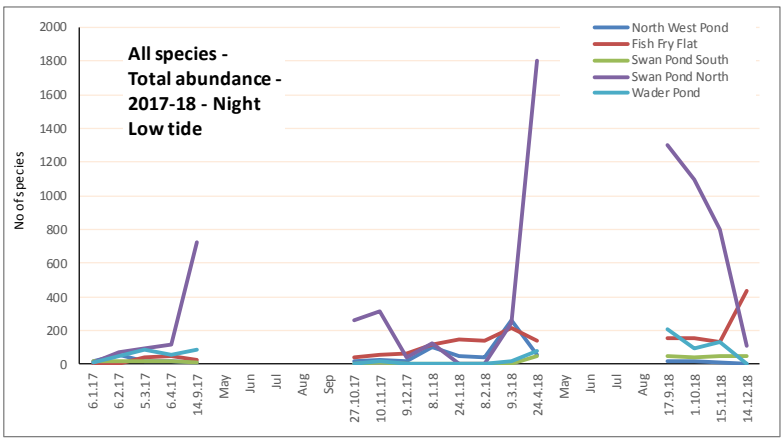


Table shows recorded habitat use and activity of the migratory shorebirds at Fish Fry Flat.

Fish Fry Flat

2017 - 2018

		Day												Night											
		High Tide						Low Tide						High Tide						Low Tide					
		Foraging			Roosting			Foraging			Roosting			Foraging			Roosting			Foraging			Roosting		
	No of Records	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water
Curlew, Eastern	13	1	4						5						2						1				
Greenshank, Common	1																					1			
Plover, Double-banded	1								1																
Plover, Pacific Golden	8													1	1	1				1	4				
Sandpiper, Curlew	1								1																
Sandpiper, Sharp-tailed	23		4	1					4	2					2	4				1	5				
Snipe, Lathams	2														1						1				
Stint, Red-necked	13		2	1	1	1			3	1		1				1					2				

Appendix C – Shorebird Compensatory Habitat – Ongoing Hydrological Monitoring (Mahmood Sadat-Noori and William Glamore

To: Philip Reid **Date:** 04/02/2019
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 will result in the creation of 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, is undertaking research onsite and has previously provided advice and recommendations via the report "Shorebirds Compensatory Habitat Area – Hydrological Controls for Ongoing Management". This memorandum provides an update on the desktop and on-ground work accomplished till December 2018 and focuses on the hydrology monitoring. Vegetation survey and monitoring is conducted concurrently with hydrology monitoring however, vegetation data and analysis will be discussed separately via another report by the University of Newcastle.

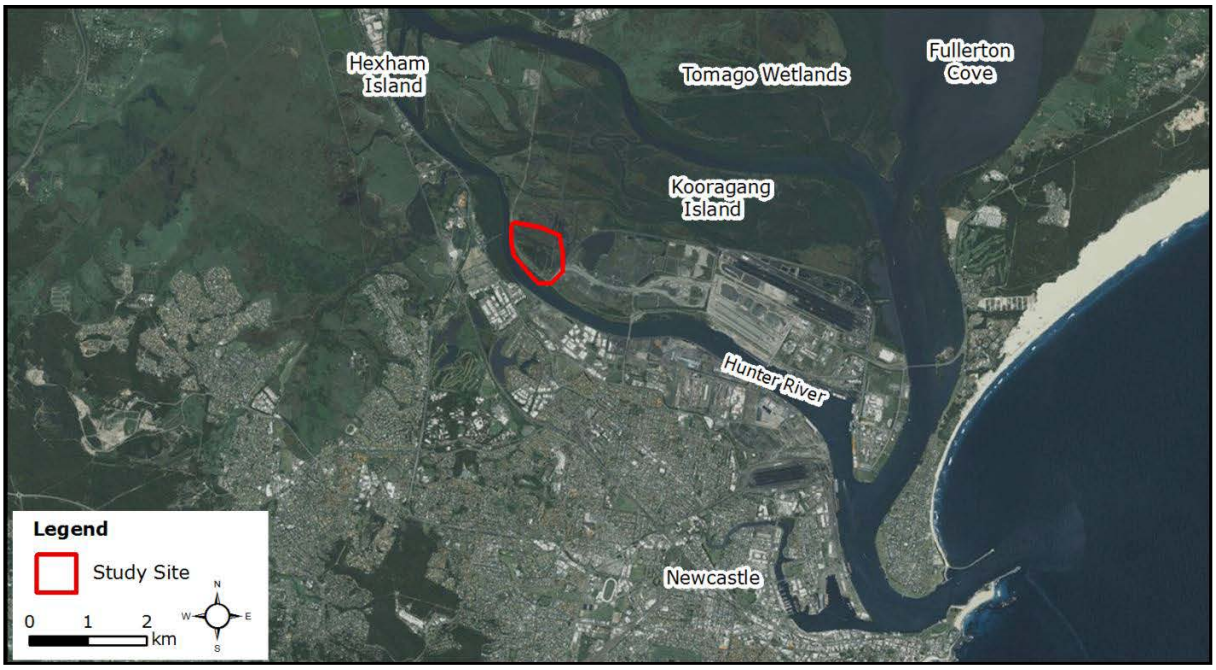


Figure1. The study site

2. Trigger Levels for 2018

Based on existing plans and Hunter River tidal levels near Area E, SmartGate trigger levels for the period January to December 2019 were created and provided to NCIG. Following discussion at the annual stakeholder meeting in 2018 regarding the development of vegetation at the site, it was concluded that the existing triggers remain for the period between January to December 2019 unless specified. It was suggested that active monitoring remains onsite, including water level monitoring and visual inspection of vegetation growth before any changes to the trigger levels. To promote the on-going success of the project, adaptive management of the trigger levels is recommended to align with the environmental response. The new synthetic tide, alongside the natural tide at Newcastle, is shown in Figure 2.

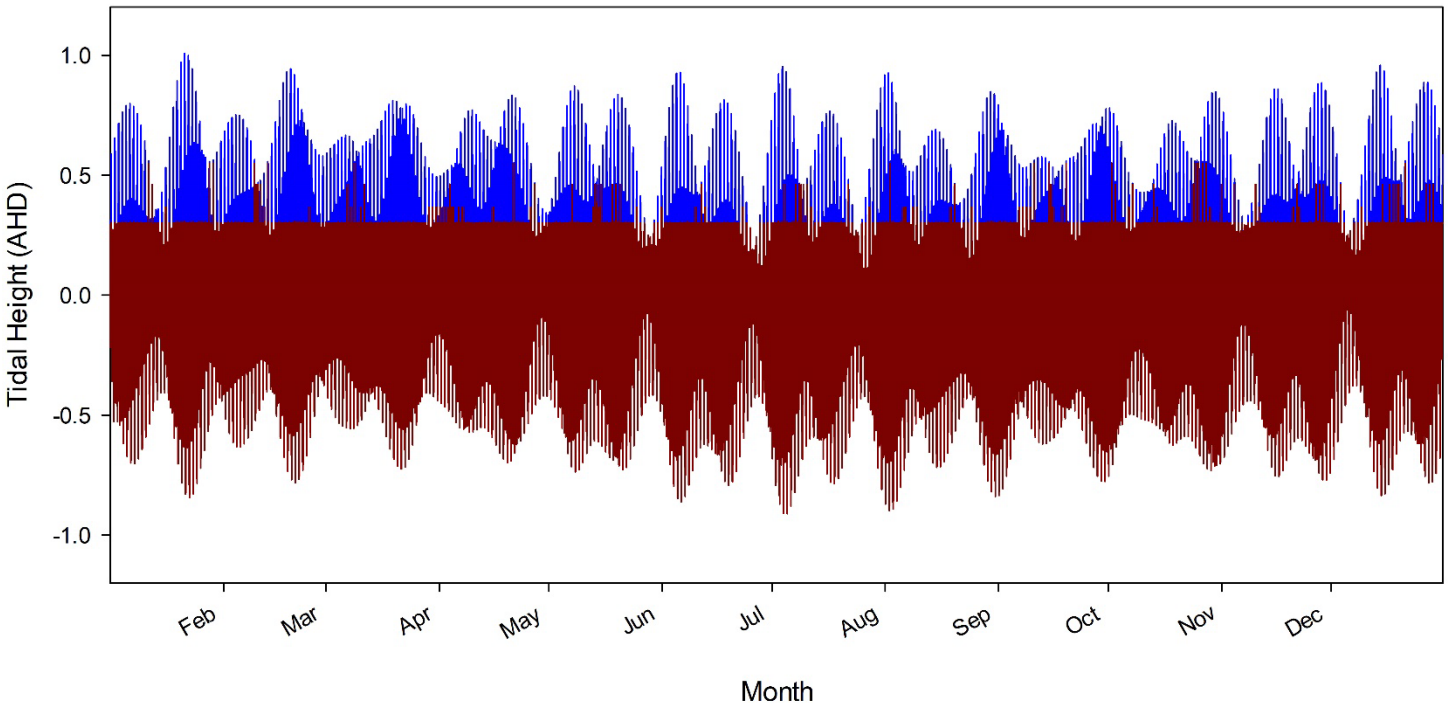


Figure 2. Newcastle natural and synthetic design tides for 2019

3. Hydrology Monitoring

3.1 Groundwater dynamics

A detailed field investigation was conducted in July 2018 to better understand groundwater movement and interactions with surface waters at Area E wetland under different conditions including 1) wetland in natural tidal conditions, 2) wetland flooded, with flushing restricted by the gates and 3) wetland drained, with the gates preventing inundation. Radon, a naturally occurring groundwater tracer was used to detect groundwater seepage into Fish Fry creek and the mudflats. A continual 24-hour time series dataset of radon (groundwater tracer) and wetland water levels covering two tidal cycles were collected for each experimental condition.

Figure 3 shows surface water and groundwater dynamics for the full 72-hr (3*24-hr) of the measurements. Results clearly showed a peak in radon (groundwater tracer) at both low tide periods over the two tidal cycles (when water depths were lower than 0.3 m) indicating groundwater discharging into the creek and wetland during low tide under natural tide conditions. It is suspected that the large number of crab burrows facilitate the seepage of groundwater into the system. Over the flooded period, water levels were maintained at around 1.4 m in Fish Fry creek (from the bed of the creek) for 24 hours. A 2-fold increase in radon (groundwater) signal from the start of this period to the end, indicted that even under flooded conditions groundwater seepage contributes to the overall surface water volume of the wetland. Once the gates were opened to drain the wetland, radon signals reached their maximum recordings, as water infiltrated into the sediment while the wetland was flooded discharged into Fish Fry creek, causing a sharp increase in radon concentrations. There was a positive and increasing trend in the radon (groundwater) signal under drained conditions indicating large volumes of groundwater seepage are likely after the wetland experiences flooding conditions.

Overall, it was observed that active groundwater seepage occurs at the wetland under various conditions and the groundwater - surface water systems are closely linked within the wetland. This maybe important as small amounts of groundwater seepage has the potential to affect the quality of surface waters, as groundwater often contains higher concentrations of organic and inorganic substances compared to surface waters. Additional detailed field investigations are ongoing.

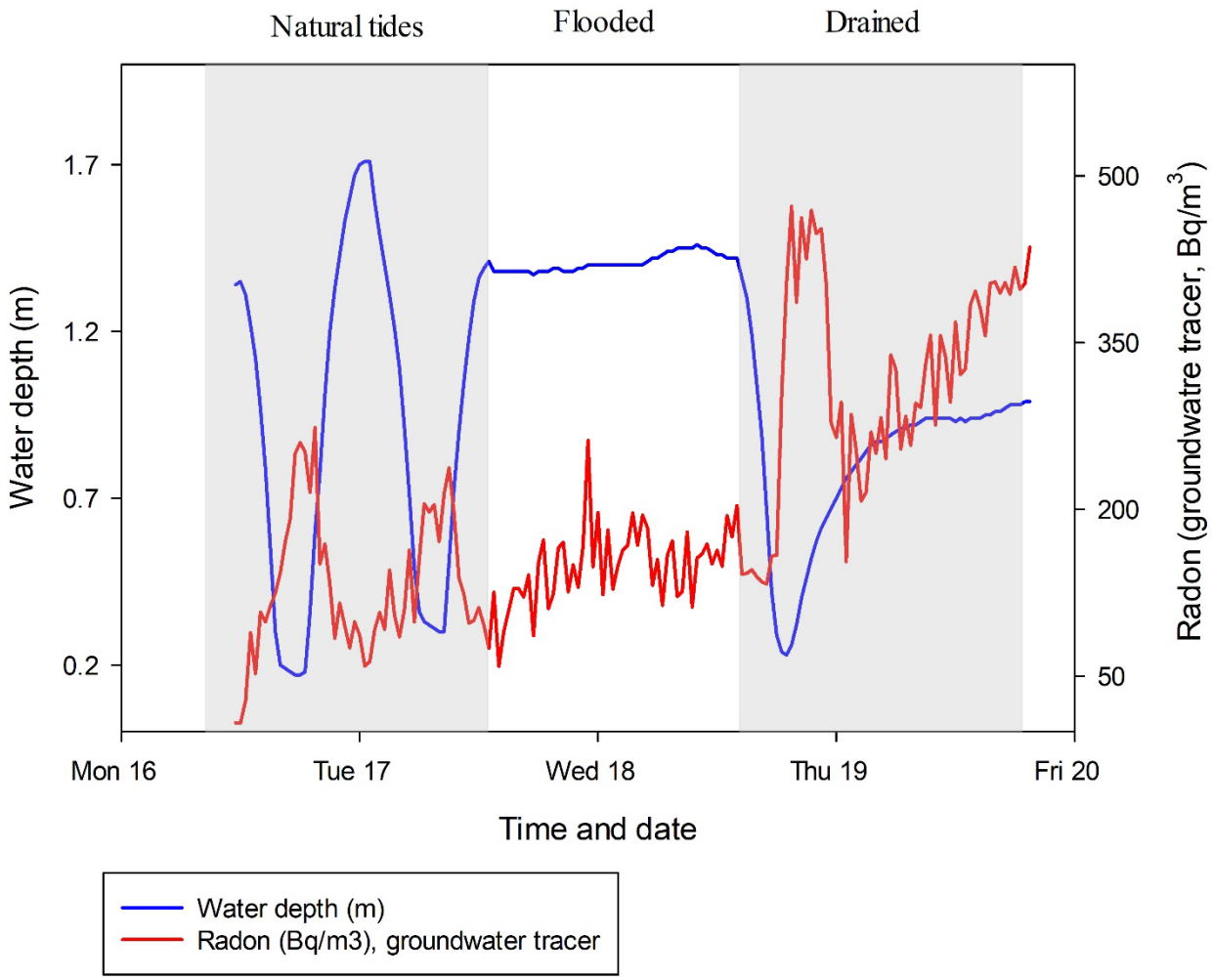


Figure 3. Surface water-groundwater interactions at the wetland under different natural tides, flooded and drained conditions.

3.2 Surface water quality

Surface water quality parameters including dissolved oxygen (percent saturated; %), pH, electrical conductivity (mS/cm), temperature (C), and chlorophyll (μg/L) were also measured over a 72-hr time period under natural, flooded and drained condition at Fish Fry creek near the gates. During natural conditions, two tidal cycles were captured in detail, with depths in the first cycle ranging from 0.2 to 1.4 m and depths in the second tidal cycle varying between 0.4 to 1.7 m, showing a 20 cm head difference between the two cycle (Figure 4). Electrical conductivity (EC) ranged from 40 to 53 mS/cm and decreased on ebb tides, although staying within oceanic water concentrations at all times. Water temperature varied between 8 to 15 °C and showed a similar trend to water depth and EC variations, lowering at ebb tides. Dissolved oxygen varied from 74 to 125% saturation with lower concentrations observed at ebb tide. pH ranged from 7.8 to 8.2 and clearly decreased at ebb tide during both the first and the second ebb tide. Chlorophyll followed an opposite trend to the tide increasing at ebb tide (>6-fold increase on the first ebb tide) and decreasing at flood tide. It was clearly observed that tidal variation controlled the water quality and hydrodynamics within the wetland over the time of the measurement.

During the 24-hr flooded conditions water depth at Fish Fry creek was controlled by the gates and was constantly held at 1.4 m depth. During this period, temperature and dissolved oxygen showed a diurnal pattern with higher temperatures and dissolved oxygen observed during the day (potentially due to photosynthesis) and lower concentrations recorded at night. pH during flood conditions were almost constant at 8.1, while EC showed an incline trend decreasing from 51 to 46 mS/cm, similar to the temperature patterns. The drop in EC over the 24-hr period could be due to chemical reactions occurring at the wetland or potentially due to groundwater seepage containing lower EC. Chlorophyll showed a trend that would be similar to natural tidal conditions with the gates open, indicating other process than tidal variations may be driving chlorophyll dynamics in the wetland.

A sharp increase, and the highest concentration for all measured parameters, was observed after the gates were opened and water was drained from the wetland (after 24-hr of flooded conditions). Water depths dropped to 0.2 m, which is similar to the water depth at low tide during the natural conditions. However, water quality parameters showed higher concentrations compared to those observed at the same water depth under natural tides,

illustrating the significant effect and changes floods may cause on the water quality of the wetland.

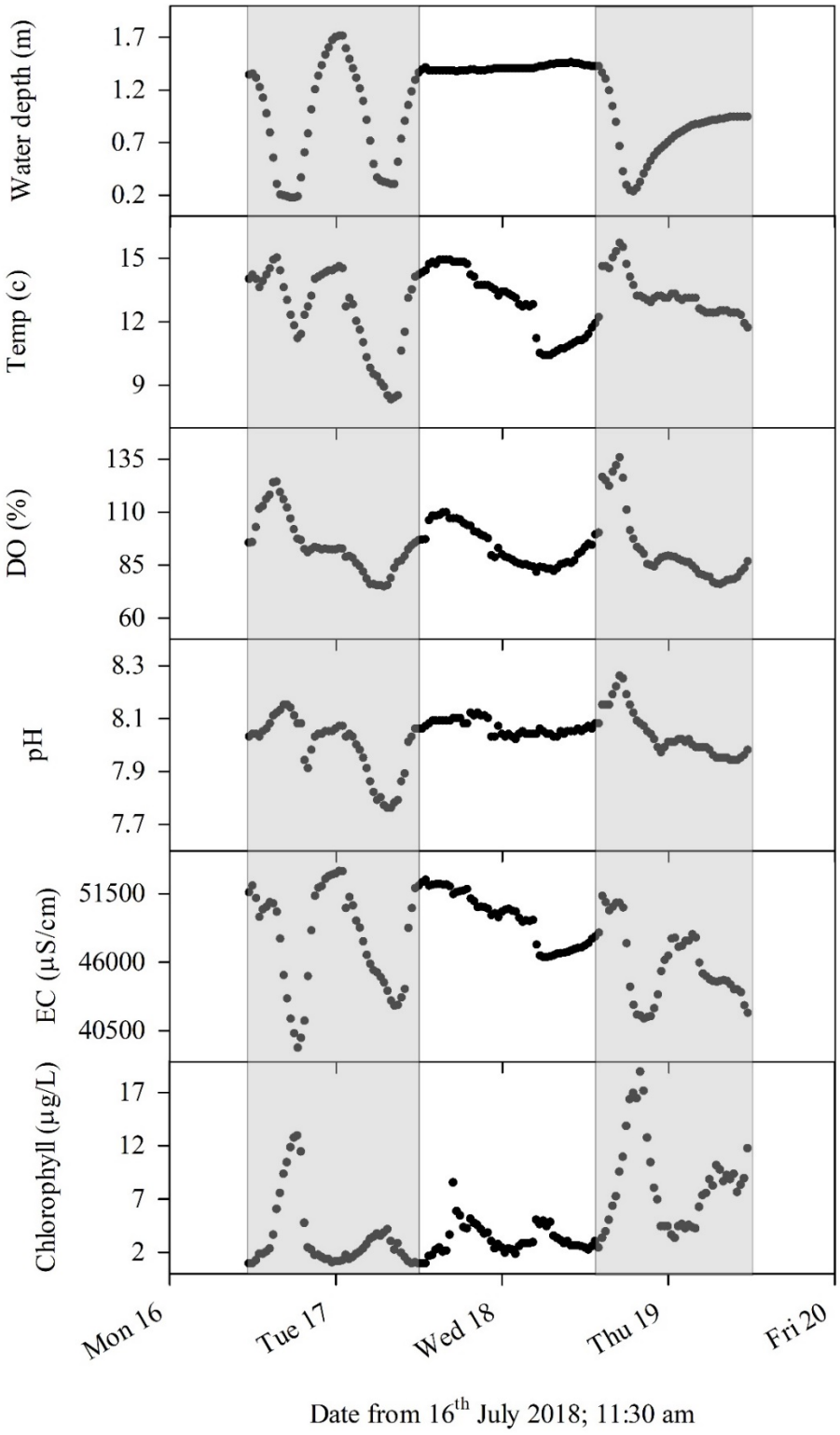


Figure 4. Surface water quality and dynamics time series measurements at Fish Fry creek over 72 hrs under natural, flood and drained conditions.

3.3 Groundwater levels

Groundwater levels at Area E are continually recorded using Solinst pressure transducer loggers placed in piezometers that were installed in November 2017. Figure 5 shows the location of the piezometers at Area E. In additional to groundwater levels, five piezometers (14, 2, 1, 7, 8, and 15) log groundwater Electrical Conductivity (EC) or salinity. These piezometers were installed in a transect to cover groundwater dynamics on both sides of Fish Fry flats. Data from the loggers were extracted and groundwater level and conductivity times-series data plots were created for the period 22nd August to 10th September 2018 for selected piezometers (Figure 6).

Data shows that piezometers 4 and 6 located on the South West side of the mud flats have the highest hydraulic head (water level normalised to surface elevation) following the topography of the area, indicating that groundwater flows towards the centre of the mudflats and drains to Fish Fry creek. Piezometers 7 and 11 located on the North side of Fish Fry creek have lower hydraulic heads. Average depth to the shallow groundwater aquifer at Area E was around 1.0 meter which is similar to previous measurements in 2018. In general, groundwater levels at Area E are greatly affected by tides and follow the tidal regime as shown in Figure 5. Groundwater level data for the second half of 2018 did not show any long-term trend and no obvious decline or incline trend was observed in the graph, indicating stable conditions throughout 2018.

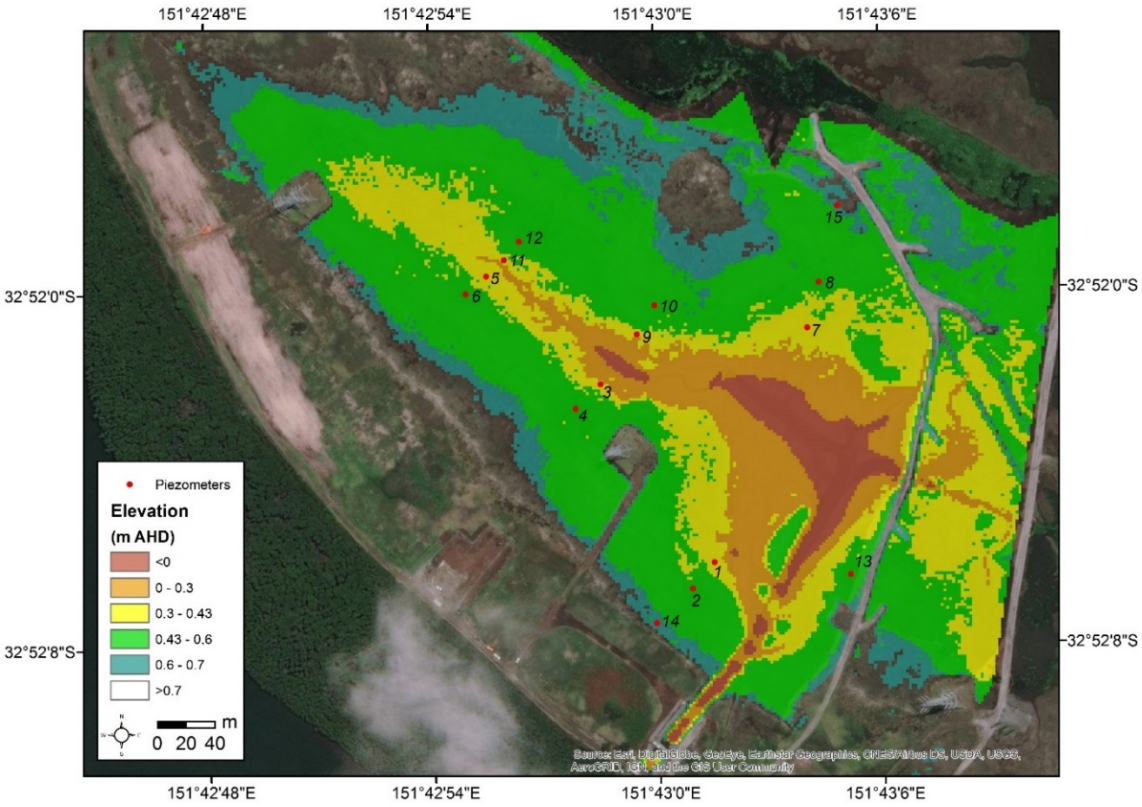


Figure 5. Location of the piezometers at Area E

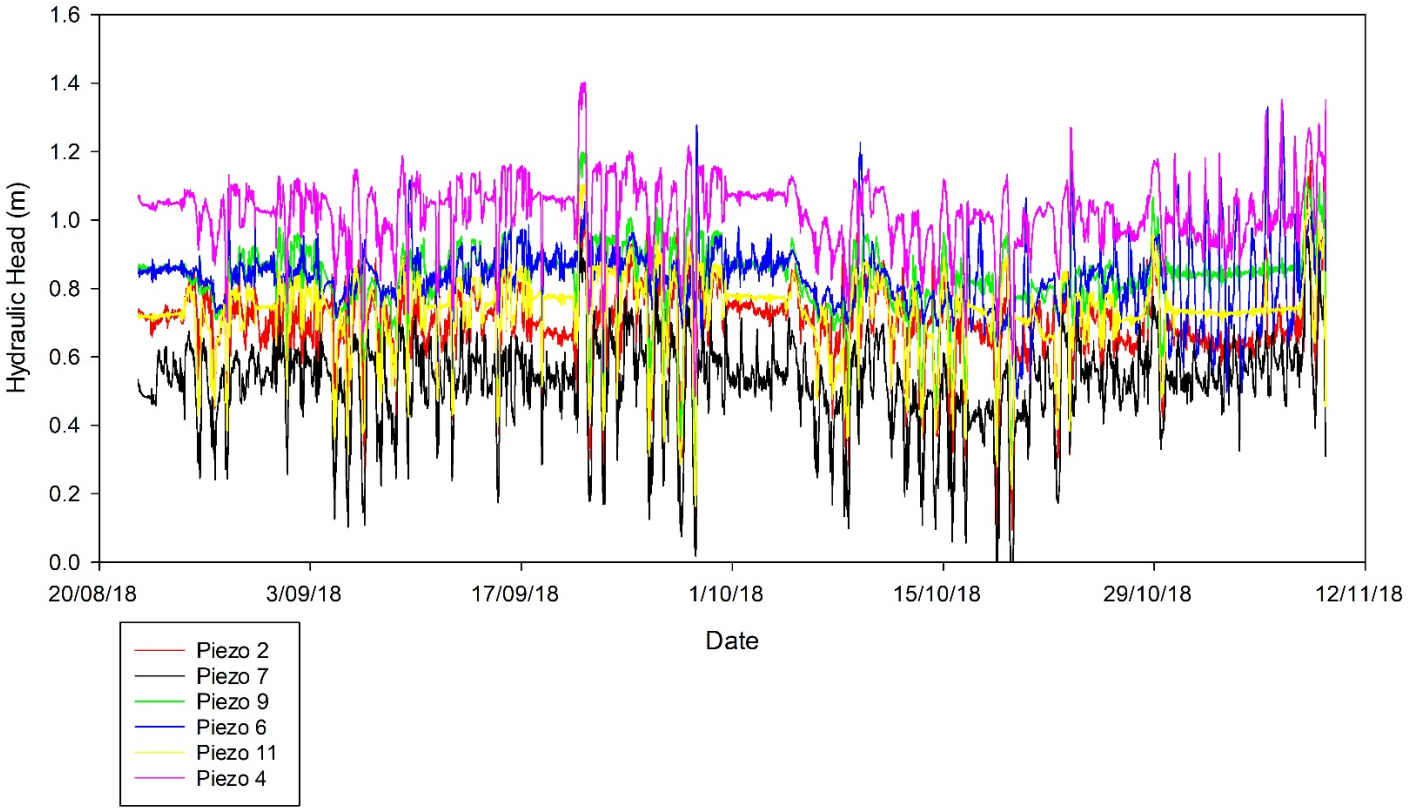


Figure 6. Groundwater level times series data from 22/08/18 to 10/11/18 for shallow bores across the site

3.4 Groundwater quality

Groundwater quality was tested for chemical, dissolved trace metals, nutrients and carbon in July 2018. Table 1 presents the results from the sampling. Conductivity is one measure of the inorganic materials including calcium, bicarbonate, nitrogen, phosphorus, iron, sulphur and other ions dissolved in a waterbody. Seawater EC is usually around 52 mS/cm (milli-siemens per cm). Groundwater conductivity (EC) data from Area A indicated groundwater at the site is hypersaline with all piezometer showing a higher EC value than seawater (52 mS/cm). The highest conductivity of 78 mS/cm was observed at piezometer 10 indicating high rates of evapotranspiration occurring at the mudflats. Average groundwater EC for the wetland was 72 mS/cm which is 1.3 times higher than seawater conductivity.

Average groundwater pH had a lower value and was more acidic that surface water pH (8.1) which was measured at the same time as groundwater sampling. Groundwater also had lower average dissolved oxygen (2.8 mg/L) compared to surface water measures (10.5 mg/L) implying that groundwater seepage or discharge can lower surface water pH and dissolved oxygen concentrations. Groundwater quality data presented in Table 1 showed high concentrations of trace metals, including iron (Fe) and manganese (Mn) which could potentially be linked to acid sulphate soils in the area. Additionally, total dissolved nitrogen (TDN) and dissolved inorganic carbon (DIC) concentrations were elevated. However, mangrove sites in Australian and worldwide are known for high dissolved inorganic carbon accumulation in their sediments (Dittmar et al., 2006). Average dissolved organic carbon and total dissolved nitrogen were in the range of wetlands in Australia surrounded by mangrove vegetation (Maher et al., 2013).

Table 1. Groundwater quality observations.

Piezo no.	Date	EC (mS/cm)	Temp	pH	DO (mg/L)	Fe (μM)	Mn (μM)	DOC (μM)	DIC (μM)	TC (μM)	TDN (μM)	TDP (μM)
1	19/07/2018	74.9	10.7	7.1	4.8	2148	36.1	645.9	5556.1	6202	142.5	3.1
3	19/07/2018	68	20.4	6.8	2.2	223	15.9	908.9	17664.6	18573.4	171.4	4.9
4	19/07/2018	75.1	12.1	7	2.1	2297	35.7	1010.6	6010.8	7021.3	195.9	3.3
6	19/07/2018	75.3	13.7	6.9	6.4	1216	32.5	925.6	7616.9	8542.5	161.3	3.2
7	19/07/2018	71.2	16.9	6.8	5.7	657	14.3	406.4	5556.8	5963.2	138.7	3.1
9	19/07/2018	62.7	17.9	7.2	0.5	759	11.9	608.3	19121.9	19730.2	125	3.1
10	18/07/2018	78.1	17	7	3.4	798	19.4	864.3	8901.1	9765.4	181.2	3
11	19/07/2018	71.1	19.9	7	2.8	1500	26.2	630.9	7875.6	8506.5	137.2	3
12	18/07/2018	71.3	16	7.3	5.9	92.7	27.1	1130.5	9102.9	10233.4	195.2	3.2
13	17/07/2018	70	17	6.4	0.4	2451	28	1079.6	2792.5	3872.1	188.9	2.8
14	18/07/2018	75.8	16.7	6.5	2.7	3475	43.4	667.9	1568	2235.9	117.8	2.8
15	17/07/2018	72.7	18.3	6.6	1.6	923	48.7	534.8	3154.7	3689.4	86	3
	Average	72.0	17.0	6.9	2.8	1070	27.6	766.1	6813.8	7763.9	151.9	3.1
	Std Error	1.2	0.8	0.1	0.6	294	3.3	67.0	1574.1	1579.8	10.0	0.2

4. Drone Survey

4.1 Vegetation development

A total of six 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, 22nd August, and 9th November in 2018. For each drone survey 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.

Figure 6 shows the imagery for the first four drone surveys and changes from February 2017 to April 2018. When comparing the images, distinct vegetation colour and coverage can be observed however, this may be due to surveys conducted at different seasons in the year with varying factors that can affect vegetation growth and spatial cover. The average monthly rainfall and temperature in the first survey (summer - top left image) were 59 mm, 29℃, respectively. The second survey was conducted in winter (top right) were the average temperature and rainfall were 12.4 ℃ and 25.8 mm. The third survey was done in spring (bottom left) with an average monthly rainfall and temperature of 113.8 mm and 24.5 ℃, and the fourth image which taken in autumn (bottom right) where average monthly temperature and rainfall were 26.5 ℃ and 88 mm, respectively. The obvious change in these four images is the spatial cover of green area in the fourth survey (April 2018) compared to images in 2017, suggesting that one-year post restoration, saltmarsh vegetation is developing and expanding in the wetland.

The latest processed drone imagery form August 2018 shows saltmarsh vegetation developing along the low tide mark on the mudflats. This survey was conducted in winter where average monthly temperature and rainfall were 13.7 ℃ and 20 mm, respectively. These weather conditions are similar to those observed in 2017 for the winter period, hence, possible effects of climatic variation are considered negligible for the purpose of comparison. An assessment between the two images (Figure 7, top right and Figure 8) shows areas where saltmarsh has started to develop.

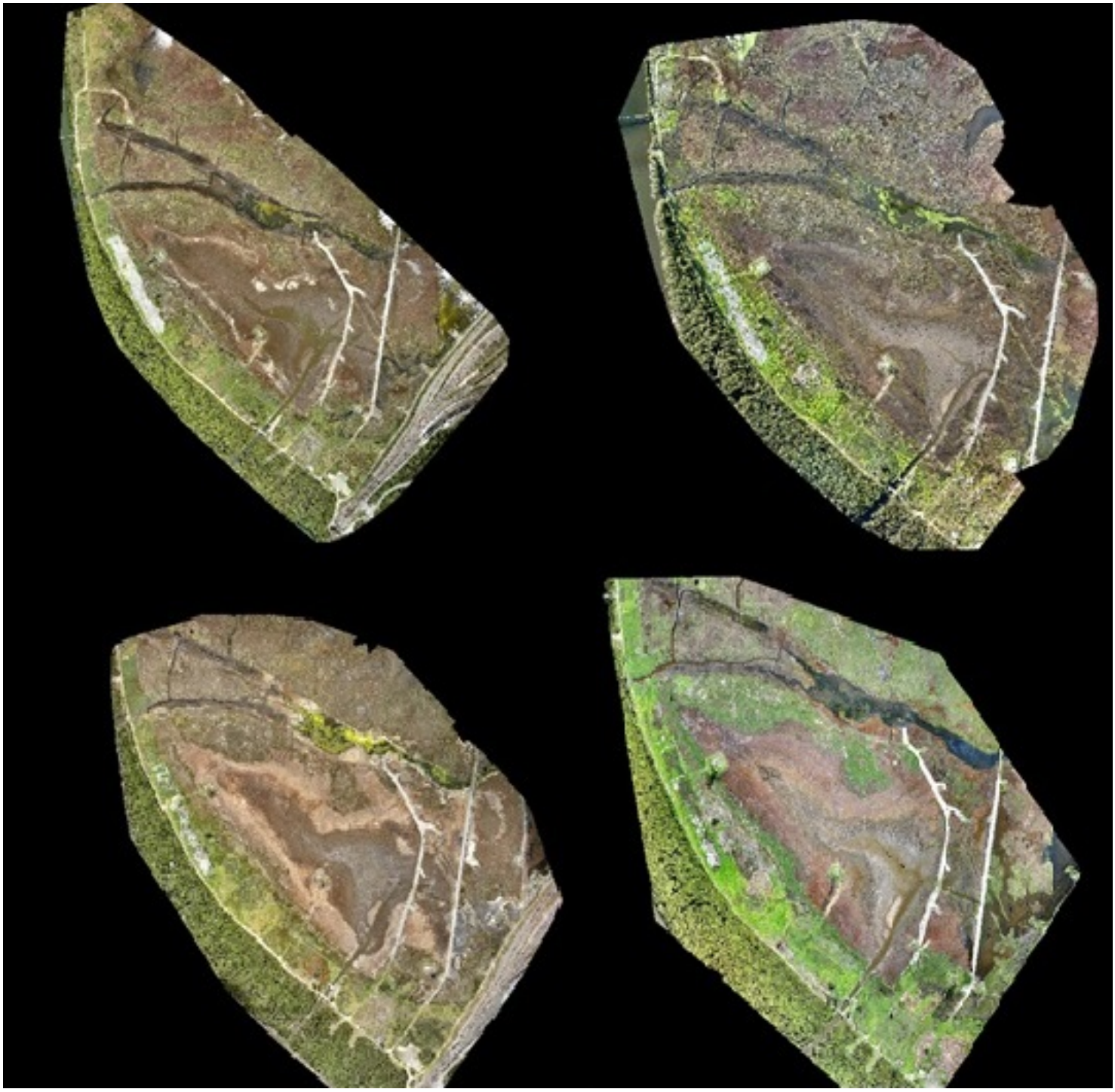


Figure 7. Drone imagery of Area E, top left: Feb-2017; top right: July-2017; bottom left: October-2017 and the bottom right: April-2018).

Figure 8. Drone imagery of Area E, taken on the 22nd August 2018.

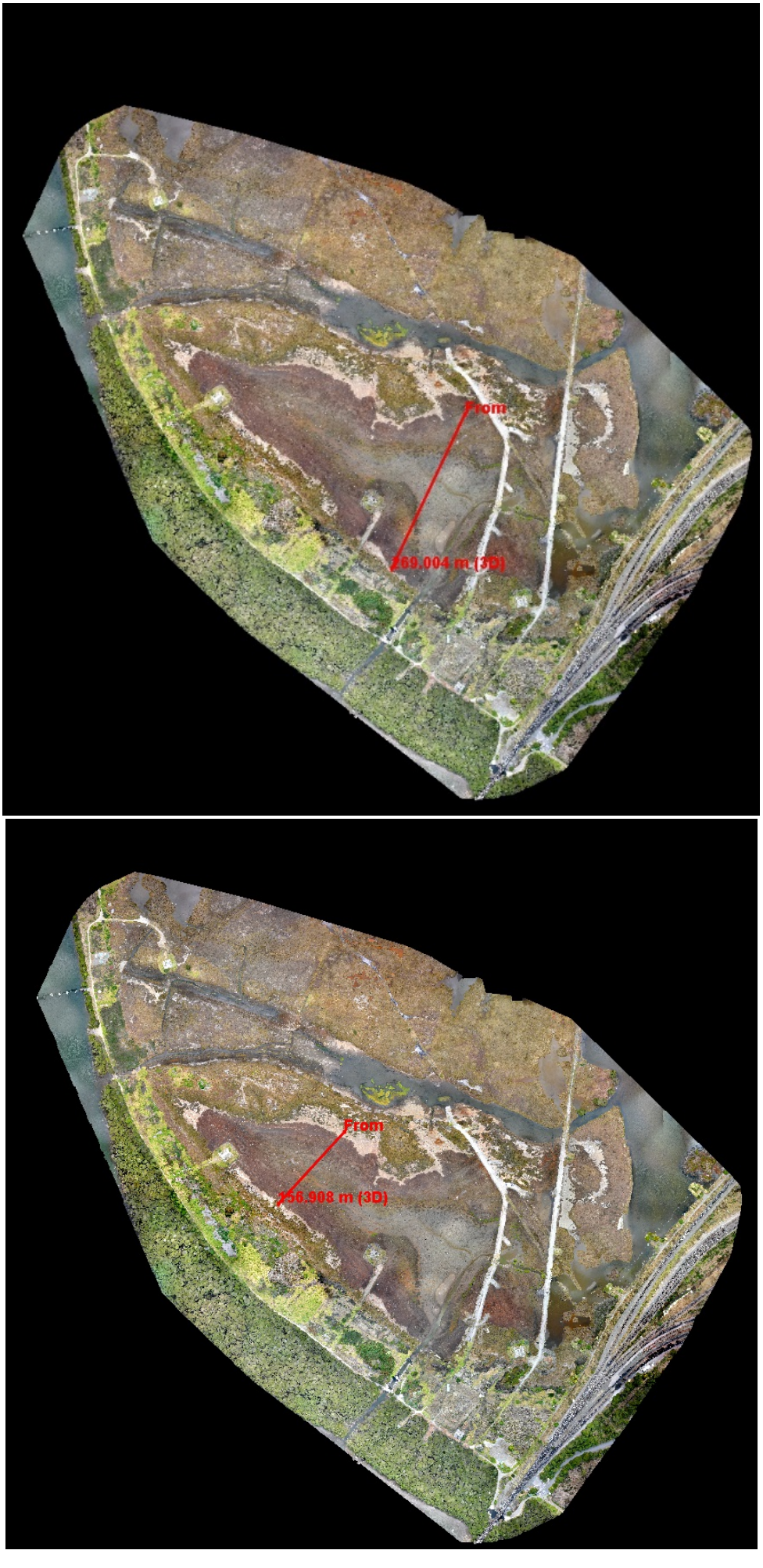


Figure 9. Location of cross section 1 (top) and 2 (bottom)

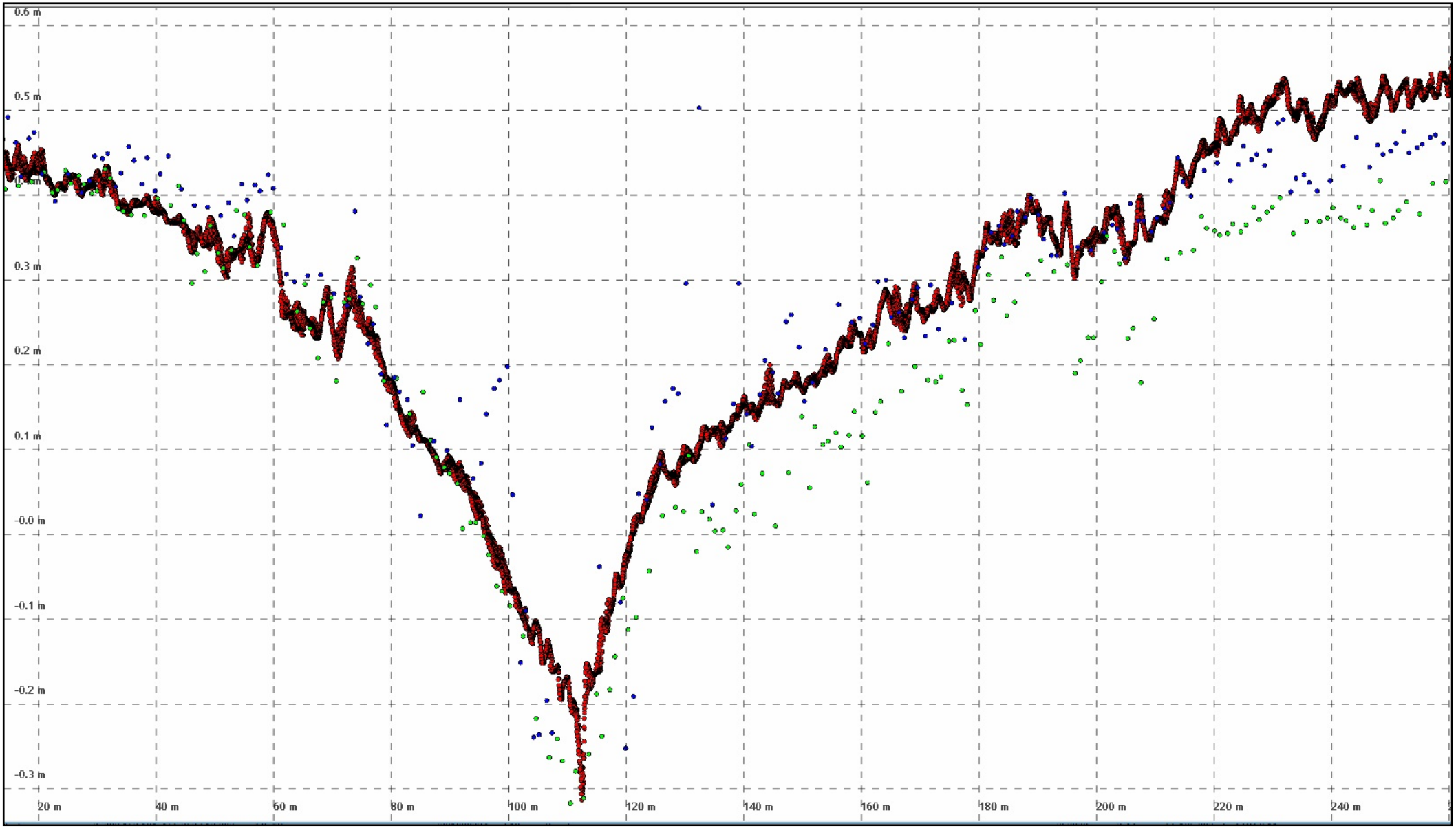


Figure 10. Elevation profile for the cross section 1 at Area E. Red line: August 2018; Green line: October 2017; Blue line: February 2017 (base line data). Y and X axis indicate elevation (AHD) and distance from the start point, respectively.

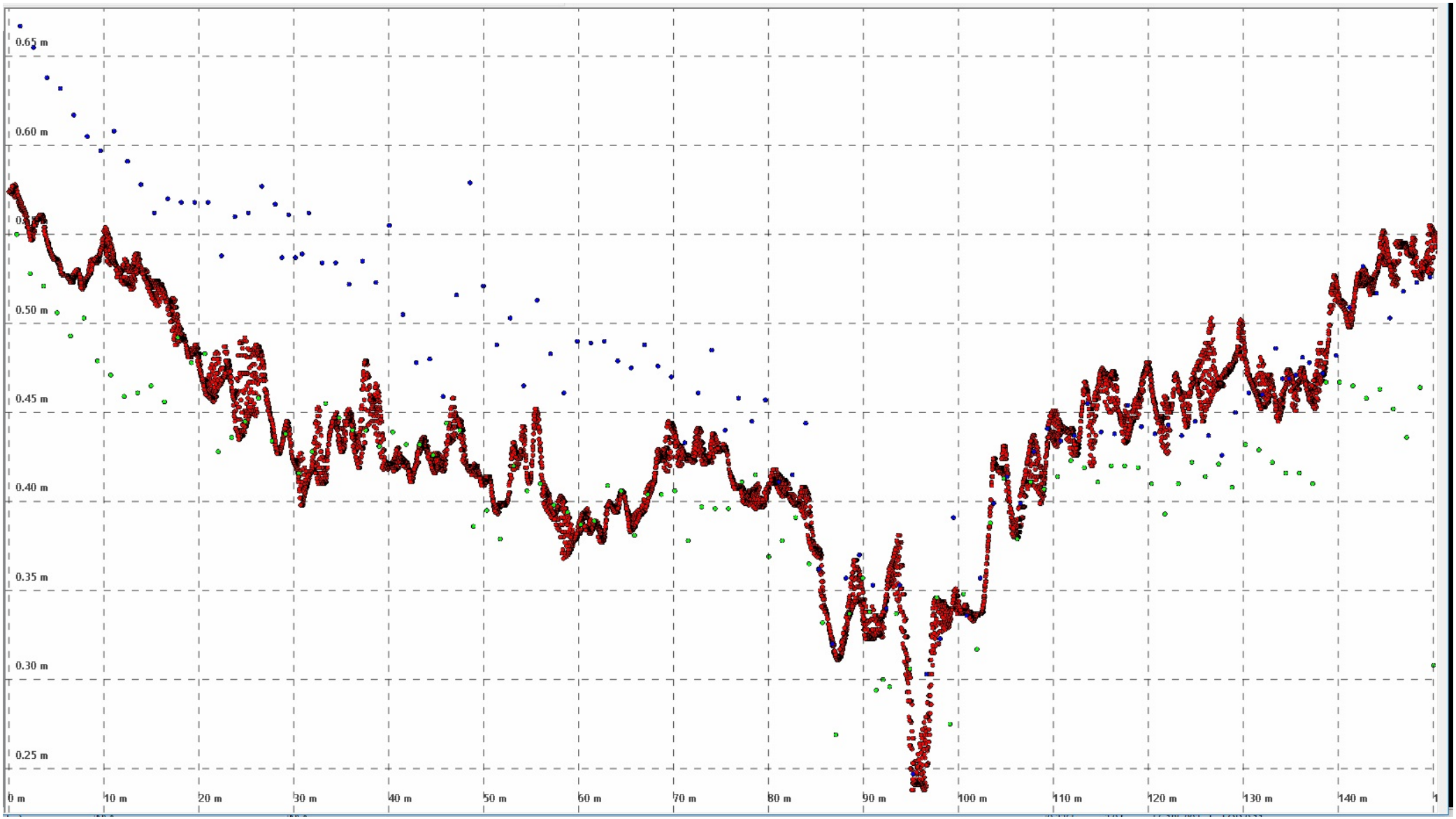


Figure 11. Elevation profile for the cross section 2 at Area E. Red line: August 2018; Green line: October 2017; Blue line: February 2017 (base line data). Y and X axis indicate elevation (AHD) and distance from the start point, respectively.

4.2 Elevation changes

To assess elevation changes at Area E the latest processed drone imagery (August 2018) were compared to the previous drone survey data in the same season (October 2017) and to the imagery obtained from the first drone survey in February 2017 which acts as the baseline data. Figure 8 shows the location of the cross-section lines where elevations profile where created and assessed. These cross sections extend the width of the wetland and were selected based on the most assumed affected areas after restoration.

The elevation profile for cross-section 1 (Figure 10) shows similar elevations for areas north of Fish Fry creek for baseline, winter 2017 and winter 2018 data, indicating no major changes in surface elevation over the last 1.5 year at the site. However, on the south side of the mud flats/Fish Fry creek, land elevation shows a slight (in some cases 10 cm) increase compared to baseline data and winter 2017 elevation data (green dots).

The second cross section (2) shows a 5 cm decrease in elevation for areas north of Fish Fry Creek when comparing the data from October 2018 to baseline data (February 2017). However, October 2018 land elevation data on the south side of the creek is consistent with those observed from the first survey in February 2017. August 2018 elevation data for cross-section 2, shows very similar (within 5 cm variation) land elevations for the same location in October 2017, indicating no major surface elevation changes for this area during the past year.

In general, elevation variations at Area E are around 0.1±0.1 meter, which is within the uncertainty of the measurement techniques used. Therefore, elevation changes at Area E 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.

References

Dittmar, T., Hertkorn, N., Kattner, G. and Lara, R.J. (2006) Mangroves, a major source of dissolved organic carbon to the oceans. Global biogeochemical cycles 20.

Maher, D.T., Santos, I.R., Golsby-Smith, L., Gleeson, J. and Eyre, B.D. (2013) Groundwater-derived dissolved inorganic and organic carbon exports from a mangrove tidal creek: The missing mangrove carbon sink? Limnology and Oceanography 58, 475–488.

Appendix D – Fish Fry Flats Vegetation and Infauna Report Methods and Preliminary Results (Caleb Rankin, UoN).

Fish Fry Flats Vegetation and Infauna Report Methods and Preliminary Results.

Date: January 2019

Report by Caleb Rankin

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Unless otherwise specified, all figures and images are created by Caleb Rankin

1 Overview

As part of their environmental offset, Newcastle Coal and Infrastructure Group (NCIG) have been leased past critical shorebird habitat on Area E, Kooragang Island, to restore to saltmarsh. This is being achieved by removing mangroves and installing floodgates in consultation with the University of New South Wales (UNSW) to encourage saltmarsh growth and bird usage (Glamore, 2017; NCIG, 2015). In order to determine the trajectory of the habitat restoration, NCIG has partnered with the University of Newcastle to identify, measure, and track overall functioning and delivery of ecosystem services. This report gives an overview of the experimental design and sampling methods and preliminary results to date. Preliminary results indicate that saltmarsh is establishing well with species richness comparable to reference sites and diverse macrofauna with large amounts of polychaetes, a large component of shorebird diets.

2 Methods

2.1 Indicators

Components of an ecosystem that indicate its health and functioning, termed ecological indicators, can be reliably used to measure and identify restoration success for habitat functioning and delivery of ecosystem services (Brudvig, 2017; Ruiz-Jaen & Aide, 2005). For this study, ecological indicators of saltmarsh functioning that may affect its value as shorebird habitat are being measured. These are plant diversity and cover, crab holes and macroinfauna (organisms that live in the soil).

2.2 Sites

Area E has historically been important shorebird habitat and the subject of various studies (e.g. Boys & Williams, 2012; Howe, Rodríguez, Spencer, MacFarlane, & Saintilan, 2010; Nelson, 2006). Mangrove invasion in the ‘90s reduced its value as shorebird habitat and prompted various efforts to restore its old structure of saltmarsh surrounding mudflats. NCIGs current restoration efforts began in 2016 with total mangrove removal. To assist mangrove exclusion and promote maximum saltmarsh growth, the tidal regime was lowered by Smart floodgates in June 2017. The highest annual tides are still allowed to flood the old high saltmarsh to prevent pasture weed invasion.

In addition to the primary study site at Area E, two control and two older restoration sites are being sampled (Table 1, Figure 1). These additional sites will give comparisons and benchmarks for the developing Area E saltmarsh from degraded to restored bird habitat. The control sites, Cobbans Creek and Crabhole Flats, were selected due to having a similar characteristics and disturbance history to Area E. These include similar structure, age and direct (e.g. grazing, invasive species, and vehicle use) and indirect (e.g. flood gates, potential for eutrophication from farms and roads, and changes in surrounding habitat) disturbances. The older restoration sites, Tomago Wetlands and

Hexham Marsh, were selected on the basis of their similar structure to Area E and for their increasing value as shorebird habitat. Each has been undergoing restoration for over 10 years (Table 1).

Each of the control and restoration sites will be sampled twice per year in June (winter) and November (summer) starting in June 2018 (4 sampling events by 2020, project end).

Table 1: Restoration and disturbance at the study sites and their part in this project.

Site	Restoration/Disturbance	Use in Project
Area E	Restoration began 2016, Previously saltmarsh and pasture invaded by mangroves. Tide gates lowering tide and excluding mangroves to promote saltmarsh growth	Study Site
Tomago Creek	Restoration began 2007, Controlling tide to discourage mangroves and flood old pasture and freshwater wetland to promote saltmarsh growth.	Restoration Site
Hexham Marsh	Restoration began 1996, Controlling tide to flood freshwater wetland/pasture to promote saltmarsh growth. Mangroves not controlled.	Restoration Site
Cobbans Creek	Drained for pasture until culvert removed in 1990, Significant mangrove encroachment into old saltmarsh.	Control Site
Crabhole Flats	Drained for pasture until culvert removal in 1993, Significant mangrove encroachment into old saltmarsh.	Control Site

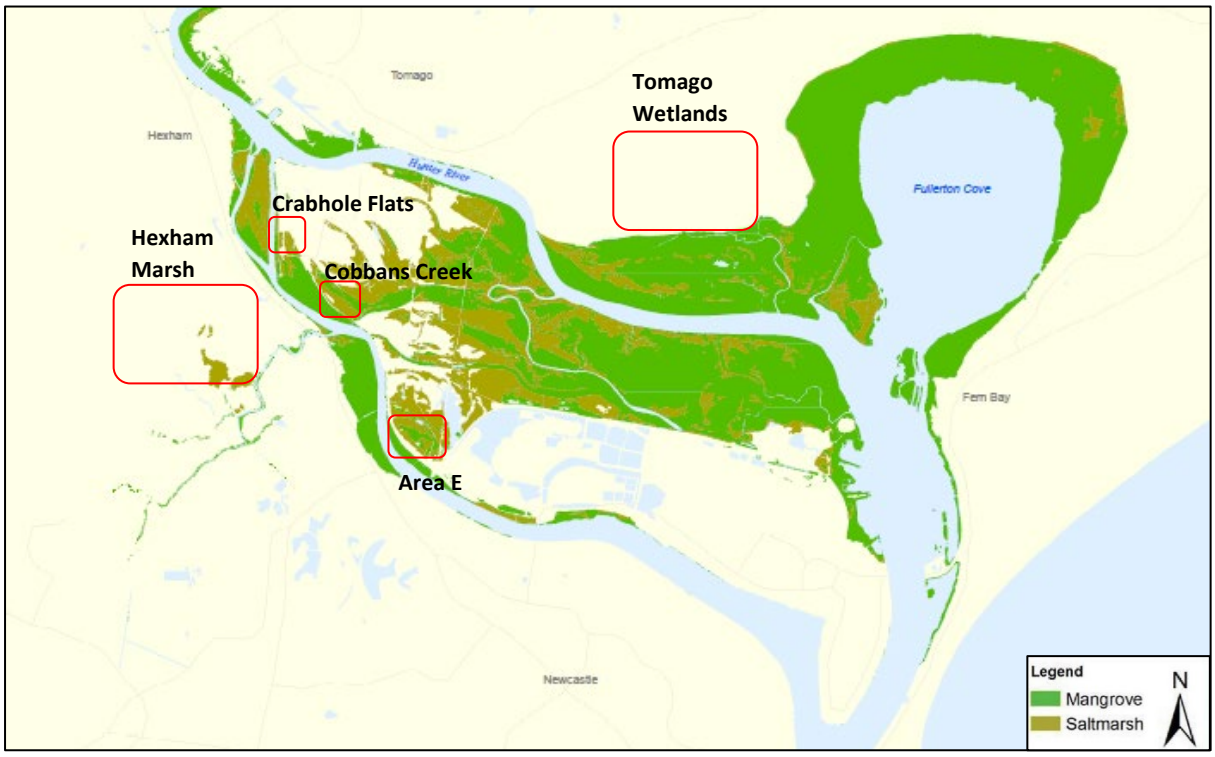

Figure 1: Locations of the study sites for this project. Image from Crease et al (2009).

2.1 Sampling strategy

For each of the ecological indicators measured, stratified random sampling is being undertaken at each site with indicators being measured in each of five zones transitioning from mudflat to saltmarsh Above Highest Tide (AHT, saltmarsh that is not inundated by the highest annual tides) based on tidal flow illustrated in Digital Elevation Maps (DEMs) (Figure 2). Saltmarsh AHT is only sampled in Area E where the tide has been lowered and existing saltmarsh remains above the highest tide.

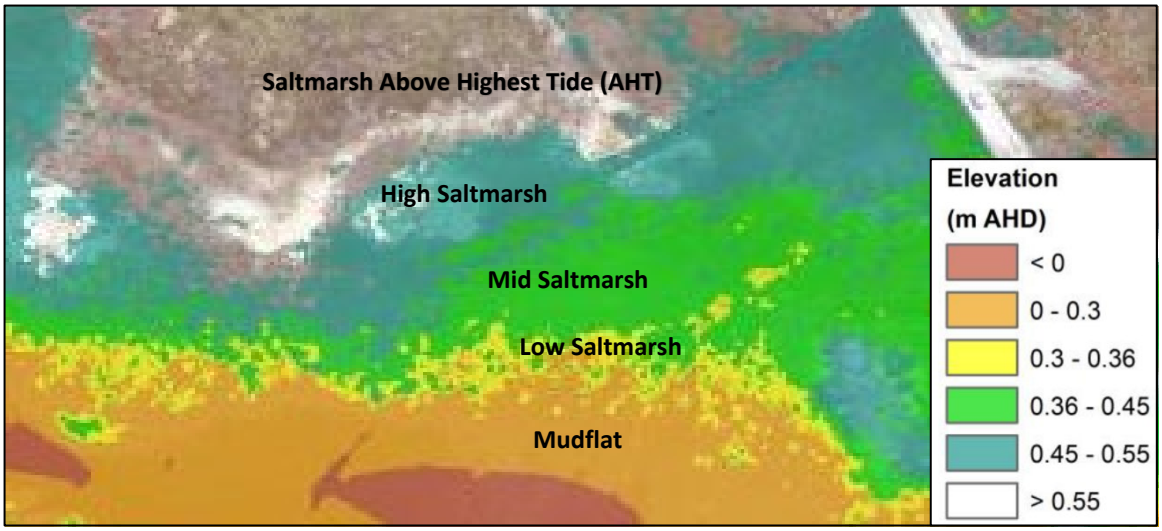

Figure 2: Digital Elevation Map detailing the tidal flow and the zones sampled from mudflat to saltmarsh Above Highest Tide (AHT). DEM map sourced from A/Prof Will Glamore, UNSW.

2.1.1 Vegetation cover, diversity and crabholes

For all sites 1m x1m quadrats divided into 25 squares with nylon twine (Figure 4B) have been set out at the sites to measure vegetation cover, diversity, and number of crabholes. Quadrat placement used a random number table to select random numbers on 50 and 100m tapes, stratified within each zone. Strata were determined by the saltmarsh zones of AHT, high, mid, and low marsh with an equal number of quadrats within each zone (Figure 3 & 4A). At Area E, 25 quadrats have been placed and surveyed in each of the four zones (25 x 4 = 100 quadrats (Figure 3)). In the other sites, 10 quadrats have been placed and surveyed in each of the three zones (high, mid, and low, 10x3 = 30 quadrats). Quadrat placement was measured from permanent infrastructure (e.g. roads, electric pylons, and old fence posts) to assist placement and relocation of the quadrats (Figure 4). Each quadrat has been marked for future sampling using a 490mm and a 225mm Supapeg® UV-Treated Polypropylene Sand Peg inserted at the diagonals of the quadrat with a numbered cattle tag attached (Figure 4). The latitude and longitude of each quadrat was taken for mapping and to assist future locating or replacement in the event of the pegs being lost.

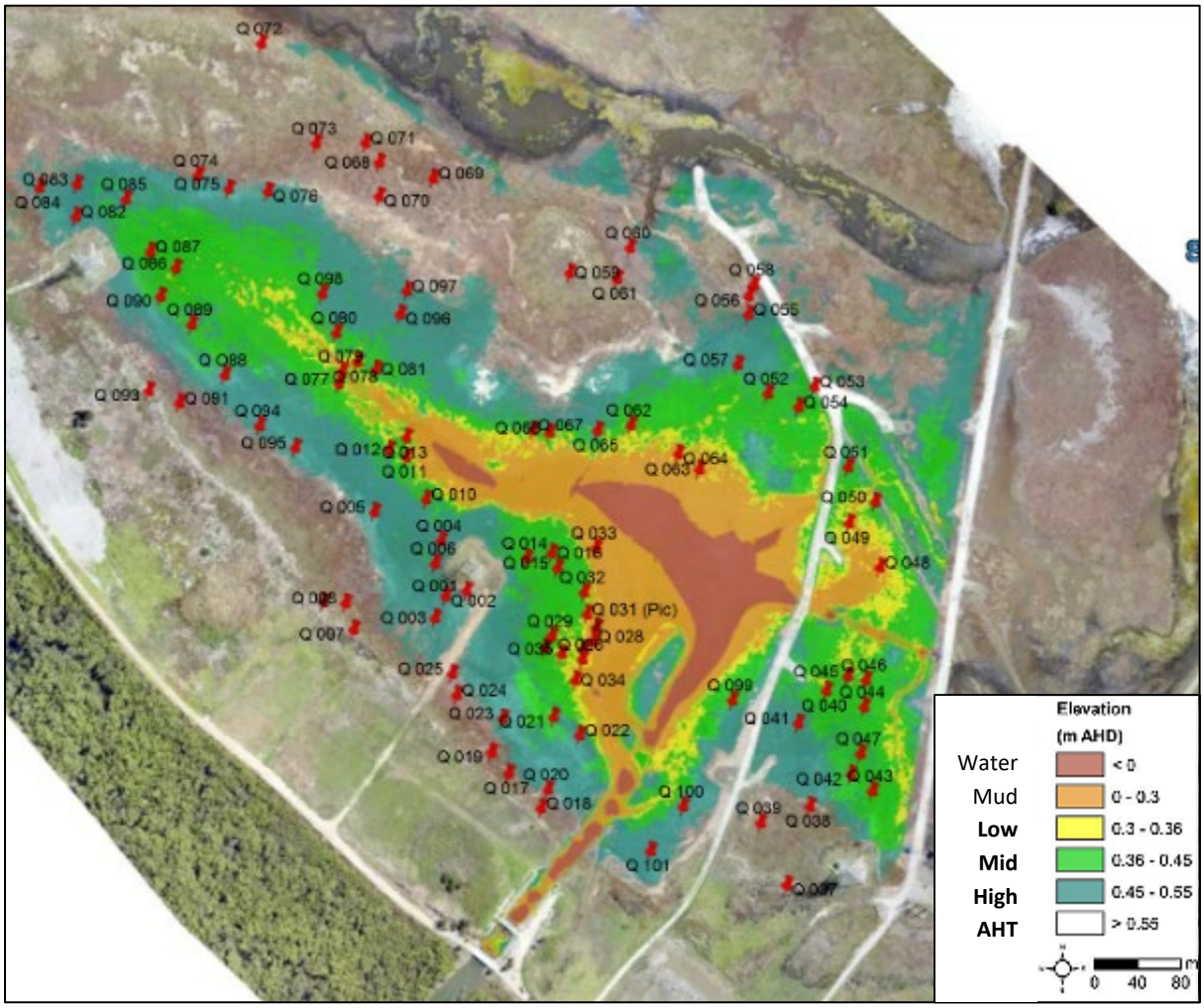

Figure 3: Placement of quadrats at Area E (red pins). DEM map sourced from A/Prof Will Glamore, UNSW.

Figure 4: The quadrat layout process used (A) and a quadrat used at Area E (B). Note the tape for determining placement and the pegs for placing the quadrat at subsequent times. Random numbers were selected from a random number table on each of the 100m and 50m tapes starting from a reference point and extending into the appropriate saltmarsh zone.

2.1.2 Infauna Sampling

6cm deep cores extracted by PVC pipes (6.2cm internal diameter) are being used for sampling macroinfauna (see Figure 5 for an overview). Once collected, the samples are placed in sample jars to be processed in the lab (Figure 6) which includes fixation, staining, washing and preservation before the infauna can be extracted and identified. In Area E, 10 cores are taken around the site in the low marsh and mudflat, the primary foraging areas for shorebirds, totalling 20 samples per sampling event (Figure 7). Samples are being taken 3 times per year starting on November 2017.

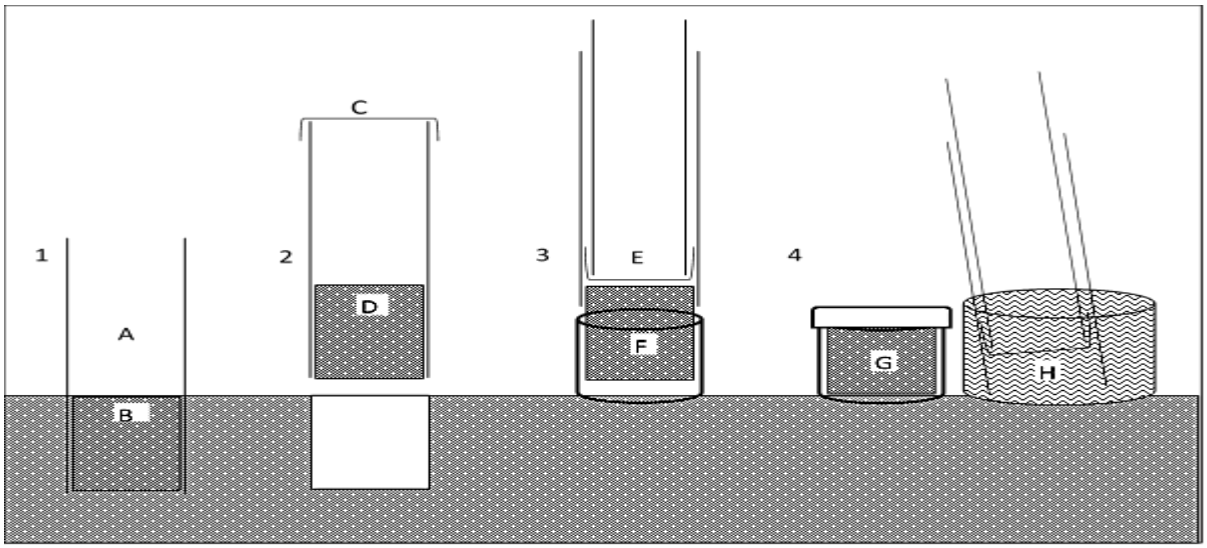

Figure 5: Procedure used for extracting sediment samples. 1 – A hollow PVC pipe (A) is inserted into the sediment (B), 2 – A fitted cap (C) is placed on the pipe and the sample (D) is extracted, 3 – The cap is removed and a plunger, consisting of a smaller pipe with attached cap (E) is used to push the sample into the sample jar (F), 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.

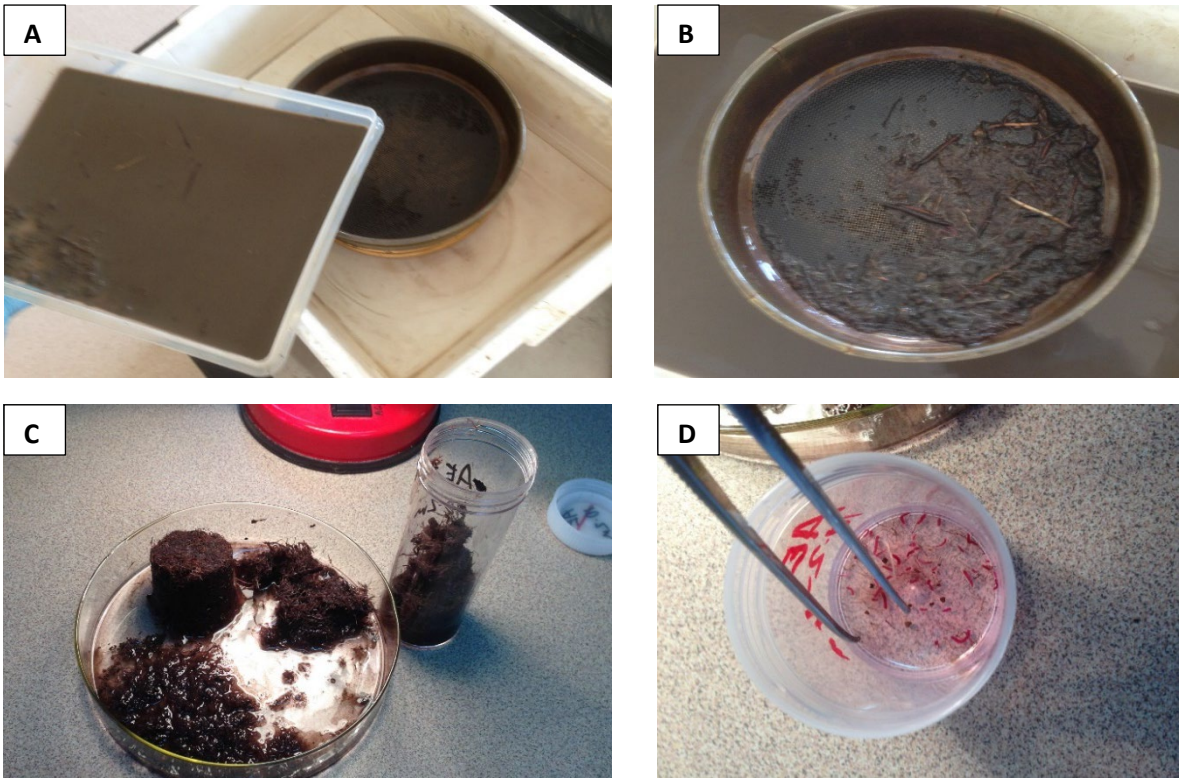

Figure 6: Processing of the infauna samples involving washing (A) and sieving (B) to remove the silt and clay, after which the infauna can be separated from the coarse matter and identified under a dissection microscope (C&D).

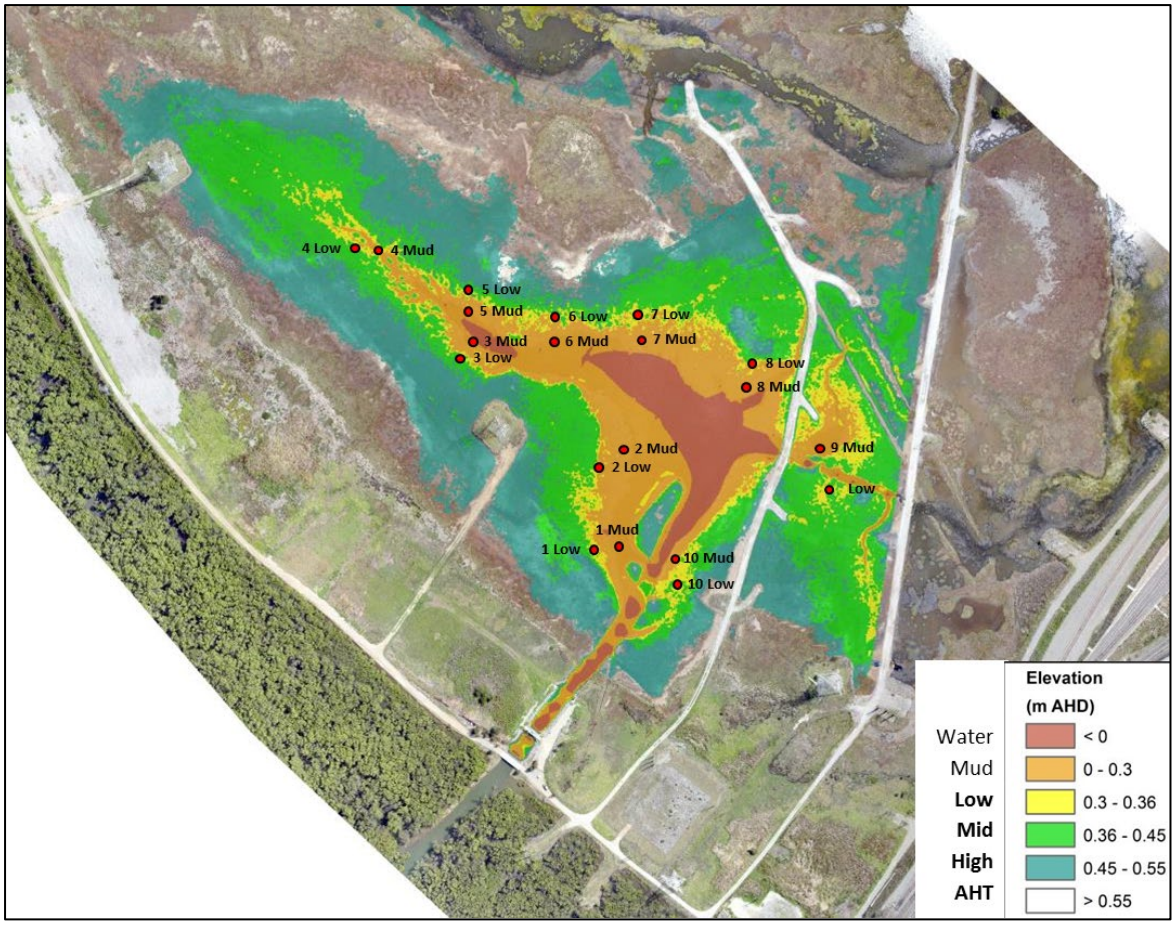

***Figure** 7:* Placement of quadrats at Area E (red pins). DEM map sourced from A/Prof Will Glamore, UNSW.

Results

2.1.3 Vegetation and crabholes

Since beginning surveys at Area E in November 2017, there has been an increase in saltmarsh cover and species richness (Figures 12 & 13). In June 2018 there was a significant increase in seedling counts (Figure 8C) which translated to the November 2018 increase in vegetation cover and species richness (Figure 8A & B). The most significant increase was in the low marsh zone, where there was previously no vegetation, and the mid marsh, where vegetation cover and species richness more than doubled from the July to November 2018 sampling events (Figure 8A & B). Dominant saltmarsh cover was *Sarcocornia quinqueflora* and *Suaeda australis* in the mid and low marsh respectively. *Sporobolus virginicus* was dominant Above the Highest Tide and present in small amounts down to the mid marsh (Figure 9A & B). *Sarcocornia quinqueflora* were the most abundant seedlings and the only ones present in the low marsh. No significant differences were observed in weed cover except for summer die back of perennial weeds in the AHT saltmarsh (Figure 8D). Comparisons between sites showed that while Area E saltmarsh cover is still significantly lower than the control and restoration sites, the plant species diversity has recovered quickly and is now comparable to the other sites (Figure 10A & B). Crabhole Flats and Hexham Marsh had similar weed cover to Area E while Cobbans Creek and Tomago Wetlands had slightly higher saltmarsh cover and lower species diversity overall (Figure 10C).

Crabhole counts at Area E decreased significantly from the November 2017 to the June 2018 sampling event but have stabilised from the June to November 2018 sampling events (Figure 11A). GoPro footage is currently being analysed to determine how representative the crabholes are of crab abundance. Comparing between sites, Hexham Marsh and Area E had the highest crabhole count in the low marsh with Cobbans Creek having the highest crabhole count in the high marsh (Figure 11B). There was little discernible relationship between vegetation and crabhole counts.

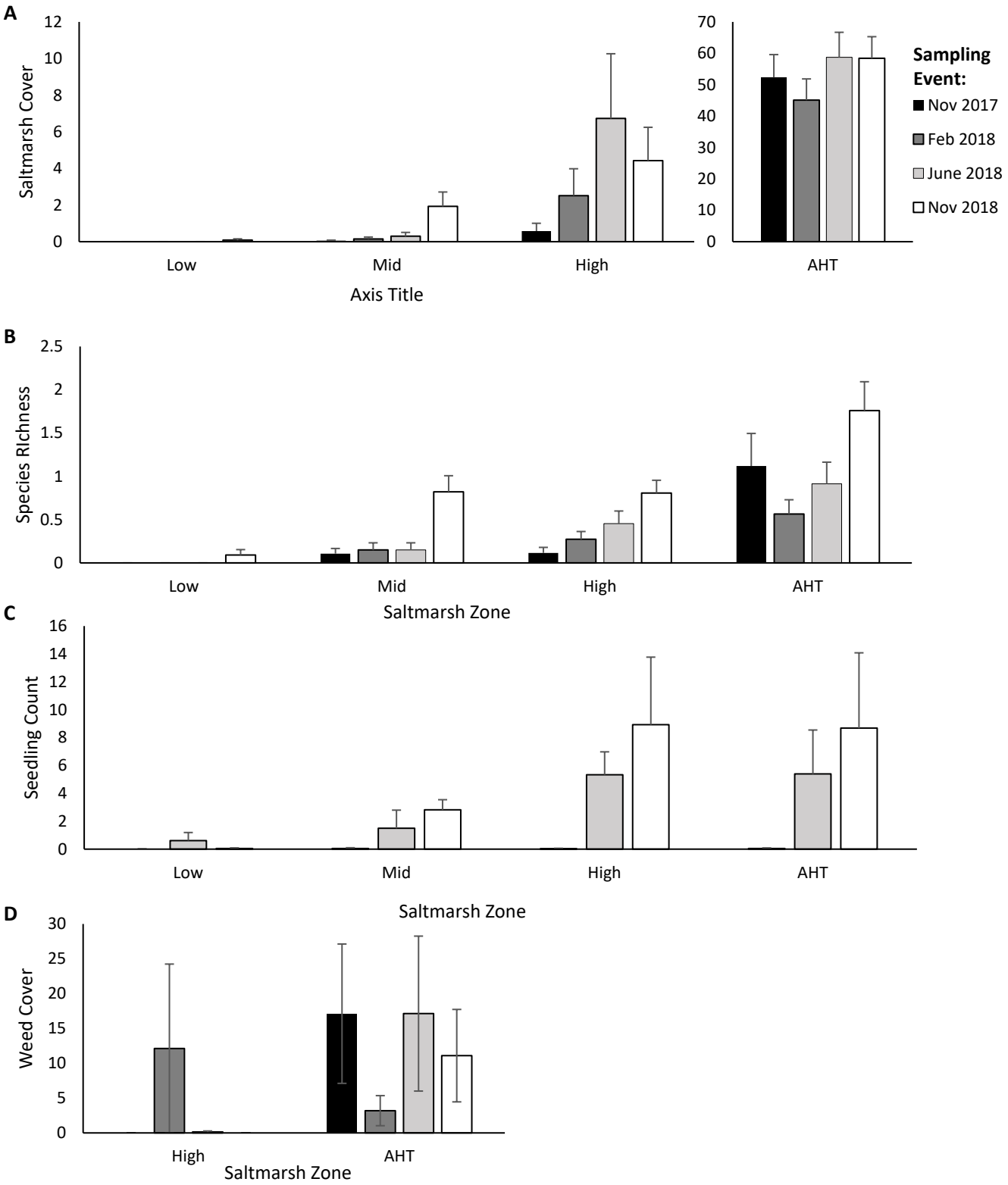

Figure 8: Changes in mean Vegetation Cover (**A**) Plant Species richness (**B**) Number of Seedlings (**C**) and Weed Cover (**D**) at Area E from November 2017 to November 2018 per m^2. Bars are mean ± standard error (se).
Measurements are from 25 quadrats for each of the saltmarsh zones on each sampling occasion (see Figure 2).

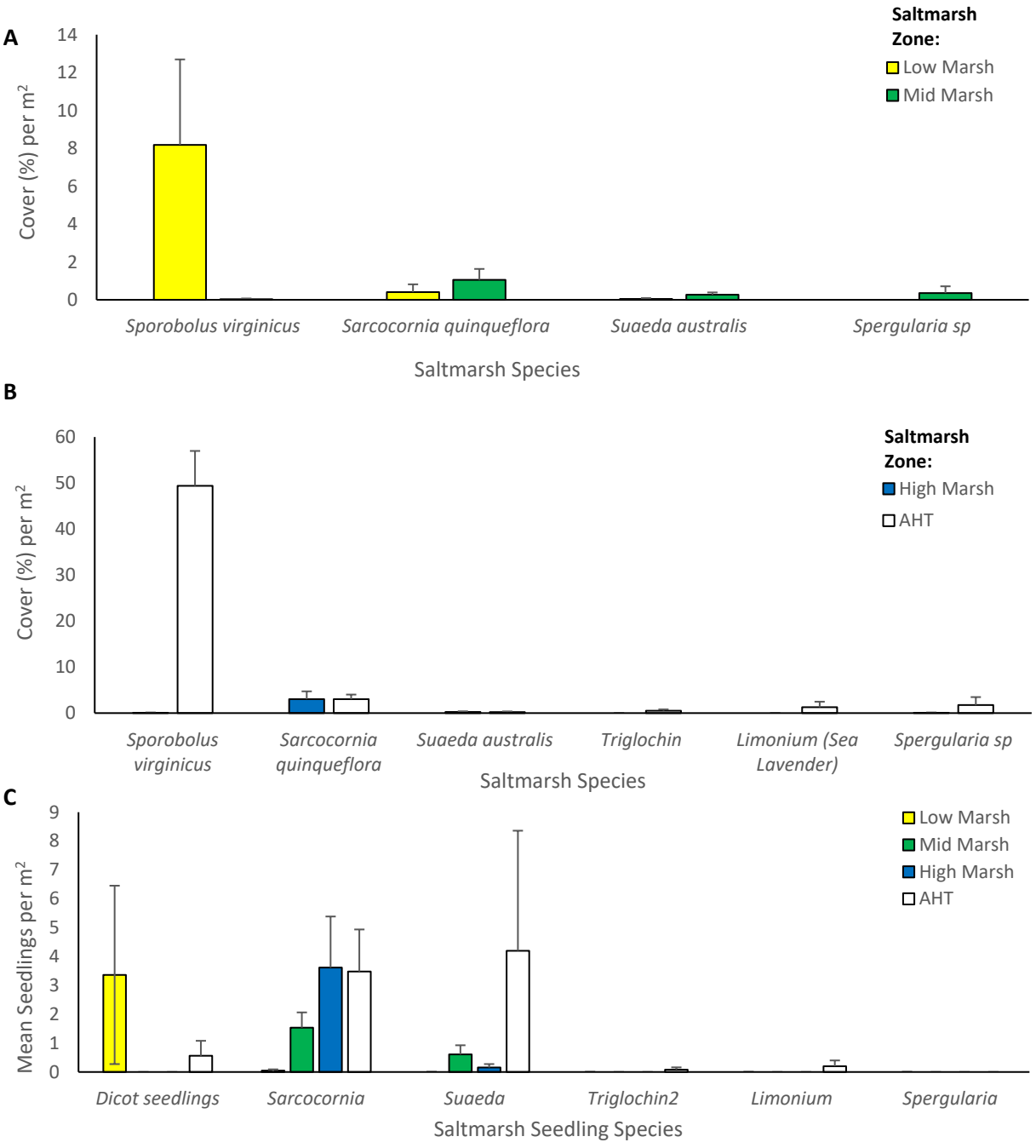

Figure 9: Mean vegetation cover (A & B) and seedling count (C) for each of the Area E saltmarsh species identified in the November 2018 sampling event. Bars are mean ± standard error (se). Measurements are from 25 quadrats for each of the saltmarsh zones (see Figure 2).

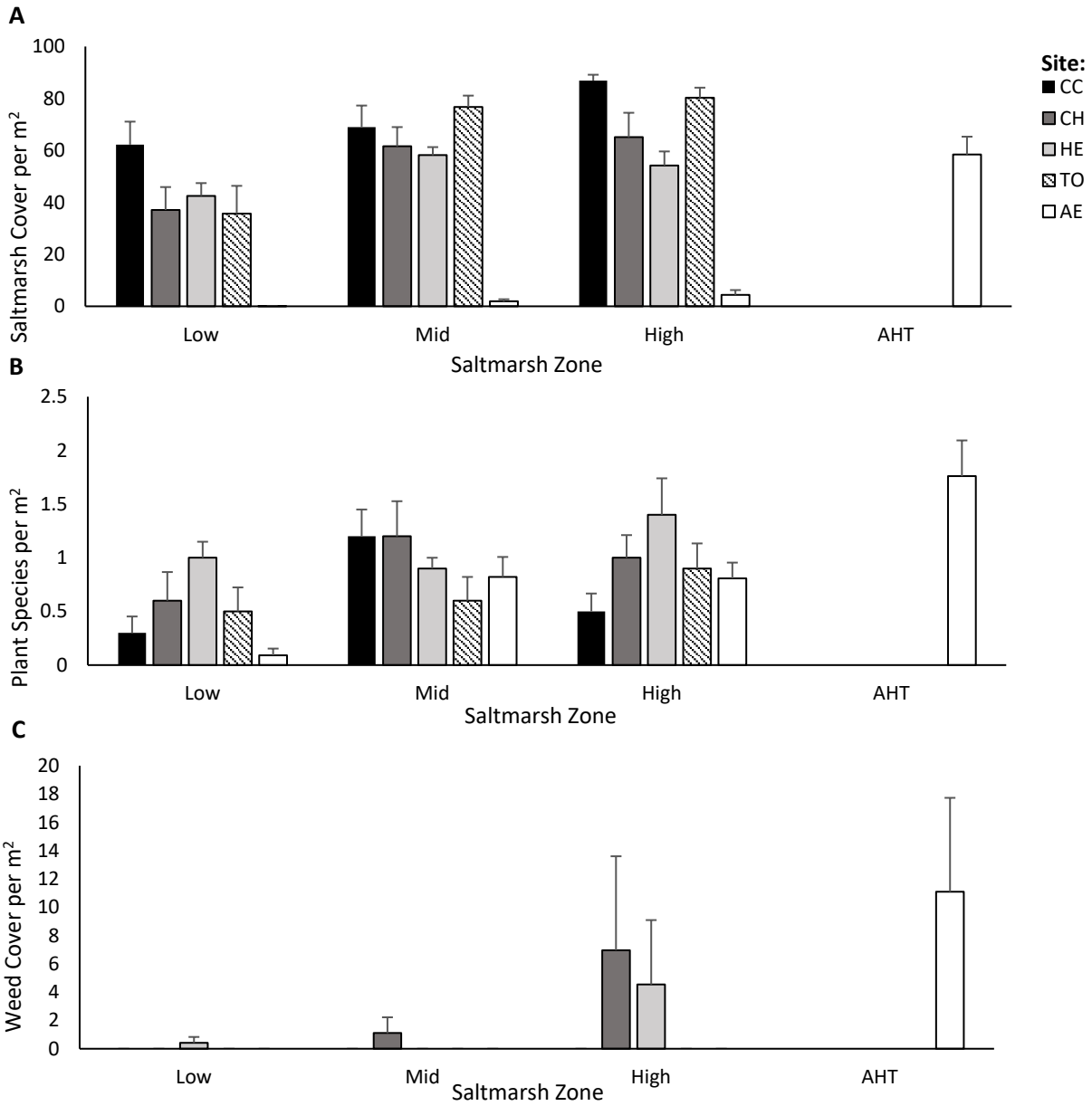

Figure 10: Comparisons for each saltmarsh zone of mean Saltmarsh Cover (**A**) Plant Species richness (**B**) and Weed Cover (**C**) For each of the sites Cobbans Creek (**CC**), Crabhole Flats (**CH**), Hexham Marsh (**HE**), Tomago Wetlands (**TO**) and Area E (**AE**), sampled in November 2018. Bars are mean ± standard error (se).
Note that the AHT zone was only sampled in AE (see 2.3 Sampling Strategy). Measurements are from 10 quadrats for each of the saltmarsh zones at CC, CH, HE, and TO and from 25 quadrats for each of the saltmarsh zones at AE (see Figure 2).

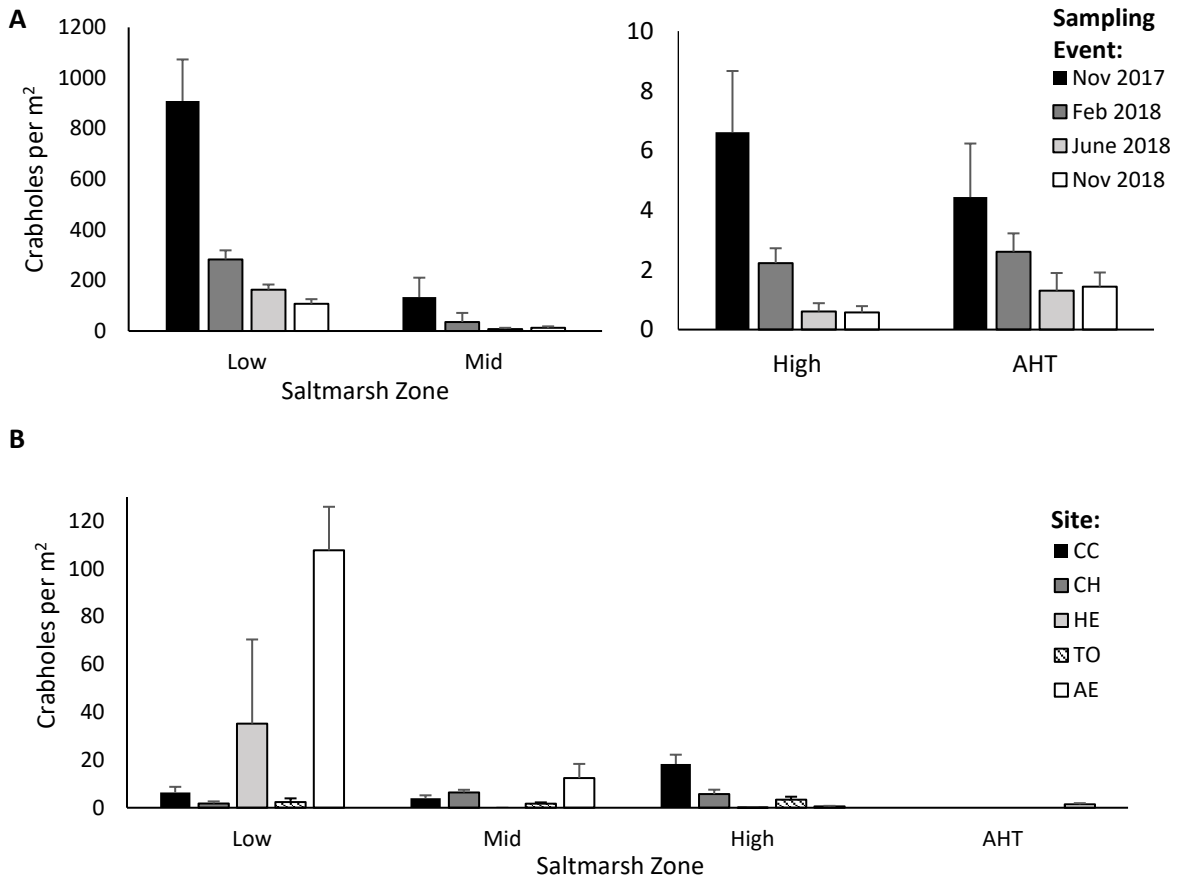

Figure 11: Mean crabhole count from February 2017 to November 2018 in Area E (**A**) and comparisons between the sites Cobbans Creek (**CC**), Crabhole Flats (**CH**), Hexham Marsh (**HE**), Tomago Wetlands (**TO**) and Area E (**AE**) for crabhole counts in each zone on November 2018 (**B**). Bars are mean ± standard error (se).
Note that the AHT zone was only sampled in AE (see 2.3 Sampling Strategy). Measurements are from 10 quadrats for each of the saltmarsh zones at CC, CH, HE, and TO and from 25 quadrats for each of the saltmarsh zones at AE (see Figure 2).

Figure 12: Examples of new plant growth at Area E in July 2018 with *Suaeda australis* seedlings (left) and young *Triglochin striata* (right). Note that new plant growth is concentrated around mangrove stumps.

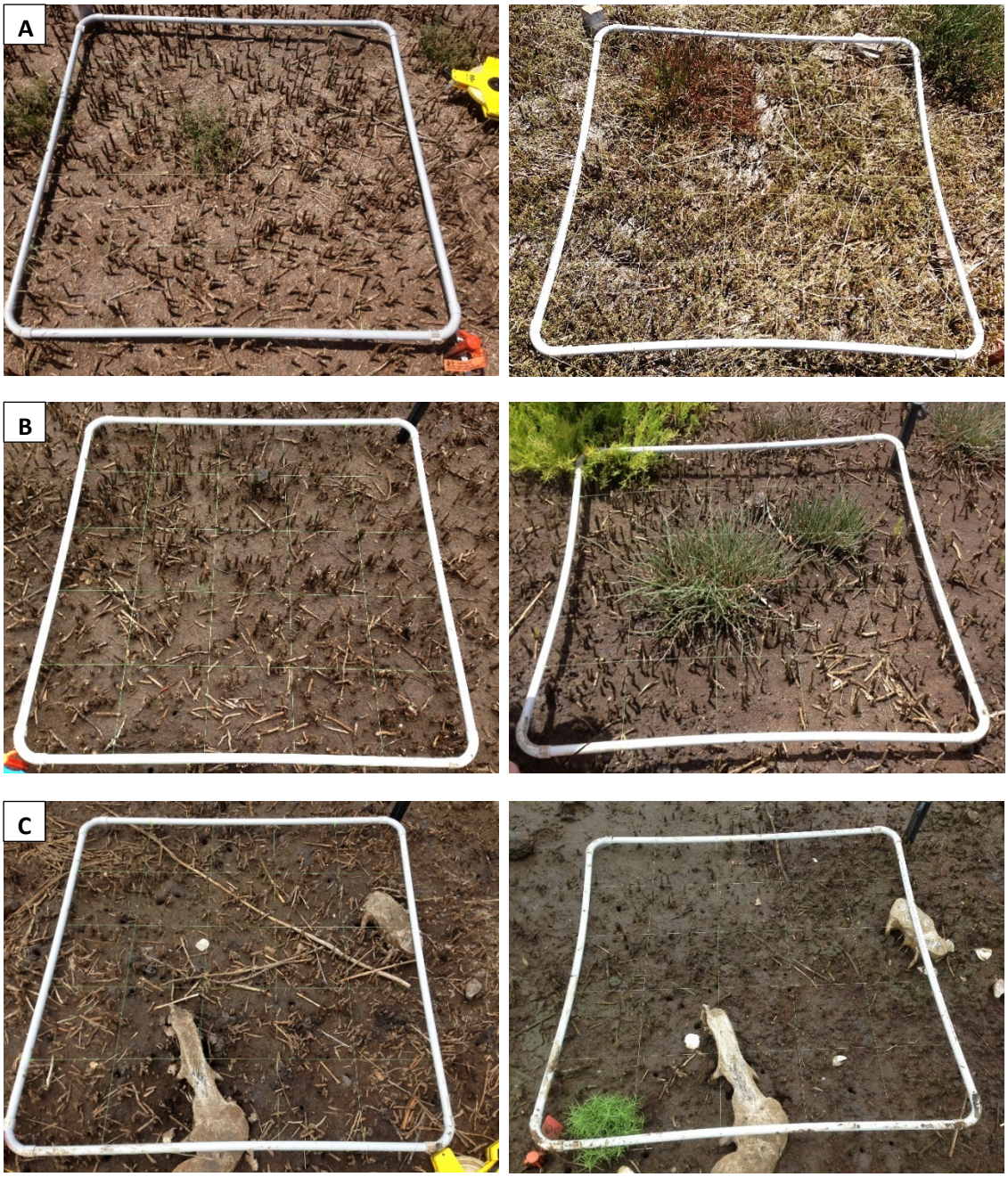

Figure 13: Examples of Area E quadrats where saltmarsh cover significantly increased from November 2017 (left) to November 2018 (right). Quadrats shown are (A) Quadrat 24 (high marsh), (B) Quadrat 50 (mid marsh), (C) Quadrat 80 (low marsh).

2.2 Macrofauna

At Area E, 10 types of macrofauna have been observed, identified to the family level where appropriate (Figure 14). From November 2017 to November 2018 there were significant changes in the abundances of various macrofauna at Area E (Figure 14). Most significantly, the 2018 abundance of bivalves (*Arthritica helmsi*) decreased to about 10% of the November 2017 abundance while amphipods and crabs in the edge marsh were absent (Figure 14B). Conversely, abundances of nereididae polychaetes (bristle worms) and oligochaetes (segmented worms) doubled.

The increase in nereididae polychaetes is promising for Area E given their importance in shorebird diets (Iwamatsu, Suzuki, & Sato, 2007). This may also reduce macroalgae blooms (Engelsen & Pihl, 2008) which negatively affect shorebird foraging (Green, Blumstein, & Fong, 2015). However, the reduction in bivalves and amphipods reduces the variety of foods available to the shorebirds. The decrease in bivalves may also allow for an increase in microalgae distribution and macroalgae growth (Page, Dugan, & Hubbard, 1992) potentially counteracting the positive effects of the polychaetes (Janousek, Currin, & Levin, 2007).

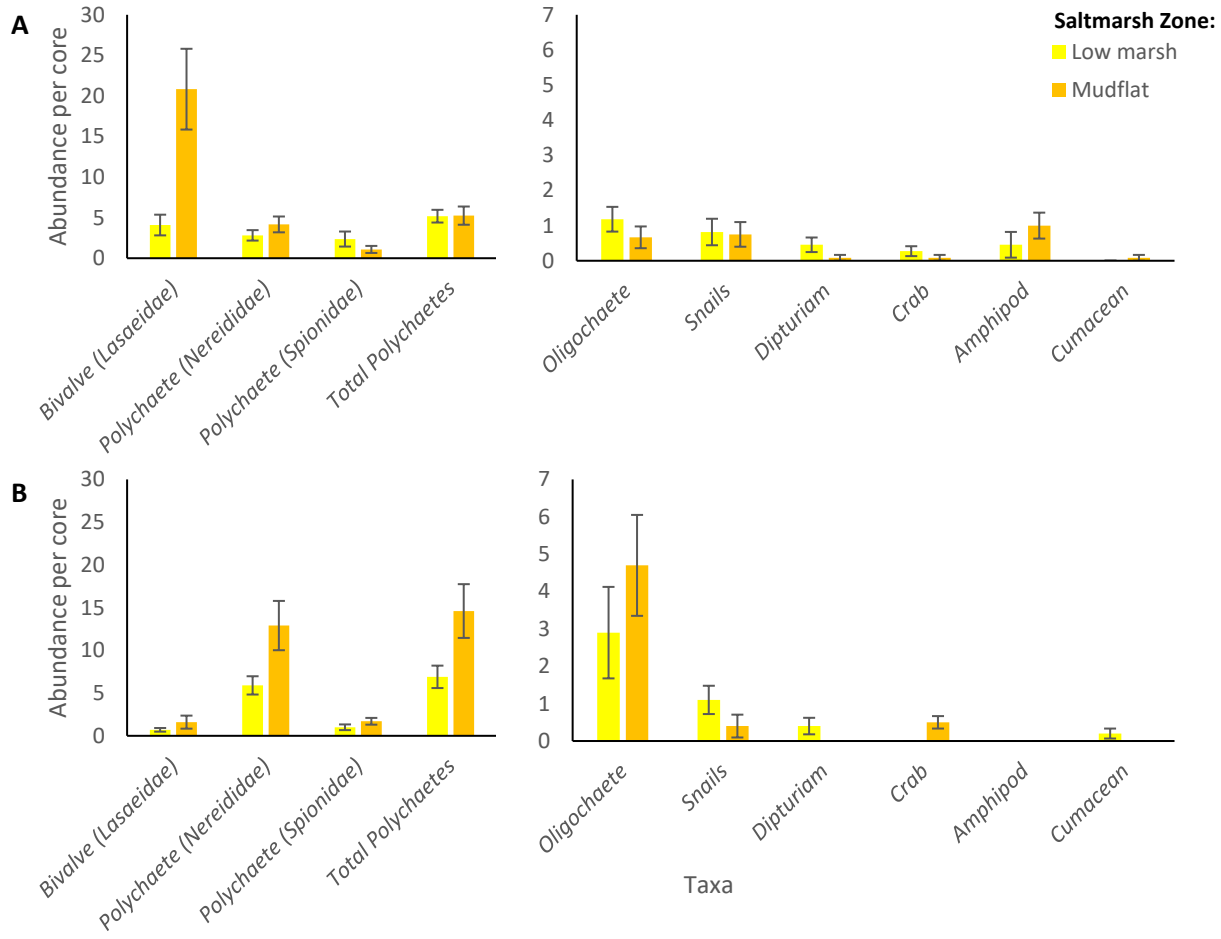

Figure 14: Mean abundance of the macrofauna taxa identified at Area E per core (181cm^3) between November 2017 (A) and November 2018 (B). Standard error (se) bars indicate where there are significant differences. Measurements are from 10 sediment cores for each of the saltmarsh zones

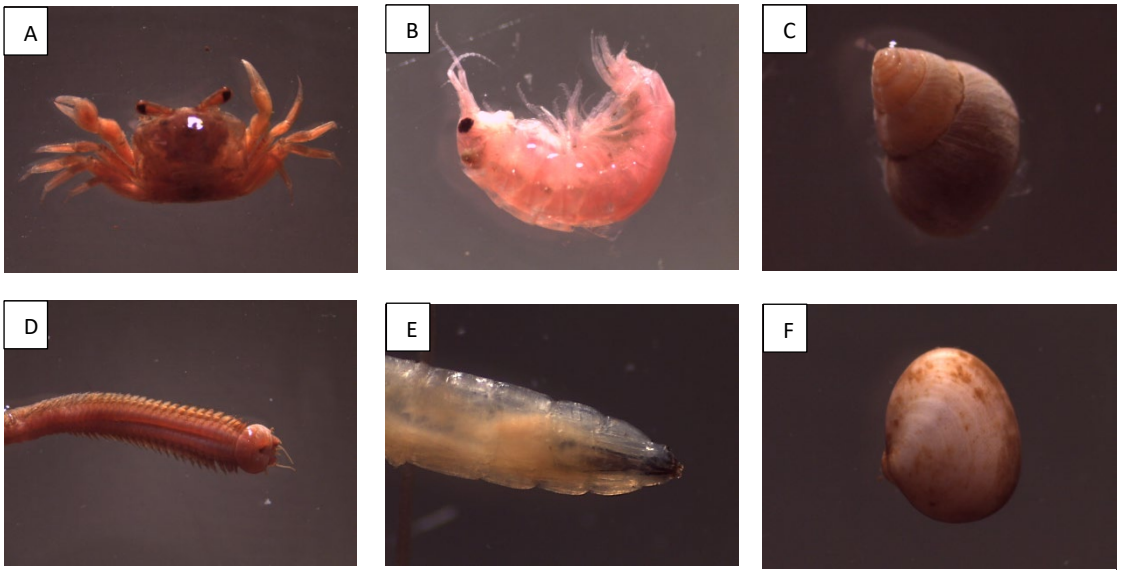

Figure 15: Pictures of macrofauna identified at Area E including crabs (A), amphipods (B), snails (C), polychaetes (D), diptera (E), and bivalves (F).

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Appendix E – NCIG Compensatory Habitat Management Mangrove Removal (CVA)

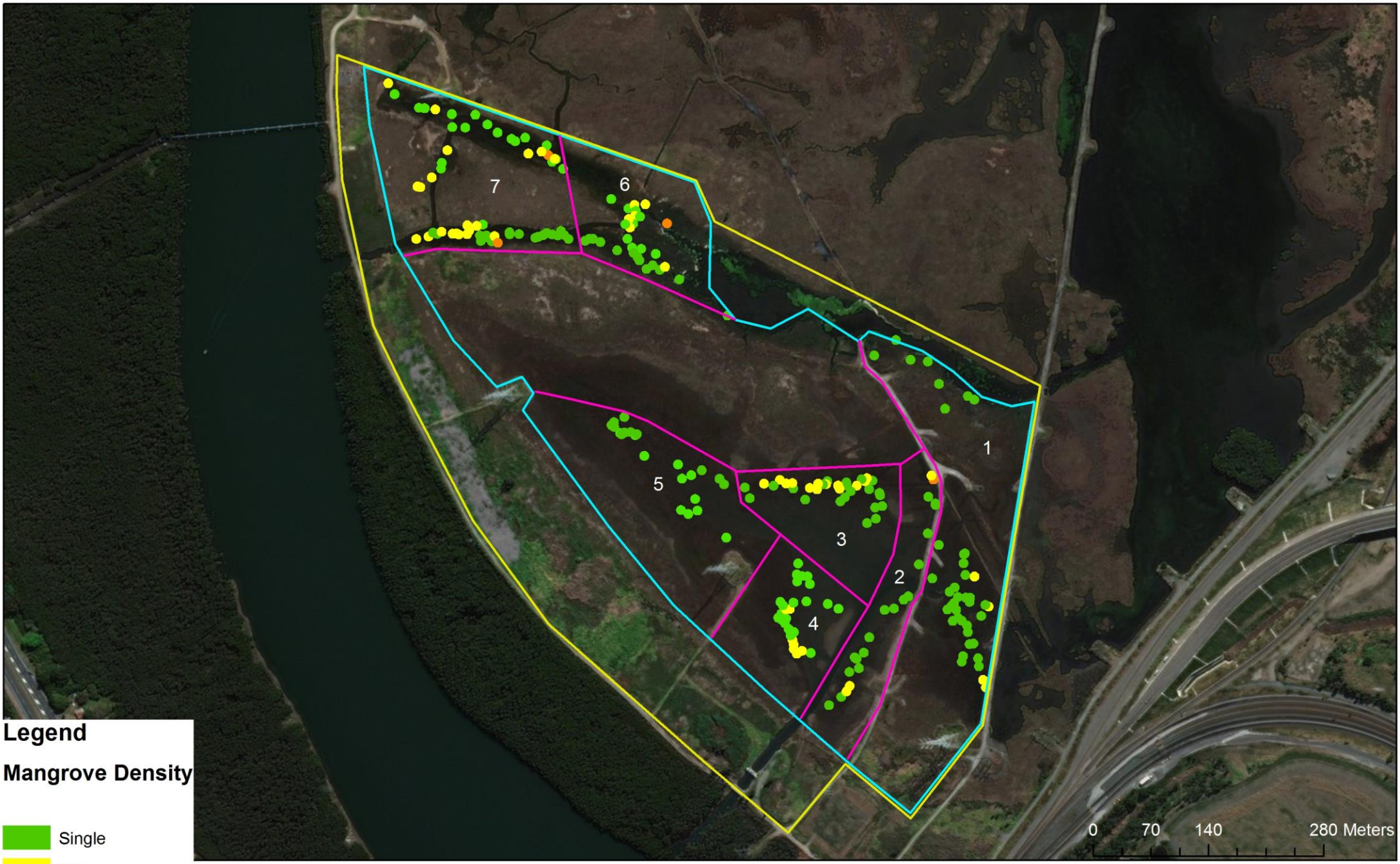
NCIG Compensatory Habitat Management

Area E Mangrove Removal

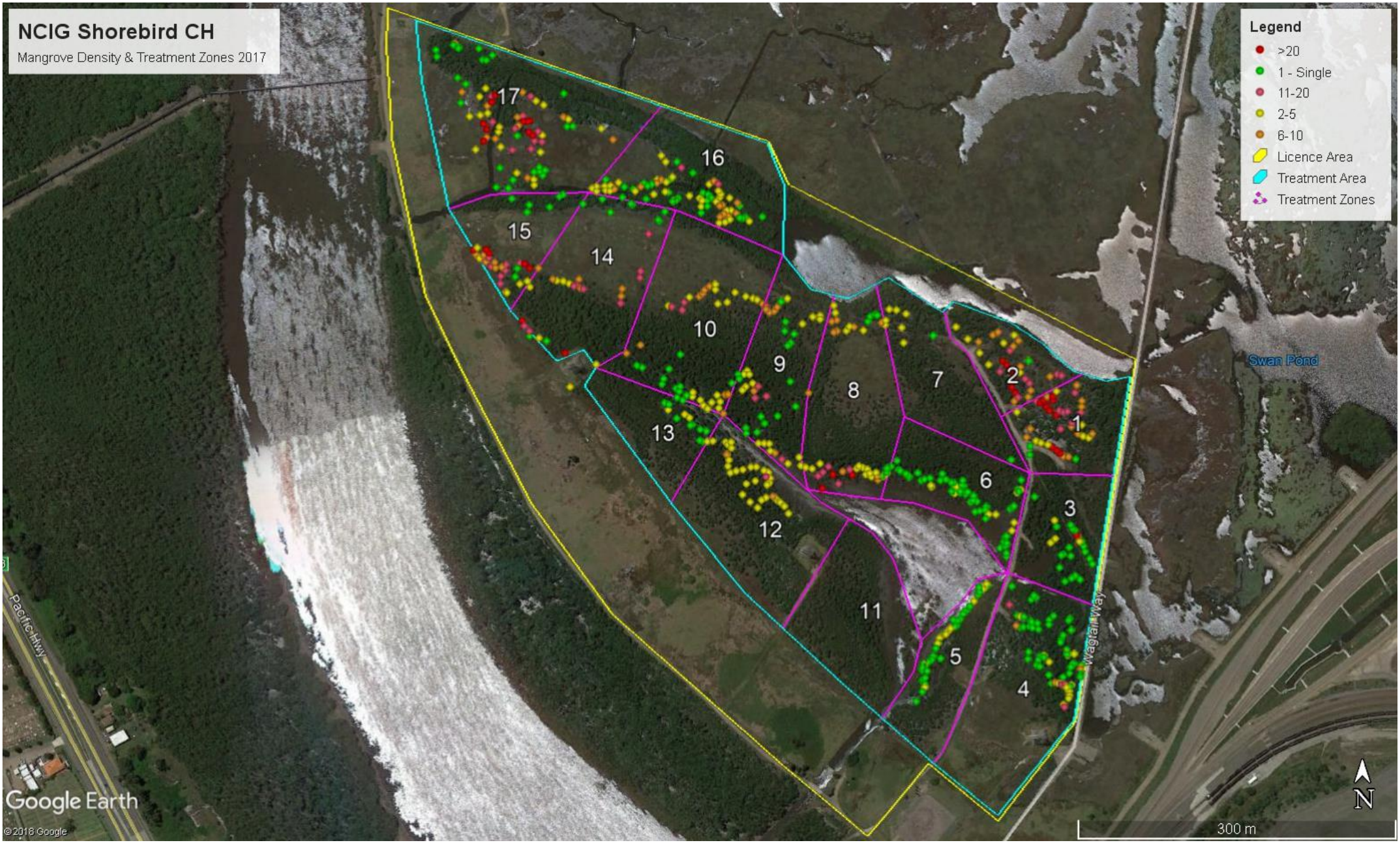
- Mangrove removal was undertaken within NCIG Shorebird Compensatory Habitat (Area E) during November 2018.
- Prior to removal mangrove distribution and density was mapped throughout the site, to inform the level of effort required for removal. Density mapping is attached, including comparison with 2017 results.
- Works were undertaken by CVA Community Engagement Teams over 5 days, removing and collecting over 2,000 mangrove seedlings and propagules.
- In addition to removal, all mangrove biomass was collected, sorted and counted, this information can be seen in the table below.
- 2018 Results show a reduction of approximately 13,000 mangrove seedlings/propagules/regrowth collected compared to 2017 results.
- Zones established in 2017 have been consolidated in 2018 to cover broader areas, as a result of reduction in mangrove density, as detailed in table below and maps attached.

NCIG Mangrove Removal Data 2018

Zones 2017	Consolidated Zones 2018	Seedlings	Propagules	Regrowth	Total
1 2 3 4	1	86	33	0	119
5 6	2 3	70 30	304 298	0 0	374 328
7 8 9 10	-	No mangroves present			0
11 12 13	4 5	54 25	505 179	0 0	559 204
14 15	-	No mangroves present			0
16 17	6 7	58 104	230 84	0 0	288 188
	Total	**427**	**1,633**	**0**	**2,060**



NCIG Shorebird Compenstatory Habitat
Mangrove Treatment Zones 2018


NCIG Shorebird CH
Mangrove Density & Treatment Zones 2017
Legend
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1 - Single
11-20
2-5
6-10
Licence Area
Treatment Area
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6
3
12
11
5
4
Swan Pond
Wagar Way
Pacific Hwy
Google Earth
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Green and Golden Bell Frog Research and Monitoring Program on Ash Island, Hunter Estuary.

Report for Jan-June 2019 (2019 Summer/Autumn Season)

Prepared for Newcastle Coal Infrastructure Group

Prepared: Dean Lenga, Assoc Prof. John Clulow

Reviewed: Prof. Michael Mahony, Dr Simon Clulow

August, 2019

Executive Summary

Key findings:

- Surveys for Green and Golden Bell Frogs (*Litoria aurea*) were conducted during Jan – April, 2019 across the NCIG CHEMP wetlands.
- 203 visual GGBF observations were made and 98 individual captures occurred (35 juveniles, 24 adult females, 39 adults males). Highest counts were in Stages, 4, 5 and 7 indicating relative importance of these stages for GGBF within the NCIG CHEMP wetlands.
- No evidence of breeding activity or breeding events was found during the Jan-April, 2019 survey period. This is attributed in part to low (below average) rainfall in the 2018/2019 summer period.
- It was noted that breeding at two waterbodies was confirmed during Sept-December, 2018 in NCIG CHEMP wetlands. Nevertheless, net breeding and recruitment activity across 2018/2019 was considered low in the NCIG CHEMP system, notwithstanding low rainfall effects, by comparison to other areas of the Ash Island-Kooragang wetlands systems.
- A management action of vegetation clearance (physical macrophyte removal) to reduce vegetation density and increase open water in waterbodies was undertaken by NCIG under the NCIG GGBF CHEMP Management Action Plan. Initial monitoring indicated re-occupation of disturbed ponds by GGBF post-clearance, and possible evidence of site fidelity by GGBF to disturbed ponds. Ongoing monitoring is required to determine if breeding events are initiated by this action.
- Ongoing research and monitoring is required to understand population trends and drivers of population recruitment and impacts of management actions aimed at supporting population persistence.

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 April, 2019. The surveys were undertaken by members of the University of Newcastle (Conservation Biology Research Group) as a part of the Compensatory Habitat and Ecological Management Program (CHEMP) of NCIG on Ash Island.

Survey Periods and Techniques

Two rounds of surveys (Table 3) were undertaken involving most of the waterbodies (ponds) in Stages 1-7 of the NCIG CHEMP constructed habitats in each round during Jan-April, 2019: Round 3 (Jan-Feb), Round 4 (March-April). The first two rounds of surveys for the 2018/2019 summer were undertaken in Sept-Oct, 2018 (Round 1) and Nov-Dec, 2018 (Round 2). These were reported on in a separate report (Lenga & Clulow/Univ Newcastle, Feb, 2019) and the two reports should be considered together. Surveys were undertaken for the presence of GGBF tadpoles and metamorphosing froglets and juvenile and adult GGBF's, as well as the presence of the invasive fish species, *Gambusia holbrooki*.

Wetlands were surveyed using standard methods for surveys of Green and Golden Bell frogs on Ash/Kooragang Islands over multiple seasons. Techniques are described below:

- Visual Encounter Surveys (VES): timed counts, adjusted for observer number, of GGBF in and around wetland habitats used to generate estimates of relative population densities.
- Capture Mark Release Surveys in GGBF occupied waterbodies:
    - Recording gender, reproductive status, weight, snout-vent length.
    - Individual adult frogs are marked with microchips.
    - Estimating population sizes at individual wetlands & across the whole landscape using mark-release-recapture data, monitoring development and growth of individuals, and the movement of individuals between wetlands.
- Fyke netting of waterbodies:
    - This allows monitoring of the presence of tadpoles, fish and invertebrates in each wetland.
    - Data on 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* is also used as an indicator of predatory pressure and impacts on GGBF in the studies wetlands.
- Habitat data collection:
    - Regular surveys are conducted of the state of the habitat in each of the monitored wetlands including: vegetation composition and percentage cover, water quality, water body size and water depth.
- Classification of developmental stages and sex of frogs:

Frogs less than 45 mm (snout-vent length) were classified as a juvenile (unsexed); > 45mm SLV but without nuptial pads during breeding season were classified as juvenile female; any frogs with nuptial pads were recognised as adult males; frogs > 60 mm (or clearly gravid) without nuptial pads were classed as adult females.

Weather data were accessed from Bureau of Meteorology, Williamstown Weather Station, for period January to June, 2019.

Habitat Management Action (Habitat Disturbance in Selected Waterbodies)

Selected waterbodies (ponds) were chosen for removal of vegetation as per the NCIG CHEMP Management Plan (2018) which establishes ongoing management actions within the compensatory habitats. The Plan recommends 60% macrophyte area cover in waterbodies reduction to 40% cover by physical removal as a routine, ongoing management action (CHEMP, 2018, Section 13.4).

The purpose of vegetation reduction or removal from time to time in GGBF habitats is to decrease the amount of emergent vegetation overgrowth and increase the amount of open water. Increasing the open water to emergent vegetation ratio within ponds effectively acts as a habitat disturbance mechanism that reduces the habitat to an earlier succession, post-disturbance phase of the pond hydro cycle. This is thought to encourage breeding events by

GGBF under favourable conditions such as rainfall events that may occur around the time of the disturbance (although there is a need for ongoing research to confirm this hypothesis).

For the Jan-June 2019 period, advantage was taken of an extended dry period to access selected ponds with extensive vegetation overgrowth within the waterbody. Thirteen ponds with complete or nearly complete vegetation overgrowth (no open water if ponds were wet, or no clear space in the centre if ponds were dry) were cleared of approximately 70% of their emergent vegetation between 11/3 and 13/3/2019 in the CHEMP habitats (Table 5). Vegetation clearance followed diurnal and nocturnal pre-clearance surveys and the removal of any captured GGBF to an undisturbed permanent pond in the nearest adjacent CHEMP stage waterbody (Table 7). Post-vegetation removal, disturbed ponds were surveyed on up to two occasions within 4 weeks (Table 7) to determine whether relocated frogs were returning to the disturbed ponds (as evidence of site fidelity) and whether new frogs were occupying the disturbed ponds. Captured GGBF were scanned for PIT tags, and if not present, PIT tags were implanted to monitor future captures and movements.

Surveys of the disturbed habitats, and adjacent undisturbed CHEMP ponds, will continue into the 2019/2020 season as a part of the NCIG CHEMP Research and Monitoring Program. This is important as there is a need to understand whether the habitat disturbance/vegetation clearance actions under the CHEMP Management Plan are having the intended outcomes (particularly whether such habitat disturbances are associated with the initiation of breeding activity).

Results

(1) Temperature, rainfall, pond volume (hydration) and water quality (Jan – June, 2019)

The average daily air temperatures for the month of January to June in 2019 were higher than the long-term (77 years) average (Table 1, Fig 1). These elevated temperatures followed on from above average temperatures at in the early summer period at the end of 2018 (Lenga and Clulow, 2019).

Field surveys were conducted in the period January to April, 2019. Other than the month of March, the late summer-autumn period of 2019 during which surveys were conducted was relatively dry with low levels of rainfall compared to the long-term average rainfall levels (Williamtown, BOM). Rainfall was well below long-term averages for the months of Jan, Feb and April, 2019, and only above average for the month of March, 2019; this was due to one pulse rainfall event (Fig 2, Table 1). The low total rainfall for the Jan-April period followed on from similarly dry months (Nov-Dec) at the end of 2018 (Lenga and Clulow, 2019). Taken together, the elevated air temperatures and below average rainfall from November, 2018 to April 2019 contributed to extensive drying of waterbodies (complete drying of most ephemeral ponds) across the Ash Island landscape (Table 2) and may have contributed to the absence of any confirmed breeding events during Jan – June, 2019 (see below). In this respect, the heavy rainfall pulse in March, 2019 (approximately 60 mm, around 17th March; Fig 2), which in previous years has been of sufficient intensity to be associated with breeding events (e.g. Oct-Nov, 2018; Lenga and Clulow, 2019) was not associated with a detectable breeding event in 2019.

Despite low rainfall leading to pond-drying events, salinities in most ponds with water remained well below thresholds that would be problematic for GGBF occupation and breeding with most below 1 ppt, and a relatively small number in the range of 1-4 ppt (Table 2). Ponds with elevated salinity were

generally ephemeral ponds that would be expected to concentrate salts as drying proceeded. Similarly, although pH values tended to acidic in a range of ponds (pH 4.67 – 6.72), these values were not indicative of major acid soil intrusion, and not likely to be problematic for GGBF occupation. The proportion of ponds that were completely dry over the Jan-April survey period are indicated as ponds with a maximum water depth of 0 mm in Table 2. These ponds were principally ephemeral ponds expected to dry over during low rainfall hydroperiods.

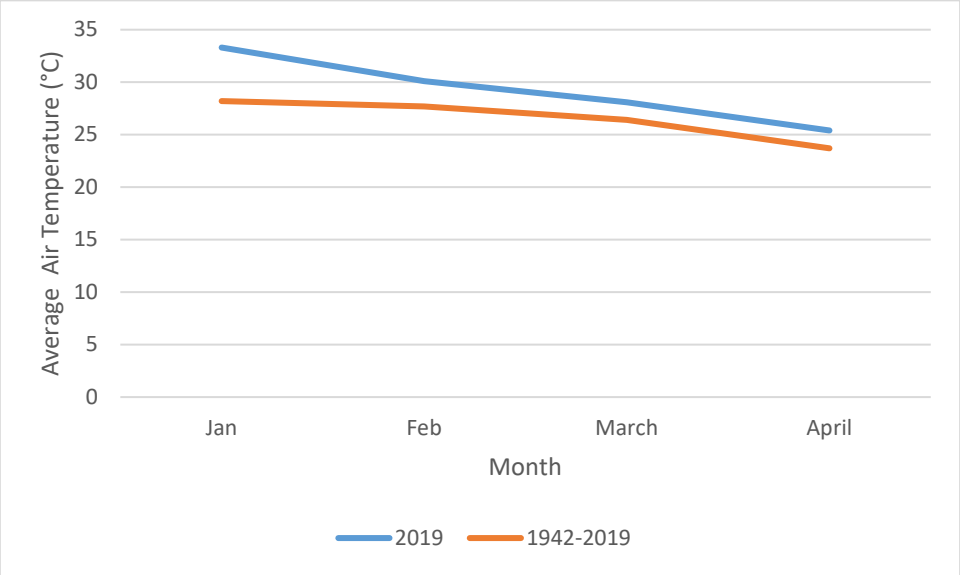


Figure 1. Average monthly air temperatures January to April 2019 and long-term average air temperatures for 1942-2019 from the Williamstown weather station (061078).

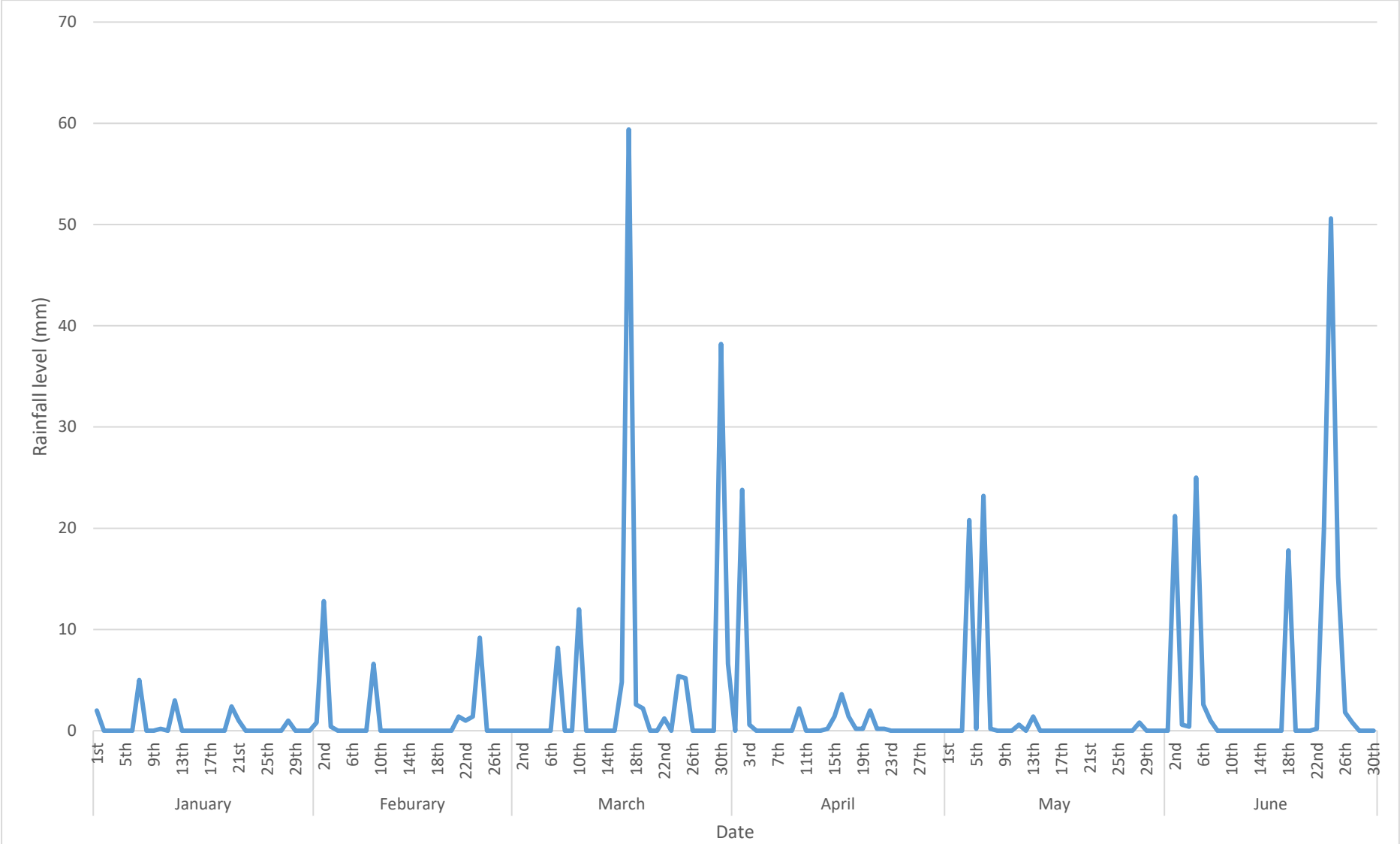


Figure 2. Daily rainfall (mm) for the months of January to June 2019 from the Williamstown weather station (061078).

Table 1. The total amount of rainfall (mm) for months January to June 2019 compared to the average long-term rainfall (mm) for the months January to June from 1942 to 2019. Recorded from the Williamstown weather station (061078).

	Jan	Feb	Mar	Apr	May	June
Total Rainfall in 2018 (mm)	14.6	33.6	145.8	36	47.2	157.2
Average Rainfall for 1942-2018 (mm)	98.7	117	120.9	110.6	108.7	125.2

(2) GGBF records during surveys (Rounds 3 and 4) - January to April, 2019.

GGBF were recorded in 11 of the 41 (about 25%) of constructed wetlands in the period January to April. Wetlands 4.9, 7.1. 7.2 & 7.3 had the highest number of total VES counts with 45, 37, 33 & 43 individuals respectively. These are ephemeral water bodies, other than pond 7.1. Despite classification as ephemeral wetlands, ponds 7.2 and 7.3 were only dry once (during March) during the survey period.

There were a total of 203 GGBF VES observations and 98 GGBF captures in surveys during the months of January to April (Rounds 3 and 4 of the 2018/2019 surveys). Of the 98 captures, there were:

- 12 Juvenile (unsexed)
- 23 Juvenile Females
- 24 Adult Females
- 39 Adult Males

All GGBF records for the spring/summer surveys of 2018/2019 are presented in Tables 3 and 4. In addition, the presence of *Gambusia* are shown in the same tables. There were a predominance of records in Stages 4, 5 and 7 suggesting these were functioning as the most active GGBF habitats during 2018/19 season.

There were no observed breeding activity and no confirmed breeding events during the Jan – April 2019 survey periods. This contrasted with confirmed breeding in two waterbodies (tadpoles confirmed) and calling males observed in 6 waterbodies during Sept-December, 2018 (Lenga and Clulow, Feb, 2019). Those breeding events were associated with high rainfall in Oct-Nov, 2018. Nevertheless, taken across the whole year (2018/2019), it should be recognised that breeding activity was not high across the system (see Discussion).

(3) Macrophyte clearance (successional disturbance) of water bodies and GGBF relocation and post-clearance movement between waterbodies.

The 13 waterbodies cleared of macrophytes are listed in Table 5; pre- and post-clearing GGBF counts at those ponds are shown in Table 6, and details of individual frog pre-clearance relocations and post-clearance movements are shown in Table 7. Pre- and post-clearance photo images are shown in Fig 3. Clearance events took place on 11-13/3/19 and post-clearance surveys took place during a period of 1-4 weeks post-disturbance.

Post-disturbance surveys found adult GGBF at cleared ponds in surveys 1-2 months post the disturbance events (Table 6). For Stage 7, counts declined by about 30% in post-disturbance surveys (Table 6). About half of the adult GGBF removed from ponds pre-clearance (especially Stage 7) returned to cleared ponds after within 1 – 2 months of pond clearing (Table 7), suggesting that some

site fidelity behaviour may have been exhibited by the frogs. The post-disturbance movement of frogs and counts may have been associated with the rainfall event in March and early April. Taken together, the data indicated that ponds with a clearance of around 70-80% of macrophytes, and which were occupied by GGBF pre-clearance, experienced post-clearance counts that were not substantially below pre-disturbance numbers. The detection of about 50% of pre-clearance frogs at the same pond post-clearance suggests that retention of frogs post-disturbance may be substantially due to site fidelity (behavioural drive to return to the same pond after relocation). This suggests that pond disturbance through macrophyte removal is a management action that may not negatively impact GGBF numbers in the short term (as well as potentially deliver long-term population benefits), although this needs to be confirmed by further intensive monitoring, and is an open research question.

Discussion

2018/2019 Season: Low rainfall, elevated temperatures and low breeding activity

There were only confirmed breeding events at two waterbodies (by the presence of tadpoles or metamorphs) during the 2018/2019 breeding season (September – April). These were in wetlands 3.1 and 5.2 in Nov/December (tadpoles detected).

No breeding activity (including calling) was detected in surveys in Jan-April. The January to April period of the 2018/2019 breeding season was characterised by below average rainfall except in March. This followed below average rainfall in the late spring (November) and early summer (December). Many of the ephemeral wetlands had dried during this period, and the continued dry conditions in January and February meant that ephemeral wetlands remained dry, and permanent wetlands were reduced in size. A contributing factor to drying wetlands was also air temperature which Jan-April was also slightly higher than long term (77 year) averages.

The prolonged period of low rainfall in the late spring and summer months is most likely a major contributing factor to the absence of recorded breeding activity in this period. The four wetlands with the highest counts of GGBF, one (7.1) is a permanent wetlands and the other three (4.9, 7.2 & 7.3) have historically retained water through dry periods. These latter three wetlands could reasonably be classified as semi-permanent. Nevertheless, these wetlands had dried by early March due to the absence of rainfall. They were recharged by rainfall in mid-March (16th and 17th) and they retained water through to April. There was no evidence that the rainfall in March 2019 resulted in breeding in these wetlands. Such early autumn rainfall events have been associated with breeding events in previous years in the NCIG CHEMP wetlands. We postulate that the rainfall event (about 60 mm) in mid-March was not sufficient to trigger breeding in the GGBF as a result of the accumulated effects of low rainfall and drying in the system over previous months.

Vegetation Clearance: Management Action (assessment to date)

The vegetation clearance undertaken with the physical removal of macrophytes in March 2019 was the first such activity undertaken to reduce macrophyte cover and increase open water towards the 30 – 60 % target under the CHEMP Management Plan (Section 13.1; CHEMP Management Plan, 2018). Resources from the Research and Monitoring program were committed to monitoring the pre-clearance removal of GGBF from the affected waterbodies, and to post-clearance monitoring at the same waterbodies until April. This provided valuable data on the persistence of GGBF at the disturbed ponds after the disturbance event, and further data indicating that a significant proportion of

relocated frogs appeared to have returned to the source waterbody, possibly indicating a site fidelity behaviour (although more work would be required to test this hypothesis).

It remains to be determined (ongoing research required as a component of the Research and Monitoring Program) whether the disturbance of waterbodies through the reduction in macrophyte overgrowth and the increase in open water results in increased breeding activity and GGBF population densities through the system. This is an important question to investigate given the trend in lower breeding activity (relative to other parts of the Ash Island-Kooragang system; see McHenry et al., 2019) and population densities that seems to be emerging following the completion of the CHEMP habitat construction and the cessation of the GGBF Reintroduction Program (cessation of the release of captive-bred bell frog tadpoles and metamorphs into the system).

Ongoing Research and Monitoring Questions:

(1)Trend in NCIG CHEMP breeding activity and population trends in comparison to other Ash Island/Kooragang Sites.

There is some indication from the data emerging in Island-wide surveys of GGBF breeding activity and population densities that the breeding activity and population densities in the "Northern" section of the Island complex (containing NCIG CHEMP and National Park wetlands) is lower than in other components of the system including BHP CHEMP wetlands ("Central Section") and NCIG/PWCS/HDC tenures in the "Southern Section" of the system (McHenry et al, 2019).

Data for this can be seen in lower GGBF survey "sensitivity" scores (measures of rates of GGBF encounters during surveys – a loose, but not unqualified, proxy for estimates of population density around waterbodies) and total frog counts – see Tables 3.1.2; 3.9.3 (McHenry et al, 2019) and in lower frequency of confirmed breeding and recruitment activity (Fig 3.6.1; McHenry et al, 2019).

An ongoing aspect (and key question) of the research and monitoring of the GGBF population in the NCIG CHEMP wetlands is to understand (i) whether the population is stable and in equilibrium or whether it could indicate a trend towards declining GGBF population in that component of the system (ii) to investigate means and mechanisms that might be employed in the system to encourage breeding activity and increasing population densities (such as through habitat disturbance and resetting of succession in waterbodies, reduction in *Gambusia* etc).

(2) Effects of Management Actions – Vegetation Clearance

As described above, initial management actions under the CHEMP Management Plan were undertaken in March, 2019 to reduce macrophyte cover in various waterbodies in the system. This is potentially an important, ongoing management action in the system to promote GGBF breeding activity and population recruitment. It is important to understand the impacts of this management approach going forward, in particular, whether there is a measurable response in the system i.e. evidence of increased breeding and recruitment in the system as a result.

References

Lenga, D & Clulow, J. February, 2019. Green and Golden Bell Frog Research and Monitoring Program on Ash Island, Hunter Estuary - Report for Sept-December 2018 (2018/2019 Summer Season). Prepared for Newcastle Coal Infrastructure Group by University of Newcastle, Conservation Biology Research Group. *Reviewed M Mahony, S Clulow.*

Newcastle Coal Infrastructure Group, 2018. Green and Golden Bell Frog Compensatory Habitat Management Plan. Author, P Reid. Document number: NCIG GGBF CH MP.

McHenry, C, Maynard, C, Callen, A & Mahony, M (2019) Green and Golden Bell Frog (*Litoria aurea*) Research Program on Kooragang Island: Annual Report (2018-2019). Prepared for Port Waratah Coal Services, Newcastle Coal Infrastructure Group and Hunter and Central Coast Development Corporation.

Table 2. Pond structure and water chemistry. Summary of data collected for all NCIG compensatory habitat ponds surveyed between the months of January to April 2019. Pond type (ephemeral, permanent or semi- permanent), and presence/absence and relative abundance of *Gambusia* shown. The total number of GGBF recorded at each pond over the 4 months of data collection are shown. Water quality data for each pond is shown as means and standard deviations, as well as the minimum and maximum water depth recorded for the season at each pond. Missing values usually due to no water in dry ponds. Abbreviations: Temp = Water Temperature; Sal = Salinity; DO = Dissolved Oxygen.

Ponds	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	0	high	5.94	0.19	28.7	1.33	0.78	0.09	1.015	0.79	156	136
1.2	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
1.3	ephemeral	0	none	5.1	0.14	24.85	2.19	0.72	0.27	0.27	0.33	50	47
1.4	ephemeral	0	medium	5.45	0.07	24.7	3.82	4.09	1.55	0.165	0.13	126	86
1.5	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
2.1	semi-permanent	0	none	-	-	-	-	-	-	-	-	0	0
2.2	ephemeral	5	none	5.95	-	24.4	-	1.87	-	0.13	-	130	130
2.3	permanent	0	none	6.13	-	28.6	-	3.41	-	0.13	-	273	273
2.4	ephemeral	0	low	6.13	-	23	-	4.57	-	0.15	-	0	0
2.5	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
3.1	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
3.2	ephemeral	0	none	-	-	-	-	-	-	-	-	-	-
3.3	permanent	0	medium	5.975	0.08	28	1.98	1.21	0.23	1.805	1.68	175	100
3.4	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
3.5	ephemeral	0	none	-	-	-	-	-	-	-	-	5	5
4.1	permanent	0	medium	4.67	-	25.6	-	0.26	-	0.25	-	150	150
4.2	permanent	0	none	4.86	-	24.5	-	0.33	-	0.2	-	45	45
4.3	permanent	0	medium	5.13	-	27.9	-	0.24	-	0.16	-	150	150
4.4	permanent	0	high	5.26	-	27.1	-	0.39	-	0.14	-	100	100

4.5	ephemeral	0	none	5.94	-	24.7	-	0.04	-	0.11	-	5	5
4.6	ephemeral	0	none	5.99	-	26	-	0.16	-	0.1	-	210	210
4.7	permanent	0	medium	5.8	-	26.2	-	0.14	-	0.42	-	60	60
4.8	permanent	2	high	6.72	-	26.4	-	0.28	-	0.47	-	150	150
4.9	ephemeral	45	none	6.47	-	26.9	-	1.51	-	0.65	-	50	50
4.10	permanent	4	high	-	-	-	-	-	-	-	-	-	-
4.11	permanent	0	low	-	-	-	-	-	-	-	-	-	-
5.1	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
5.2	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
5.3	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
5.4	ephemeral	3	none	5.97	-	26.5	-	0.28	-	1.75	-	30	30
5.5	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
5.6	ephemeral	1	none	5.72	-	23.7	-	0.23	-	3.21	-	10	10
5.7	permanent	1	low	5.94	-	28.9	-	0.21	-	0.77	-	45	45
5.8	permanent	9	high	5.97	-	28.6	-	0.19	-	2.66	-	-	-
6.1	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0
6.2	ephemeral	0	low	6.05	-	26	-	0.46	-	0.19	-	10	10
6.3	permanent	0	high	6.17	-	28	-	0.3	-	0.34	-	100	100
6.4	ephemeral	0	low	-	-	-	-	-	-	-	-	0	0
6.5	ephemeral	0	low	-	-	-	-	-	-	-	-	0	0
6.6	permanent	1	low	5.83	-	24.3	-	0.23	-	1.36	-	70	70
7.1	permanent	49	high	6.2	-	25.9	-	2.55	-	0.17	-	90	90
7.2	ephemeral	31	none	6.14	-	24.8	-	0.62	-	0.09	-	15	15
7.3	ephemeral	52	medium	5.9	-	24.2	-	3.62	-	0.49	-	5	5
K58B	ephemeral	0	none	-	-	-	-	-	-	-	-	0	0

Table 3. Numbers of frogs observed and *Gambusia* abundance data collected for all NCIG compensatory habitat ponds surveyed between the months of September 2018 to April 2019, presented for each of the four survey rounds. Each pond of the NCIG compensatory habitat was surveyed at least once during each round; ponds with an asterisk (*) were surveyed more than once during that round. *Gambusia* Abundance scale: low=1-40 individuals, Medium= 41-80, High= 81+. An "-" indicates ponds not surveyed in each round; '0' indicates pond surveyed but not frogs found.

		Round 1 (Sept & Oct 2018)		Round 2 (Nov& Dec 2018)		Round 3 (Jan & Feb 2019)		Round 4 (March & April 2019)		Total
Pond	**Type**	GGBF Numbers	Gambusia Abundance	GGBF Numbers	Gambusia Abundance	GGBF Numbers	Gambusia Abundance	GGBF Numbers	Gambusia Abundance	GGBF Numbers
1.1	permanent	0*	High	0	High	0	High	0	High	0
1.2	ephemeral	1	None	0	None	0	None	0	None	1
1.3	ephemeral	0*	None	0	None	0	None	0	None	0
1.4	ephemeral	0	Medium	0	Medium	0	Medium	0	High	0
1.5	ephemeral	-	-	0	None	0	None	0	None	0
2.1	semi-permanent	0	None	0	Low	0	Medium	0	None	0
2.2	ephemeral	0	None	0	None	0	None	5	None	5
2.3	permanent	0	None	0	None	0	None	0	None	0
2.4	ephemeral	0	None	0	Low	0	Low	0	None	0
2.5	ephemeral	-	-	0	Low	0	Medium	0	None	0
3.1+3.2	ephemeral	0	None	0	None	0	None	0*	None	0
3.3	permanent	0	Medium	0	Medium	0	Medium	0*	Medium	0
3.4	ephemeral	0	None	1	None	0	None	0*	None	1
3.5	ephemeral	0	None	0	None	0	None	0*	None	0
4.1	permanent	0	Low	0	Medium	0*	Medium	-	-	0
4.2	permanent	0	None	0	None	0*	Low	-	-	0
4.3	permanent	0	Medium	0	Medium	0*	None	-	-	0
4.4	permanent	0	Medium	0	High	0*	Medium	-	-	0
4.5	ephemeral	1	None	0	None	0*	None	0	None	1
4.6	ephemeral	0	None	0	None	0*	None	0	Low	0

4.7	permanent	0*	Medium	0	Medium	0*	Medium	0	Medium	0
4.8	permanent	0	High	0	High	2*	High	0*	High	2
4.9	ephemeral	8*	None	7	None	45*	None	0*	None	60
4.10	permanent	0	High	0	High	2	High	2	High	4
4.11	permanent	0	Low	0	Low	0*	-	0	Low	0
5.1	ephemeral	6*	None	5	None	0*	None	0*	None	11
5.2	ephemeral	0	None	1	None	0*	None	0*	None	1
5.3	ephemeral	1	None	0	None	0*	None	0	None	1
5.4	ephemeral	0	None	0	None	3*	None	0	None	3
5.5	ephemeral	0	None	0	None	0*	None	0*	None	0
5.6	ephemeral	0	None	0	None	1*	None	0*	None	1
5.7	permanent	0	Medium	0	Low	0*	Medium	1	Low	1
5.8	permanent	0	High	0	High	9*	High	0	High	9
6.1	ephemeral	0	Low	-	Low	0	None	-	-	0
6.2	ephemeral	0	Low	-	Low	0	None	-	-	0
6.3	permanent	0	High	-	High	0	High	-	-	0
6.4+6.5	ephemeral	0	Low	-	Low	0	None	-	-	0
6.6	permanent	0	Low	-	Low	1	Low	-	-	1
7.1	permanent	5*	High	4	High	37*	High	12*	High	58
7.2	ephemeral	10*	None	7	None	29*	None	1*	None	47
7.3	ephemeral	3*	Low	0	Medium	24*	Low	28*	Medium	55
K58B	ephemeral	2*	Low	0	None	0*	None	0*	Low	2

Table 4. Breakdown of the GGBF frog counts at each pond in each round from the 2018/2019 season (Rounds 1-4) separated by sex/age class. An "-" indicates ponds not surveyed in each round; '0' indicates pond surveyed but not frogs found. Rounds 1 and 2 are from Sept-Dec 2018 surveys.

		Adults Males				Adult Females				Juvenile/Juvenile Females			
Ponds	**Type**	**Round 1**	**Round 2**	**Round 3**	**Round 4**	**Round 1**	**Round 2**	**Round 3**	**Round 4**	**Round 1**	**Round 2**	**Round 3**	**Round 4**
1.1	permanent	0	0	0	0	0	0	0	0	0	0	0	0
1.2	ephemeral	1	0	0	0	0	0	0	0	0	0	0	0
1.3	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
1.4	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
1.5	ephemeral	-	0	0	0	-	0	0	0	-	0	0	0
2.1	semi-permanent	0	0	0	0	0	0	0	0	0	0	0	0
2.2	ephemeral	0	0	0	1	0	0	0	3	0	0	0	0
2.3	permanent	0	0	0	0	0	0	0	0	0	0	0	0
2.4	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
2.5	ephemeral	-	0	0	0	-	0	0	0	-	0	0	0
3.1+3.2	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
3.3	permanent	0	0	0	0	0	0	0	0	0	0	0	0
3.4	ephemeral	0	0	0	0	0	0	0	0	0	1	0	0
3.5	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
4.1	permanent	0	0	0	-	0	0	1	-	0	0	0	-
4.2	permanent	0	0	0	-	0	0	0	-	0	0	0	-
4.3	permanent	0	0	0	-	0	0	0	-	0	0	0	-
4.4	permanent	0	0	0	-	0	0	0	-	0	0	0	-
4.5	ephemeral	0	0	0	0	1	0	0	0	0	0	0	0
4.6	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
4.7	permanent	0	0	0	0	0	0	0	0	0	0	0	0
4.8	permanent	0	0	0	0	0	0	0	0	0	0	2	0
4.9	ephemeral	3	4	8	1	2	2	4	0	0	0	2	0

4.10	permanent	0	0	0	0	0	0	0	1	0	0	0	1
4.11	permanent	0	0	0	0	0	0	0	0	0	0	0	0
5.1	ephemeral	1	2	0	0	0	0	0	0	0	0	0	0
5.2	ephemeral	0	1	0	0	0	0	0	0	0	0	0	0
5.3	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
5.4	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
5.5	ephemeral	0	0	0	0	0	0	0	0	0	0	0	0
5.6	ephemeral	0	0	0	0	0	0	0	0	0	0	1	0
5.7	permanent	0	0	0	0	0	0	0	0	0	0	0	0
5.8	permanent	0	0	2	0	0	0	0	0	0	0	3	0
6.1	ephemeral	0	-	0	-	0	-	0	-	0	-	0	-
6.2	ephemeral	0	-	0	-	0	-	0	-	0	-	0	-
6.3	permanent	0	-	0	-	0	-	0	-	0	-	0	-
6.4+6.5	ephemeral	0	-	0	-	0	-	0	-	0	-	0	-
6.6	permanent	0	-	0	-	0	-	0	-	0	-	0	-
7.1	permanent	1	0	1	2	0	0	3	4	3	3	7	5
7.2	ephemeral	2	3	5	1	1	2	2	0	2	1	3	0
7.3	ephemeral	0	0	5	13	2	0	0	5	0	0	4	8
K58B	ephemeral	0	0	0	0	0	0	0	0	1	0	0	0

Table 5. Macrophyte clearance surveys & relocation of frogs of ponds disturbed. Along with number of GGBF found in the treated ponds in the post disturbance surveys. Ponds with "-" were not surveyed on that date. '0' indicates pond surveyed, no record.

	Pre-clearance Surveys				Post-disturbance survey			
Pond	Date	Number of Frogs	Disturbance Date	Removed to Pond	18/03/2019	4/04/2019	10/04/2019	11/04/2019
3.1	10/03/2019	0	11/03/2019		0	-	-	0
3.2	10/03/2019	0	11/03/2019		0	-	-	0
3.5	10/03/2019	0	11/03/2019		0	-	-	0
4.8	13/03/2019	0			0	-	0	-
4.9	13/03/2019	1	13/03/2019	pond 4.8, -32.84135, 151.70765	0	-	0	-
5.1	10/03/2019	0	12/03/2019		-	0	-	-
5.2	10/03/2019	0	12/03/2019		-	0	-	-
5.5	10/03/2019	0	12/03/2019		-	0	-	-
5.6	10/03/2019	0	12/03/2019		-	0	-	-
5.7	10/03/2019	0				1	-	-
7.1	10/03/2019	-			7	5	-	-
7.2	10/03/2019	1	12/03/2019	pond 7.1, -32.84608, 151.70306	1	0	-	-
7.3	10/03/2019	9	12/03/2019	pond 7.1, -32.84608, 151.70306	9	12	-	-

Table 6. Comparisons of total number GGBF observed in each wetland in stage 7 before (25/02/2019) and after vegetation removal (18/03/2019, 4/04/2019).

	Date	Wetland	Total GGBF seen
Pre-vegetation removal	25/02/2019	7.1	15
	25/02/2019	7.2	0
	25/02/2019	7.3	9
Post-vegetation removal	18/03/2019	7.1	7
	18/03/2019	7.2	1
	18/03/2019	7.3	9
	4/04/2019	7.1	5
	4/04/2019	7.2	0
	4/04/2019	7.3	12

Table 7. Post-disturbance "surveys", showing the records of individual GGBF relocated prior to the macrophyte clearance in the three post- disturbance surveys. "-" indicates source ponds not re-surveyed on that date, "NA" indicates source pond resurveyed, but individual frog was not encountered.

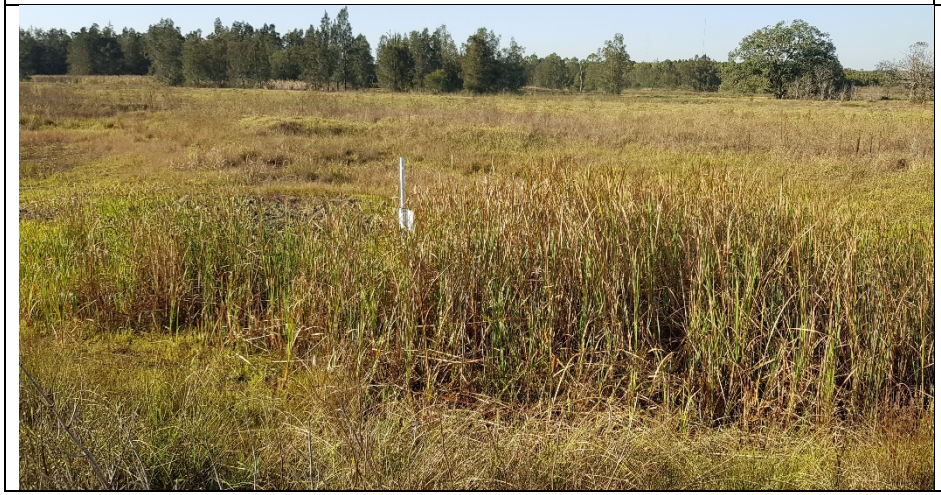
			Post-Disturbance Surveys		
Frog ID	Source Pond Pre-clearance	Moved to Pond	18/03/2019	4/04/2019	10/04/2019
0007D2502C	7.3	pond 7.1, '-32.84615, 151.70300	NA	NA	-
0007D184EE	7.3	pond 7.1 '-32.84615, 151.70294	7.1	NA	-
0007A09629	7.3	pond 7.1, '-32.84615, 151.70294	7.3	7.3	-
0007D247DD	7.3	pond 7.1, '-32.84613, 151.70305	NA	NA	-
0007A0E463	7.3	pond 7.1, '-32.84615, 151.70300	7.3	NA	-
0007D6453D	7.1	pond 7.1, '-32.84609, 151.70299	7.3	7.3	-
0007D1B5DF	7.3	pond 7.1, '-32.84609, 151.70299	NA	NA	-
0007A0DADB	7.3	pond 7.1, '-32.84613, 151.70305	7.3	NA	-
0007D1F2F2	7.3	pond 7.1, '-32.84608, 151.70306	NA	NA	-
0007D29080	7.3	pond 7.1, '-32.84608, 151.70306	NA	NA	-
0007D3D47E	4.9	pond 4.8, -32.84135, 151.70765	-	-	NA

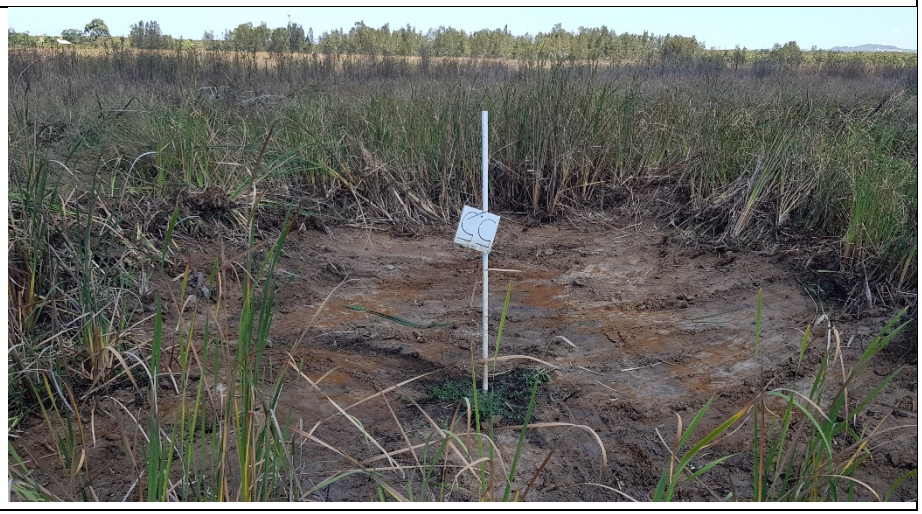
Figure 3. Pond Photo points before and after macrophyte clearance on Ash Island NCIG CHEMP wetlands 3.1, 3.2, 3.5, 4.9, 5.2, 5.5, 5.6, 7.2 & 7.3

Ponds 3.1 and 3.2	
Pre-clearance	
Post-clearance	

Pond 3.5	
Pre-clearance	Post-clearance

Pond 4.9	
Pre-clearance	
Post-clearance	

5.2	
Pre-clearance	Post-clearance
	

5.5	
Pre-clearance	Post-clearance
	

5.6	
Pre-clearance	Post-clearance

7.2	
Pre-clearance	
Post-clearance	

7.3	
Pre-clearance	Post-clearance

Fish Fry Flats Vegetation and Infauna Report Methods and Preliminary Results.

Date: July 2019

Report by Caleb Rankin – University of Newcastle

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Unless otherwise specified, all figures and images are by Caleb Rankin

1 Overview

As part of their environmental offset, Newcastle Coal and Infrastructure Group (NCIG) have been leased past critical shorebird habitat at Area E, Kooragang Island, to restore to saltmarsh. This is being achieved by removing mangroves and installing floodgates in consultation with the University of New South Wales (UNSW) to encourage saltmarsh growth and bird usage (NCIG 2015). In order to determine the trajectory of the habitat restoration, NCIG has partnered with UNSW and the University of Newcastle to identify, measure, and track overall functioning and delivery of ecosystem services. This report gives an overview of some of the measures taken, the methodology, and preliminary results to date. Preliminary results indicate that saltmarsh is establishing well and feeding sources for birds are developing. Thus, no corrective action needs to be taken at this time.

2 Methods

2.1 Indicators

Components of an ecosystem that indicate its health and functioning, termed ecological indicators, can be reliably used to measure and identify restoration success for habitat functioning and delivery of ecosystem services (Brudvig, 2017; Ruiz-Jaen & Aide, 2005). For this report, ecological indicators of saltmarsh functioning that may affect its value as shorebird habitat are being measured. These are plant diversity and cover, crab holes, and macroinfauna (organisms that live in the soil).

2.2 Sites

Area E has historically been important shorebird habitat and the subject of various studies (e.g. Boys & Williams, 2012; Howe, Rodríguez, Spencer, MacFarlane, & Saintilan, 2010; Nelson, 2006). Mangrove invasion in the ‘90s reduced its value as shorebird habitat and prompted various efforts to restore the saltmarsh and mudflat habitat. NCIGs current restoration efforts began in 2016 with total mangrove removal. To assist mangrove exclusion and promote maximum saltmarsh growth, the tidal regime was lowered by Smart floodgates in June 2017. The highest annual tides are still allowed to flood the old high saltmarsh to control pasture weed invasion.

In addition to the primary study site at Area E, 2 control and 2 older restoration sites are being sampled (Table 1, Figure 1). These will give comparisons and benchmarks for the developing Area E saltmarsh from degraded to restored bird habitat. The control sites, Cobbans Creek and Crabhole Flats, were selected due to having a similar characteristics and disturbance history to Area E. These include similar structure, age and direct (e.g. grazing, invasive species, and vehicle use) and indirect (e.g. flood gates, potential for eutrophication from farms and roads, and changes in surrounding habitat) disturbances. The restoration sites, Tomago Wetlands and Hexham Marsh, were selected on the basis of their similar structure to Area E and for their increasing value as shorebird habitat. Each has been undergoing restoration for over 10 years (Table 1).

Table 1: Restoration and disturbance at the study sites and their part in this project.

Site	Restoration/Disturbance	Use in Project
Area E	Restoration began 2016, Previously saltmarsh and pasture invaded by mangroves. Tide gates lowering tide and excluding mangroves to promote saltmarsh growth	Study Site
Tomago Creek	Restoration began 2007, Controlling tide to discourage mangroves and flood old pasture and freshwater wetland to promote saltmarsh growth.	Restoration Site
Hexham Marsh	Restoration began 1996, Controlling tide to flood freshwater wetland/pasture to promote saltmarsh growth. Mangroves not controlled.	Restoration Site
Cobbans Creek	Drained for pasture until culvert removed in 1990, Significant mangrove encroachment into old saltmarsh.	Control Site
Crabhole Flats	Drained for pasture until culvert removal in 1993, Significant mangrove encroachment into old saltmarsh.	Control Site

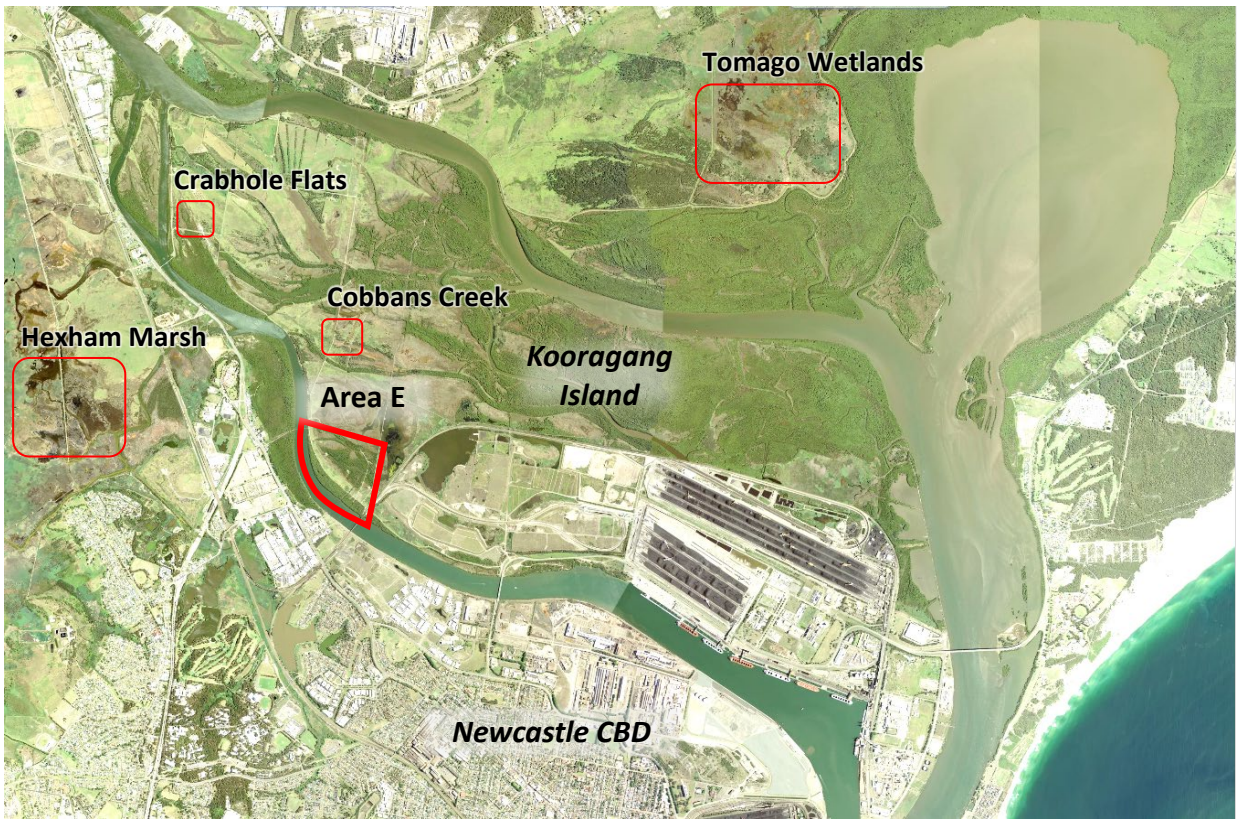

Figure 1: Locations of the study sites for this project. Image from NSW Six Maps.

Sampling at Area E commenced in 2017 with sampling 3 time a year in November (summer), February-March (autumn), and June-July (winter). Each of the control and restoration sites are being sampled twice per year in June-July (winter) and November (summer) starting in June 2018. Sampling for all sites is continuing until November 2019 (Table 2).

Table 2: *Outline of past and future sampling events at each of the study sites.*

		Sampling Events						
Site	**N sample Events**	**Nov 2017**	**Feb 2018**	**June 2018**	**Nov 2018**	**Mar 2019**	**July 2019**	**Nov 2019**
Area E	7	X	X	X	X	X	X	X
Tomago Wetlands	3				X		X	X
Hexham Marsh	3				X		X	X
Cobbans Creek	4			X	X		X	X
Crabhole Flats	4			X	X		X	X

2.1 Sampling strategy

For each of the ecological indicators measured, stratified random sampling is being undertaken at each site with indicators being measured in each of five zones transitioning from mudflat to saltmarsh Above Highest Tide (AHT, saltmarsh that is not inundated by the highest annual tides) based on tidal flow illustrated in Digital Elevation Maps (DEMs) (Figure 2). Saltmarsh AHT is only sampled in Area E where the tide has been lowered and existing saltmarsh remains above the highest tide.

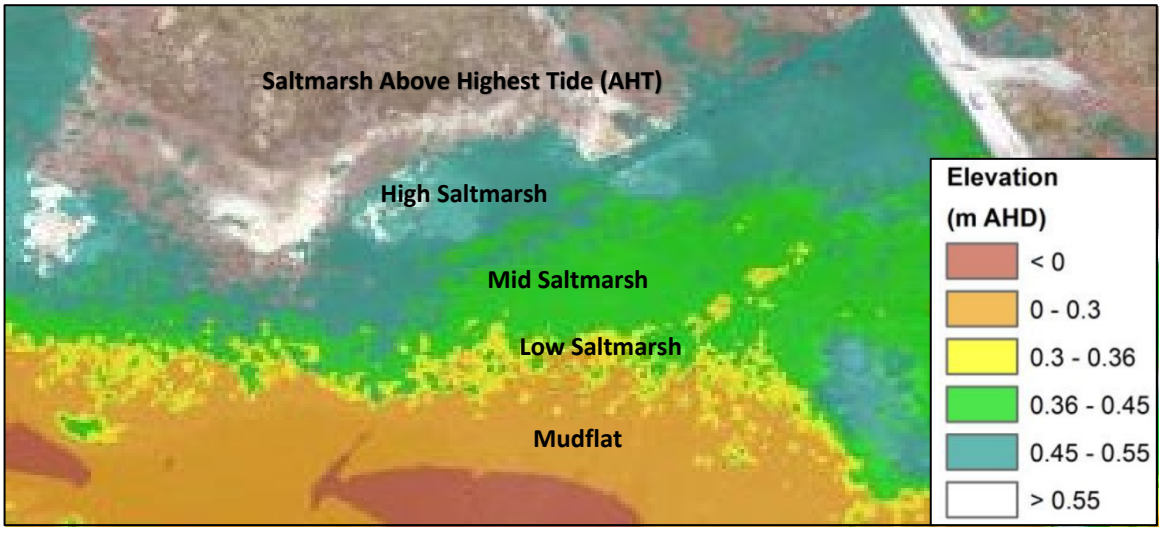

Figure 2: Digital Elevation Map detailing the tidal flow and the zones sampled from mudflat to saltmarsh Above Highest Tide (AHT). DEM map sourced from A/Prof Will Glamore, UNSW.

3 Results

3.1 Vegetation cover, diversity and crabholes

For all sites 1m x1m quadrats divided into 25 squares with nylon twine (Figure 4B) have been set out at the sites to measure vegetation cover, diversity, and number of crabholes. Quadrat placement used a random number table to select random numbers on 50 and 100m tapes, stratified within each zone. Strata were determined by the saltmarsh zones of AHT, high, mid, and low marsh with an equal number of quadrats within each zone (Figure 3&4A). At Area E, 25 quadrats have been placed and surveyed in each of the four zones (25x4 = 100 quadrats (Figure 3)). In the other sites, 10 quadrats have been placed and surveyed in each of the three zones (high, mid, and low, 10x3 = 30 quadrats). Quadrat placement was measured from permanent infrastructure (e.g. roads, electric pylons, and old fence posts) to assist placement and relocation of the quadrats (Figure 4). Each quadrat has been marked for future sampling using a 490mm and a 225mm Supapeg® UV-Treated Polypropylene Sand Peg inserted at the diagonals of the quadrat with a numbered cattle tag attached (Figure 4). The latitude and longitude of each quadrat was taken for mapping and to assist future locating or replacement in the event of the pegs being lost.

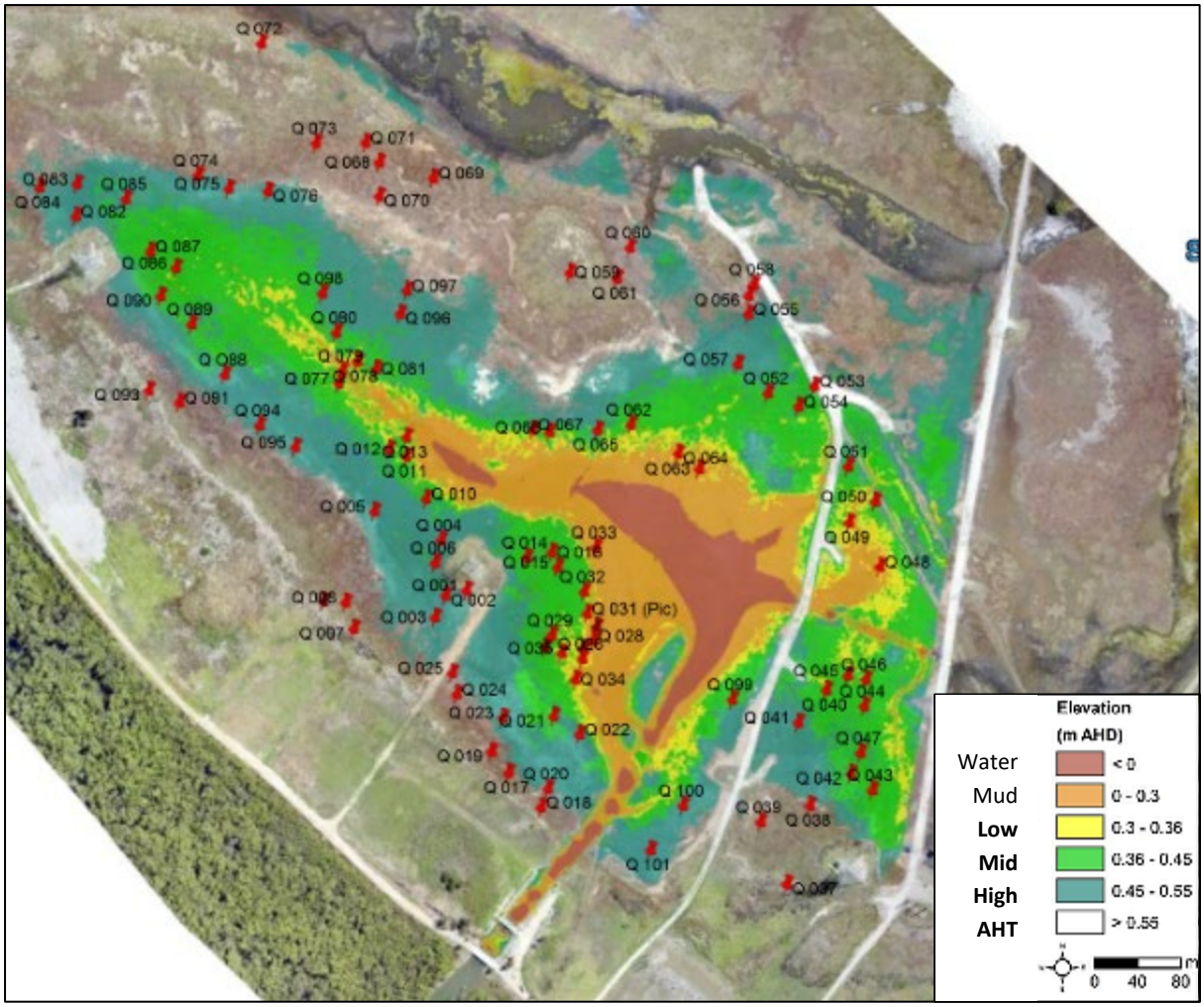

Figure 3: Placement of quadrats at Area E (red pins). DEM map sourced from A/Prof Will Glamore, UNSW.

Figure 4: The quadrat layout process used (A) and a quadrat used at Area E (B). Note the tape for determining placement and the pegs for placing the quadrat at subsequent times. Random numbers were selected from a random number table on each of the 100m and 50m tapes starting from a reference point and extending into the appropriate saltmarsh zone.

3.1.1 Infauna Sampling

6cm deep cores extracted by PVC pipes are being used for sampling macroinfauna (see Figure 5 for an overview). Internal diameters for the pipes are 6.2cm for the macrofauna and 3.8cm for the meiofauna. In Area E, 10 cores are taken at random points around the site in each of the saltmarsh zones from AHT to Mudflat (5 zones) totalling 50 samples per sampling event. 10 samples are being taken per year starting on November 2017. Once collected, the samples are placed in sample jars to be processed in the lab (Figure 6) which includes fixation, staining, washing and preservation before the infauna can be extracted and identified. Given the time required to collect the data and the limited infauna present in the Mid to AHT zones, processing of the low marsh and mudflat infauna is prioritised.

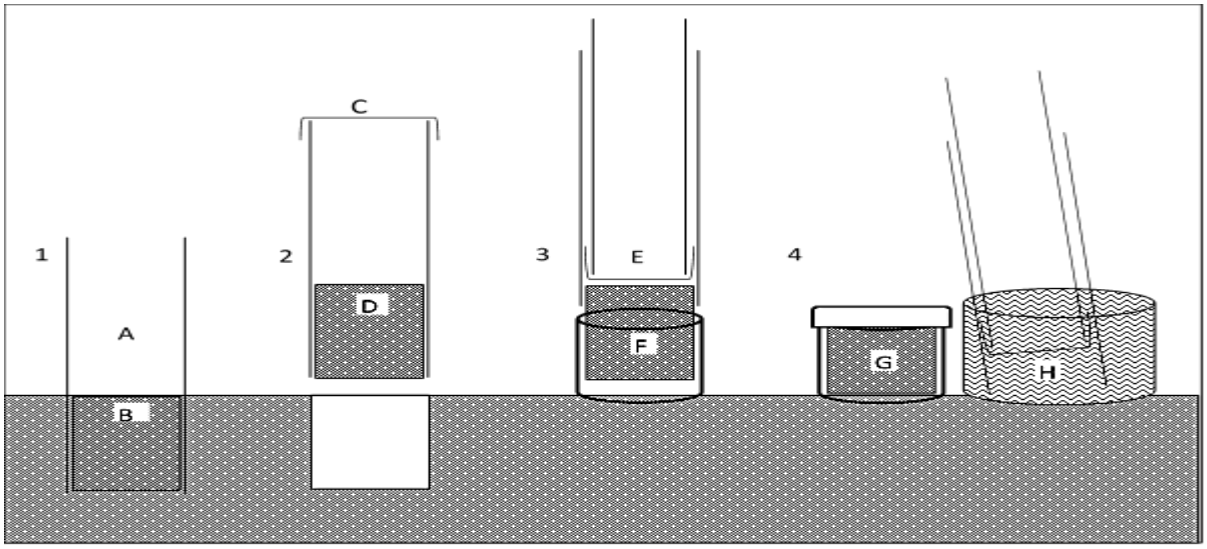

Figure 5: Procedure used for extracting sediment samples. 1 – A hollow PVC pipe (A) is inserted into the sediment (B), 2 – A fitted cap (C) is placed on the pipe and the sample (D) is extracted, 3 – The cap is removed and a plunger, consisting of a smaller pipe with attached cap (E) is used to push the sample into the sample jar (F), 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.

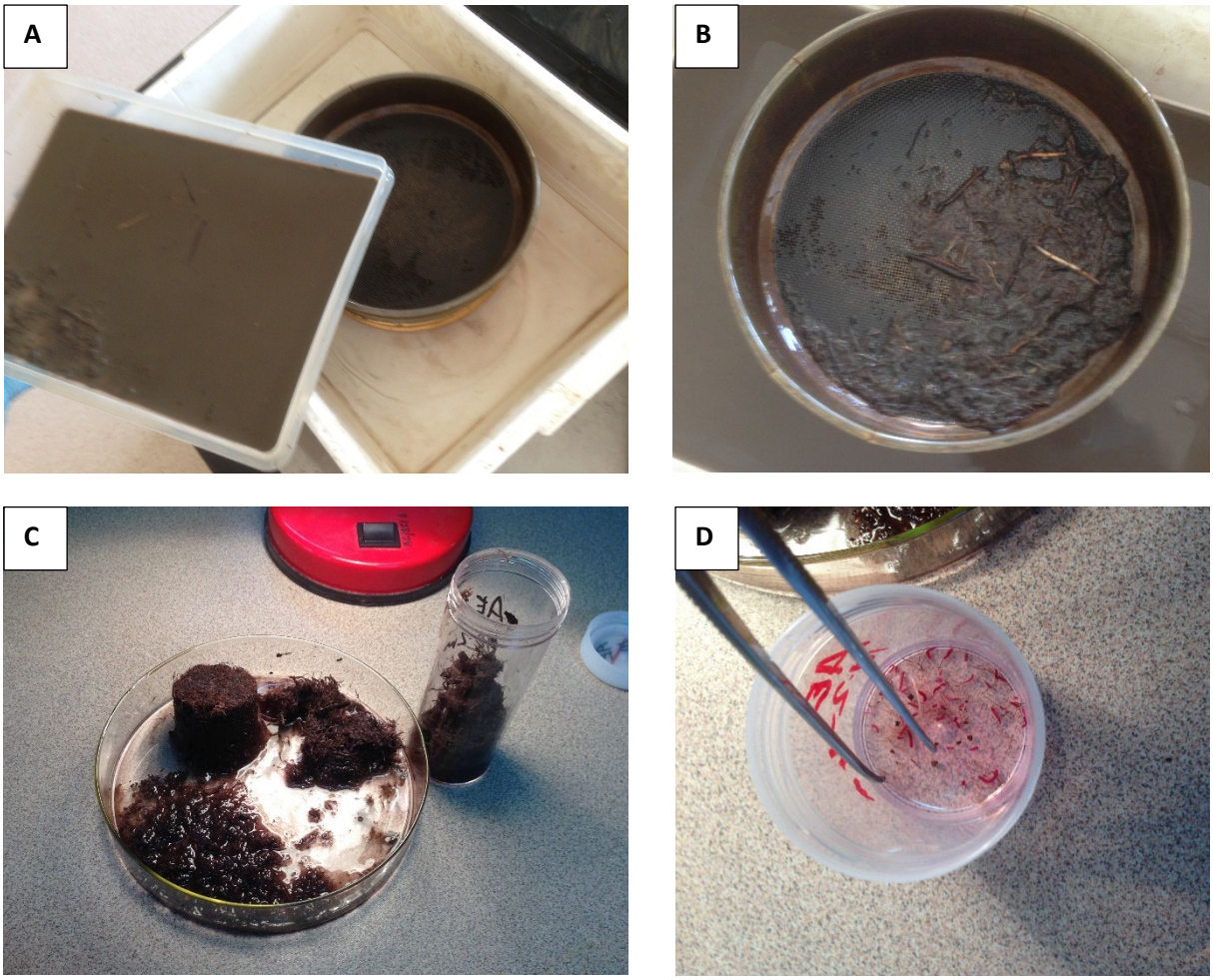

Figure 6: Processing of the infauna samples involving washing (A) and sieving (B) to remove the silt and clay, after which the infauna can be separated from the coarse matter and identified under a dissection microscope (C&D).

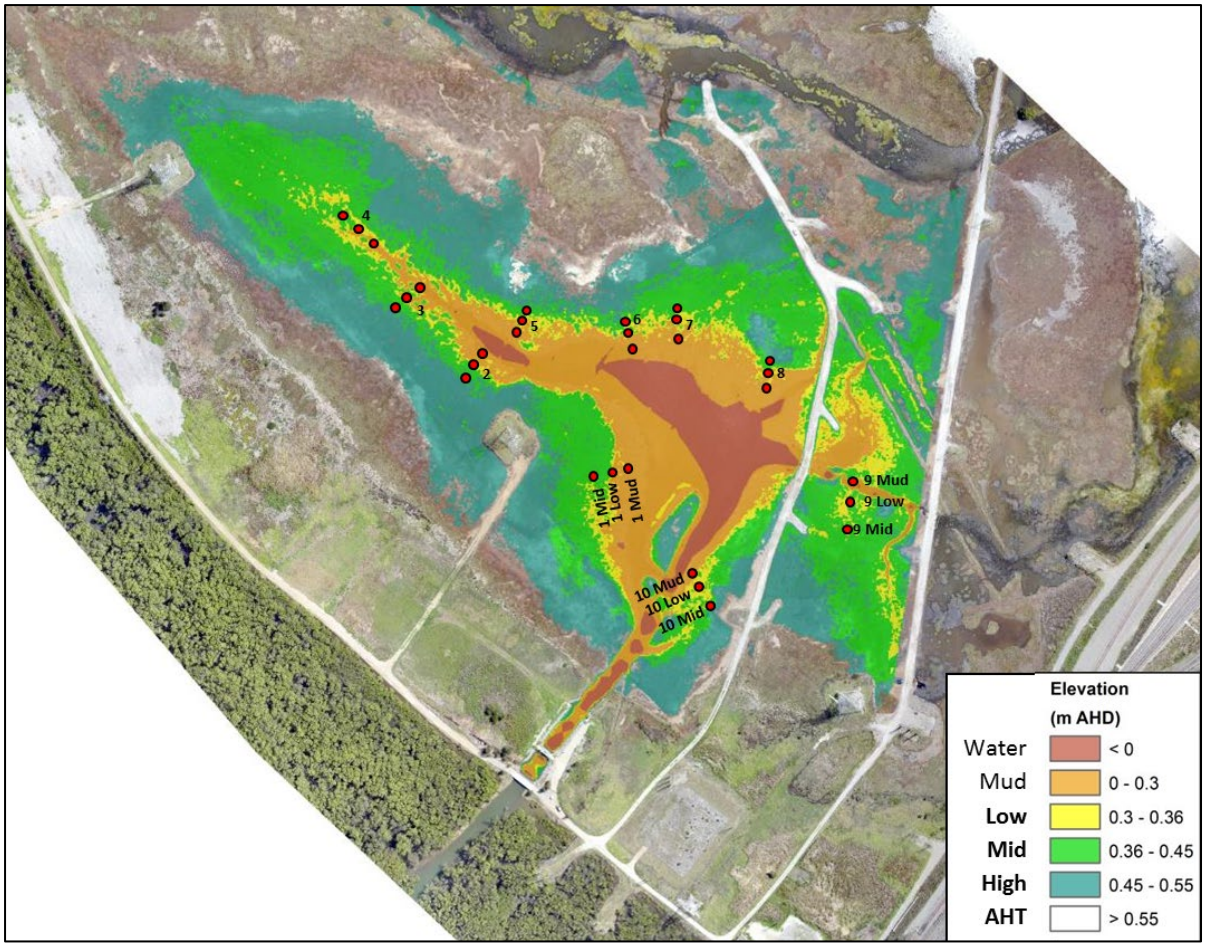

Figure 7: location of infauna samples taken at Area E (red dots). DEM sourced from A/prof William Glamore, UNSW.

3.2 Results

3.2.1 Vegetation and crabholes

Since beginning surveys at Area E in November 2017, there has been an increase in saltmarsh cover and species richness. In June 2018 there was a significant increase in seedling counts (Figure 7 C) which translated to the November 2018 increase in vegetation cover and species richness (Figure 7 A&B). Seedling counts were significantly higher in the July 2019 survey (Figure 7 C), primarily comprised *S. quinqueflora* and *S. australis*. The most significant increase in plant cover was in the low marsh zone, where there was previously no vegetation, and the mid marsh, where vegetation cover and species richness more than doubled from the June 2018 to the July 2019 sampling events (Figure 7 A&B). Dominant saltmarsh cover is currently *Sarcocornia quinqueflora* and *Suaeda australis* in the high mid and low marsh zones. *Sporobolus virginicus* has remained dominant Above the Highest Tide with limited growth recorded in the lower zones (Figure 8 A&B). No significant differences were observed in weed cover except for summer die back of perennial weeds in the AHT saltmarsh (Figure 8 C). Comparisons between sites showed that while Area E saltmarsh cover is still significantly lower than the control and restoration sites, the plant species diversity has recovered quickly and si now comparable to the other sites (Figure 9 A&B). Crabhole Flats and Hexham Marsh had similar weed cover to Area E while Cobbans Creek and Tomago Wetlands had slightly higher saltmarsh cover and lower species diversity overall (Figure 9 C).

Crabhole counts at Area E decreased significantly from the November 2017 to the June 2018 sampling event but have stabilised since with no significant changes (Figure 10 A). Comparing between sites, Hexham Marsh and Area E had the highest crabhole count in the low marsh with Cobbans Creek having the highest crabhole count in the high marsh (Figure 10 B). There was little discernible relationship between vegetation and crabhole counts.

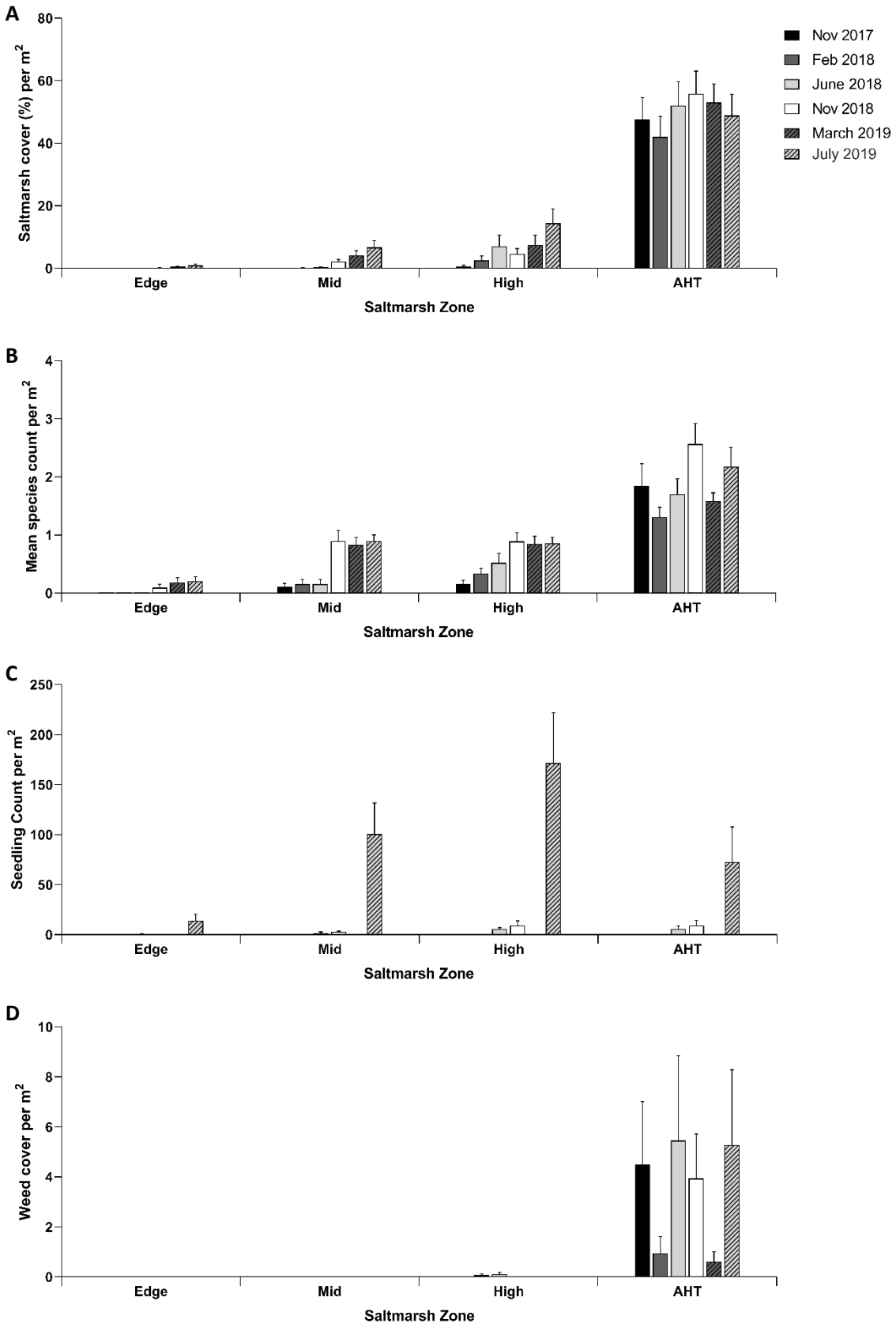

Figure 8: Changes in mean Saltmarsh Cover (**A**) Plant Species richness (**B**) Number of Seedlings (**C**) and Weed Cover (**D**) at Area E from November 2017 to July 2019. Standard error (se) bars indicate where there are significant differences. Measurements are from 25 quadrats for each of the saltmarsh zones on each sampling occasion (see Figure 2).

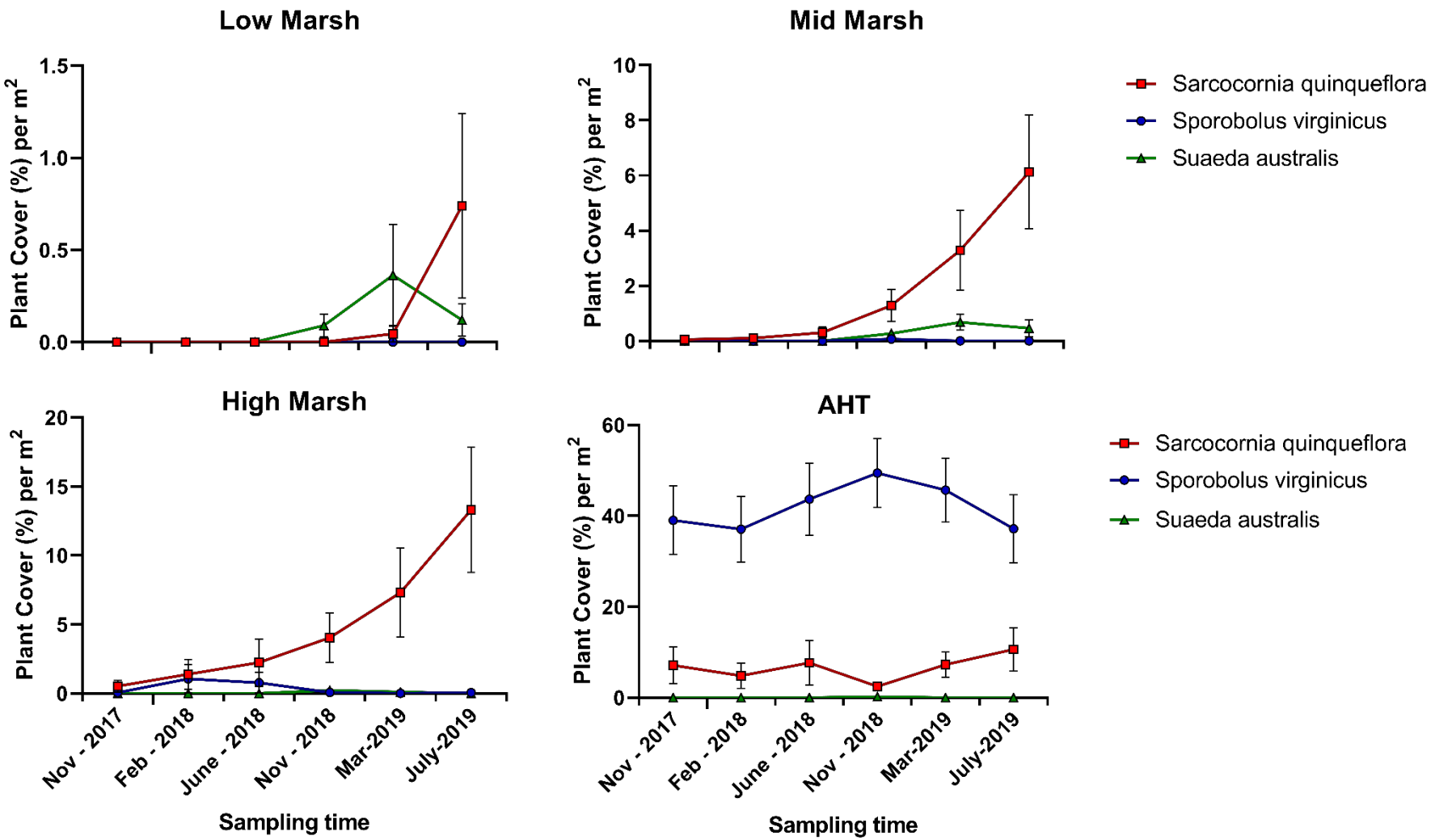

Figure 9: Changes in Area E mean plant composition (±se) in each marsh zone focusing on the dominant saltmarsh species from November 2017 to July 2019.

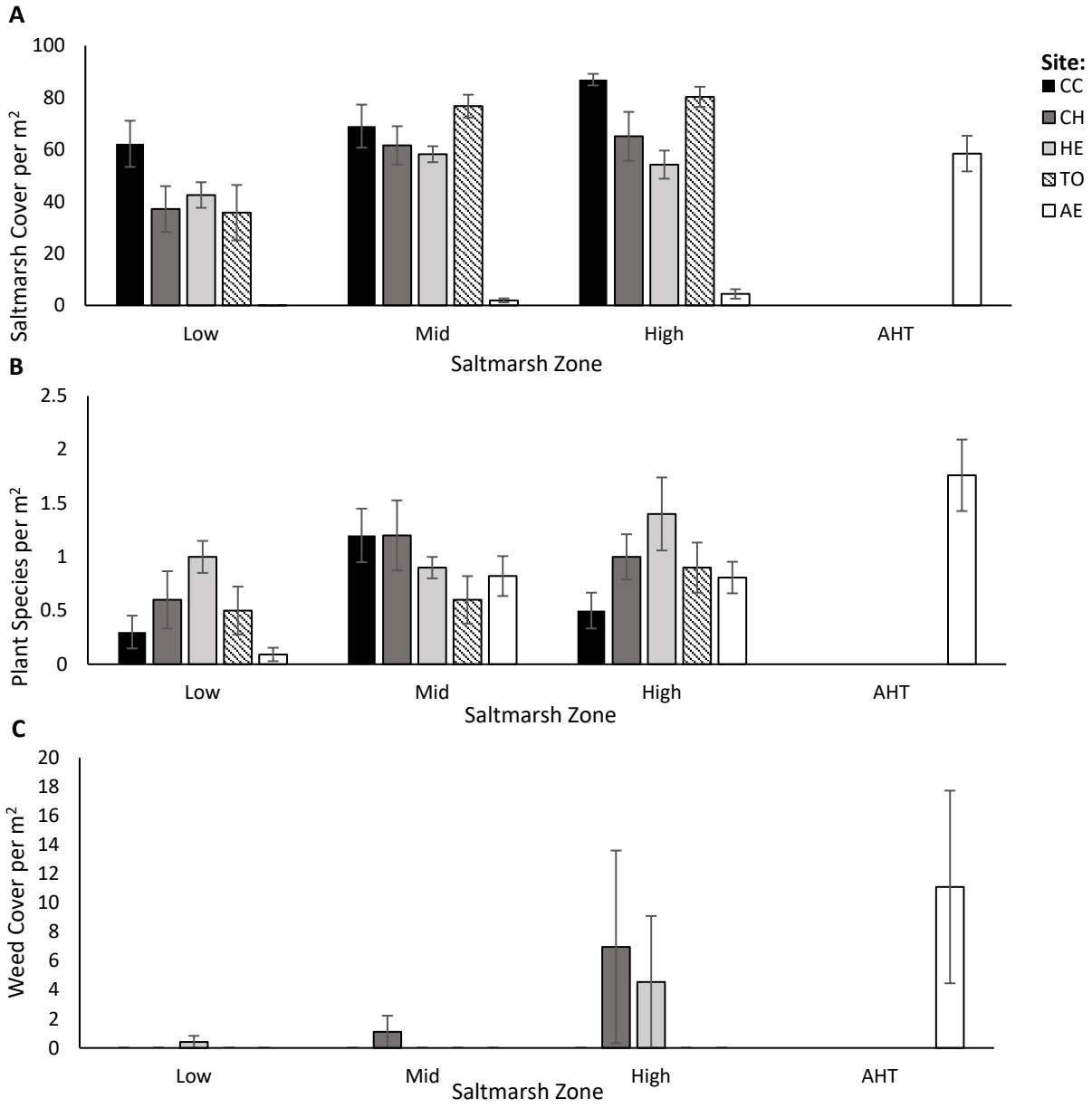

Figure 10: Comparisons for each saltmarsh zone of mean Saltmarsh Cover (**A**) Plant Species richness (**B**) and Weed Cover (**C**) (±se) For each of the sites Cobbans Creek (**CC**), Crabhole Flats (**CH**), Hexham Marsh (**HE**), Tomago Wetlands (**TO**) and Area E (**AE**), sampled in November 2018.
Note that the AHT zone was only sampled in AE (see section 2.3-Sampling Strategy). Measurements are of 10 quadrats for each of the saltmarsh zones at CC, CH, HE, and TO and 25 quadrats for each of the saltmarsh zones at AE (see Figure 2).

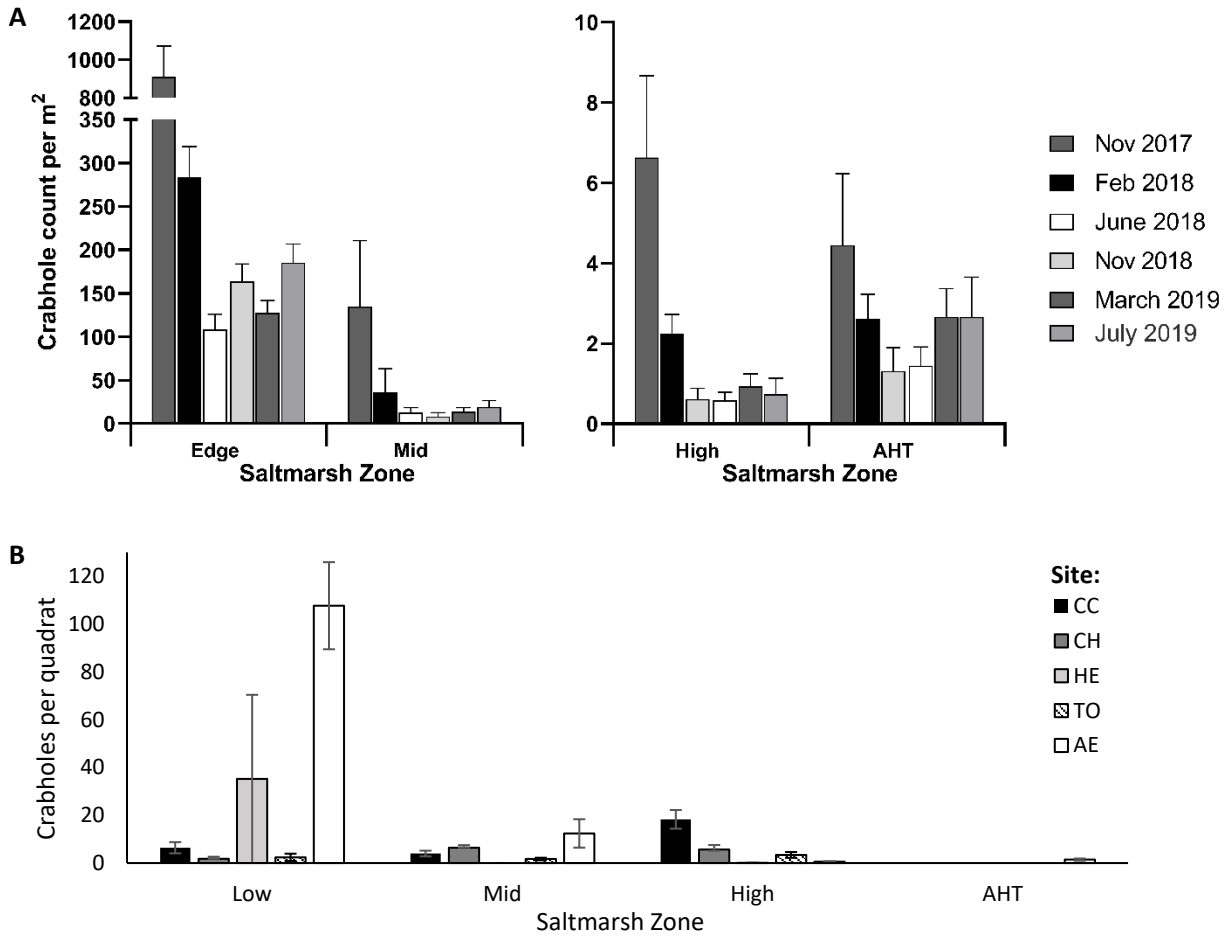

Figure 11: Mean crabhole count from February 2017 to July 2019 in Area E (**A**) and comparisons between the sites Cobbans Creek (**CC**), Crabhole Flats (**CH**), Hexham Marsh (**HE**), Tomago Wetlands (**TO**) and Area E (**AE**) for crabhole counts in each zone on July 2019 (**B**). Standard error (se) bars indicate where there are significant differences.
Note that the AHT zone was only sampled in AE (see 2.3 Sampling Strategy). Measurements are from 10 quadrats for each of the saltmarsh zones at CC, CH, HE, and TO and from 25 quadrats for each of the saltmarsh zones at AE (see Figure 2).

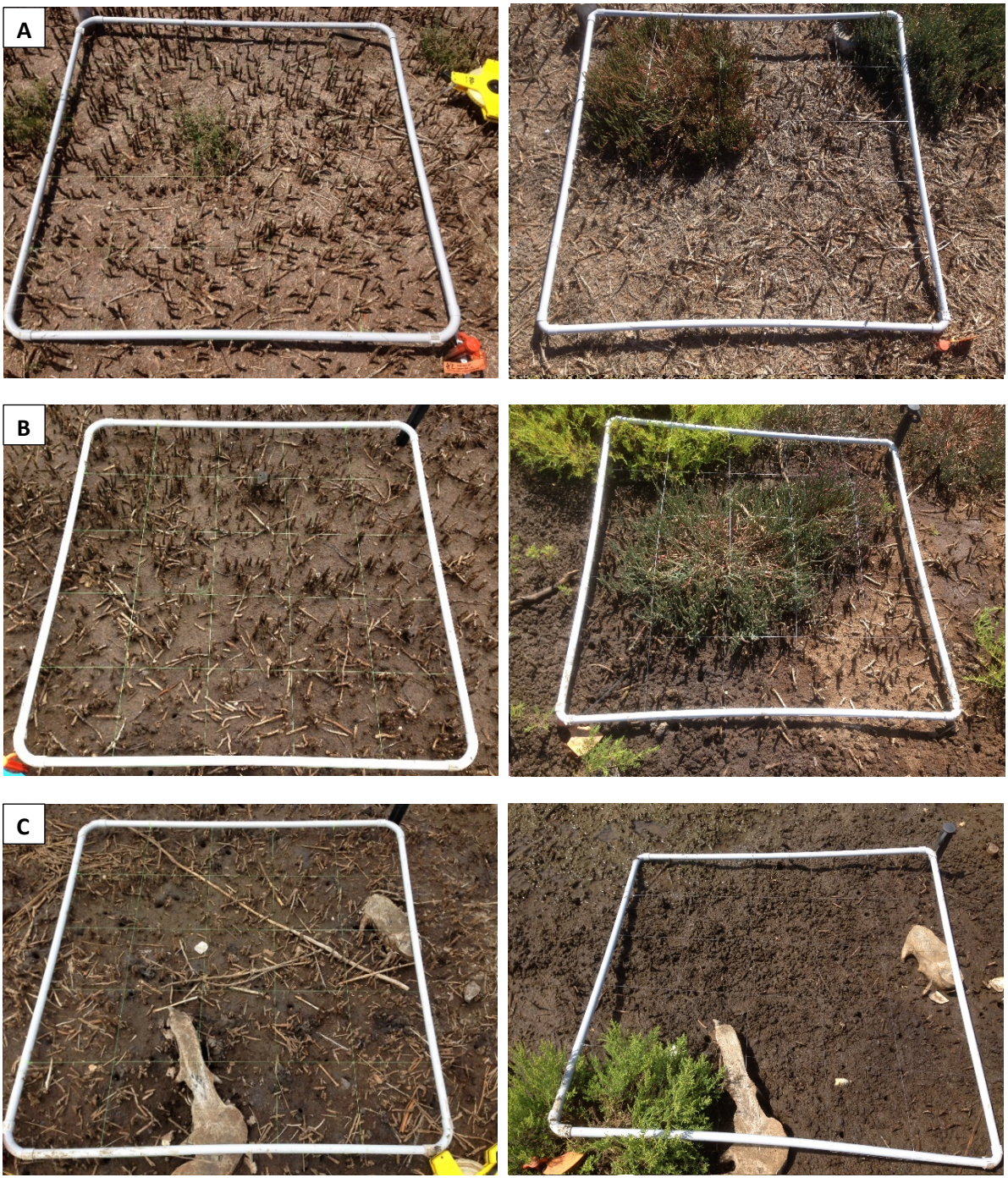

Figure 12: Examples of Area E quadrats where saltmarsh cover significantly increased from November 2017 (left) to July 2019 (right). Quadrats shown are (A) Quadrat 24 (high marsh), (B) Quadrat 50 (mid marsh), (C) Quadrat 80 (low marsh).

3.3 Macrofauna

At Area E a variety of macrofauna has been observed (Figure 13) with a difersity and abundance higher than most of the control and reference sites (Figure 14). From November 2017 to November 2018 there were significant changes in the abundances of various macrofauna at Area E (Figure 15). Most significantly, the 2018 abundance of Bivalves (Galeomin) decreased to about 10% of the November 2017 abundance while Amphipods and Crabs in the edge marsh were absent (Figure 15). Conversely, abundances of Nereidid Polychaetes (bristle worms) and Oligochaetes (segmented worms) increased significantly.

While the decrease in bivalves may allow for an increase in microalgae macroalgae growth (Page, Dugan, & Hubbard, 1992), the increase in Nereidid Polychaetes is promising for Area E given their importance in shorebird diets (Iwamatsu, Suzuki, & Sato, 2007). This may also reduce the macroalgae blooms (Engelsen & Pihl, 2008) which negatively affect shorebird foraging (Green, Blumstein, & Fong, 2015).

Figure 13: Pictures of macrofauna identified at the study sites including crabs (A), amphipods (B), snails (C), bristle worm (polychaete) (D), insect larvae (diptura) (E), and bivalves (F).

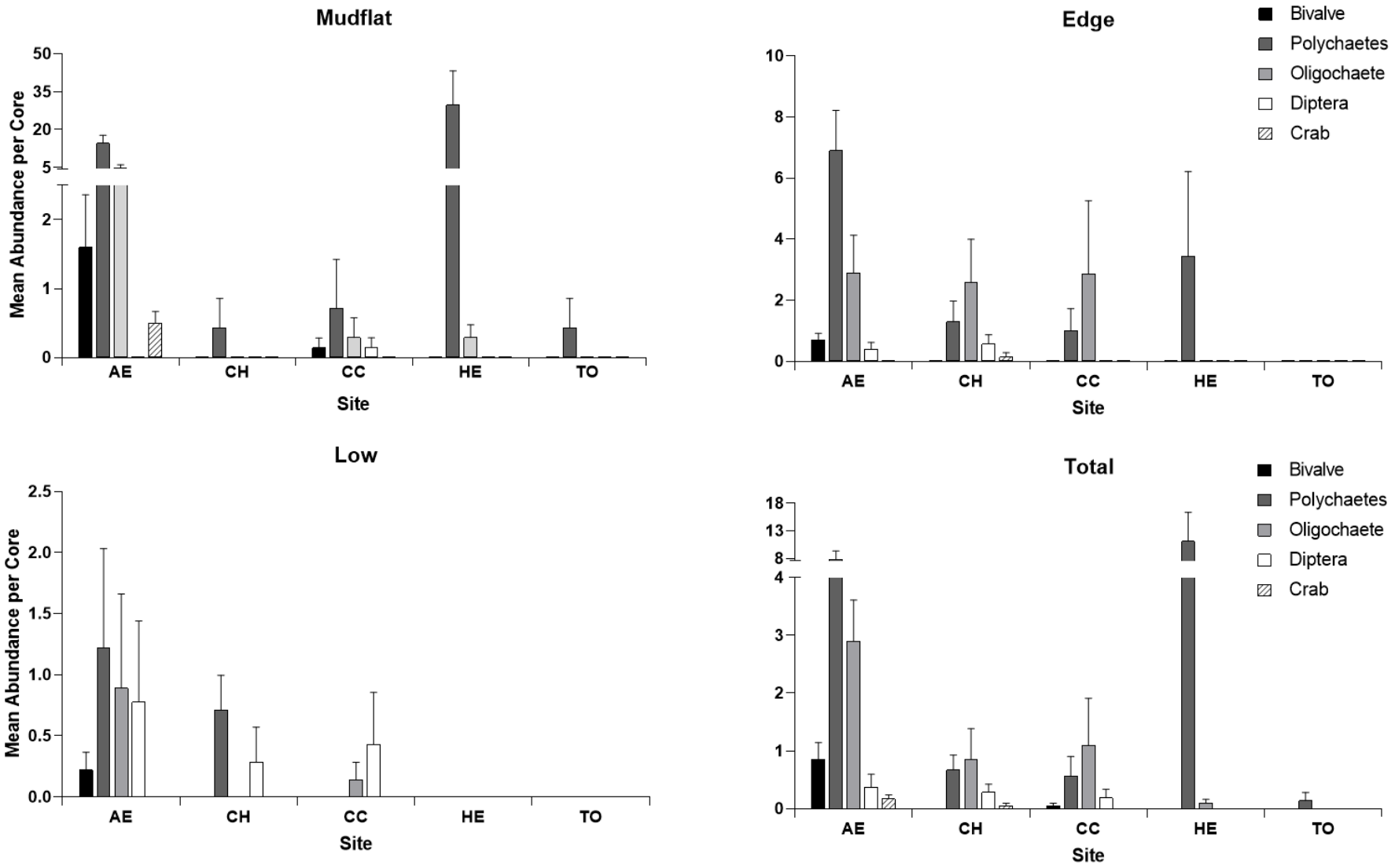

Figure 14: Mean abundance (±se) of the macrofauna taxa identified at each of the study sites Area E (**AE**), Crabhole Flats (**CH**), Cobbans Creek (**CC**), Hexham Marsh (**HE**), and Tomago Wetlands (**TO**) in November 2018. Measurements are from 10 sediment cores for each of the saltmarsh zones

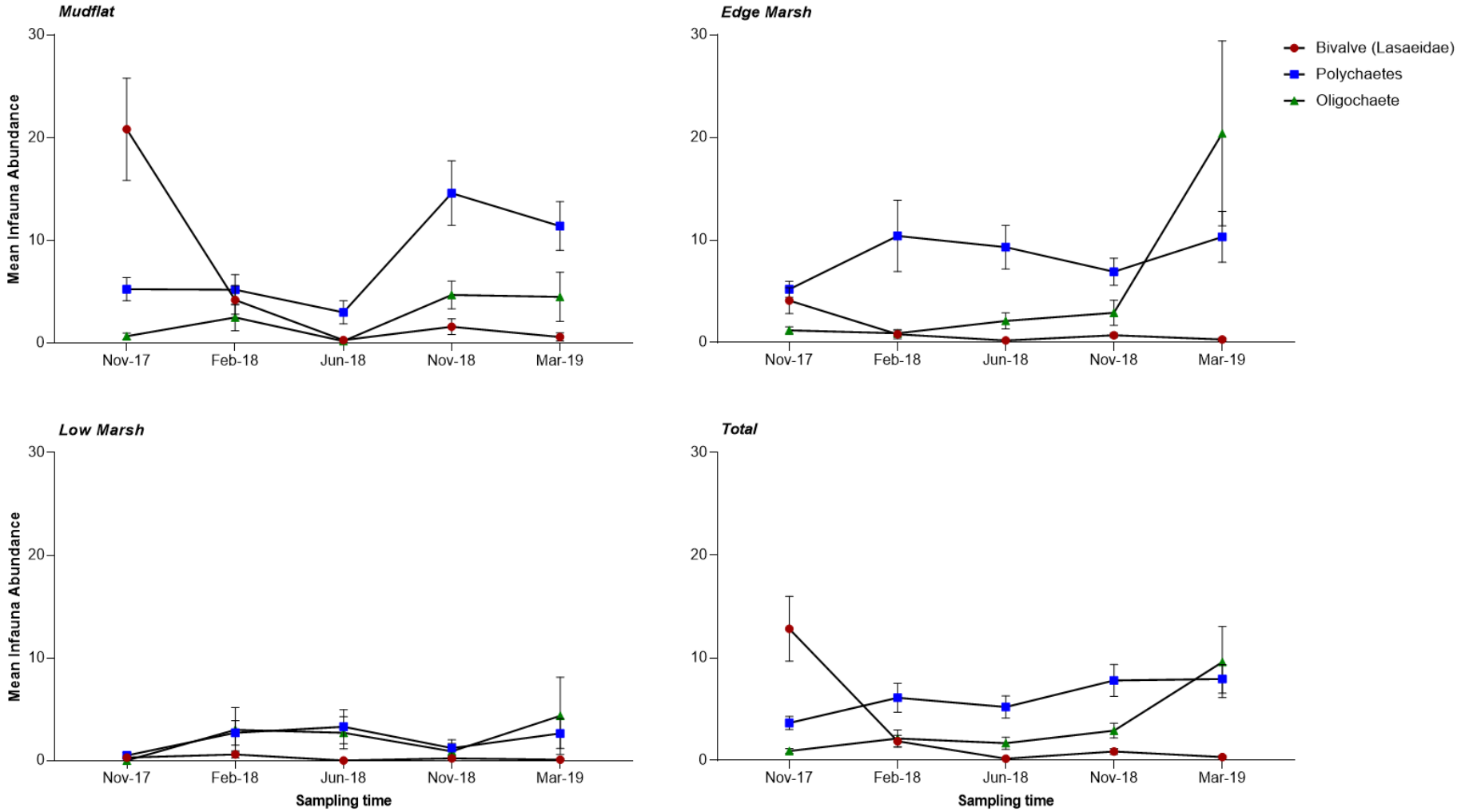

Figure 15: Changes in mean macrofaunal composition (±se) at Area E for each zone sampled from November 2017 to March 2019.

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To: Philip Reid, Hayley Ardagh **Date:** 1/07/2019
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 will result in the creation of 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, is undertaking research onsite and has previously provided advice and recommendations via the report "Shorebirds Compensatory Habitat Area – Hydrological Controls for Ongoing Management". This memorandum provides an update on the desktop and on-ground work accomplished till June 2019 and focuses on the hydrology monitoring and drone surveys. Vegetation survey and monitoring is conducted concurrently with hydrology monitoring however, vegetation data and analysis will be discussed separately via another report by the University of Newcastle.

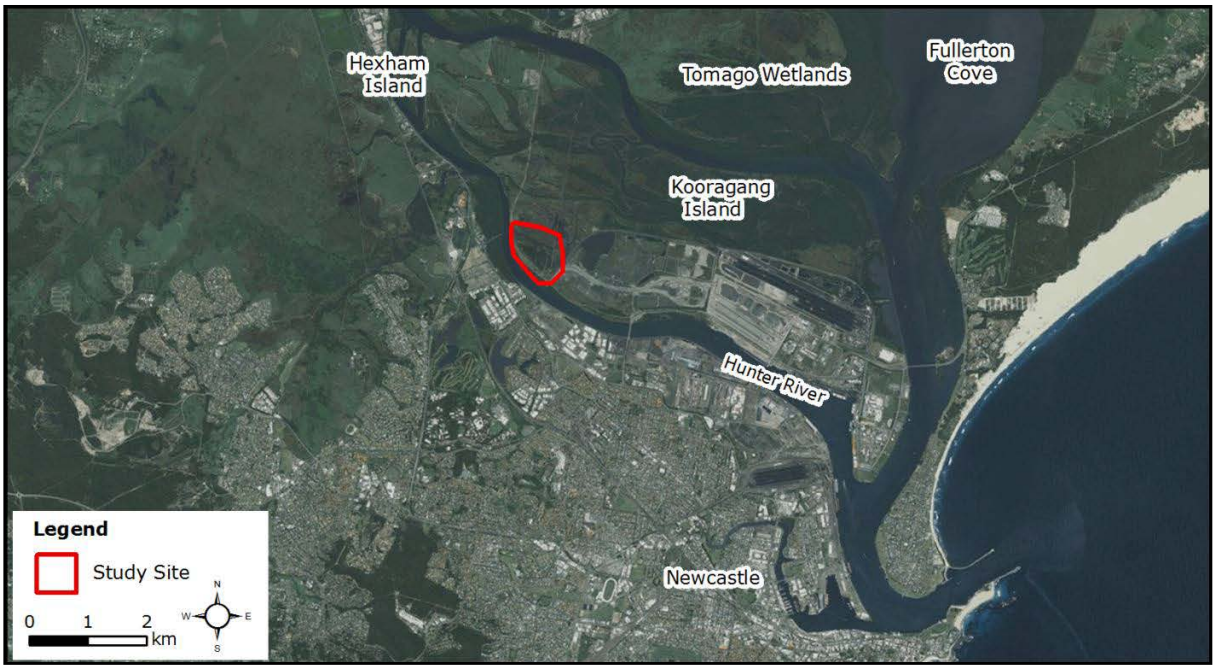

Figure1. Study site

2. Trigger Levels for 2019

Based on existing plans and Hunter River tidal levels near Area E, SmartGate trigger levels for the period January to December 2019 were created and provided to NCIG earlier this year. Following discussion at the annual stakeholder meeting in September 2018 regarding the progress of vegetation development at the site, it was concluded that the existing triggers remain until the next review (annual skate holder meeting) unless specified. Beefily, water levels within the wetland are mostly kept below 0.3 m AHD. At this height water levels in Fish Fry Creek are contained in-channel and minor inundation of mudflat area occurs. This height was chosen as the optimum level that promotes natural saltmarsh hydrology and discourages mangrove habitat. The gates are opened on approximately 60 tides in a year (put700) to allow water levels beyond 0.3 m AHD and inundation to happen. The designed water levels ensure that Fish Fry Creek remains hydrologically disconnected from Wader Pond and Swan Pond (> 0.7 m AHD).

It is suggested that active monitoring remains onsite, including surface water level monitoring and visual inspection of vegetation growth before any changes to the trigger levels. Due to the nature of the project, adaptive management of the trigger levels that aligns with environmental conditions is recommended. The new synthetic tide, alongside the natural tide at Newcastle, is shown in Figure 2. The graph shows the entire 700 tidal cycle that occur in a year.

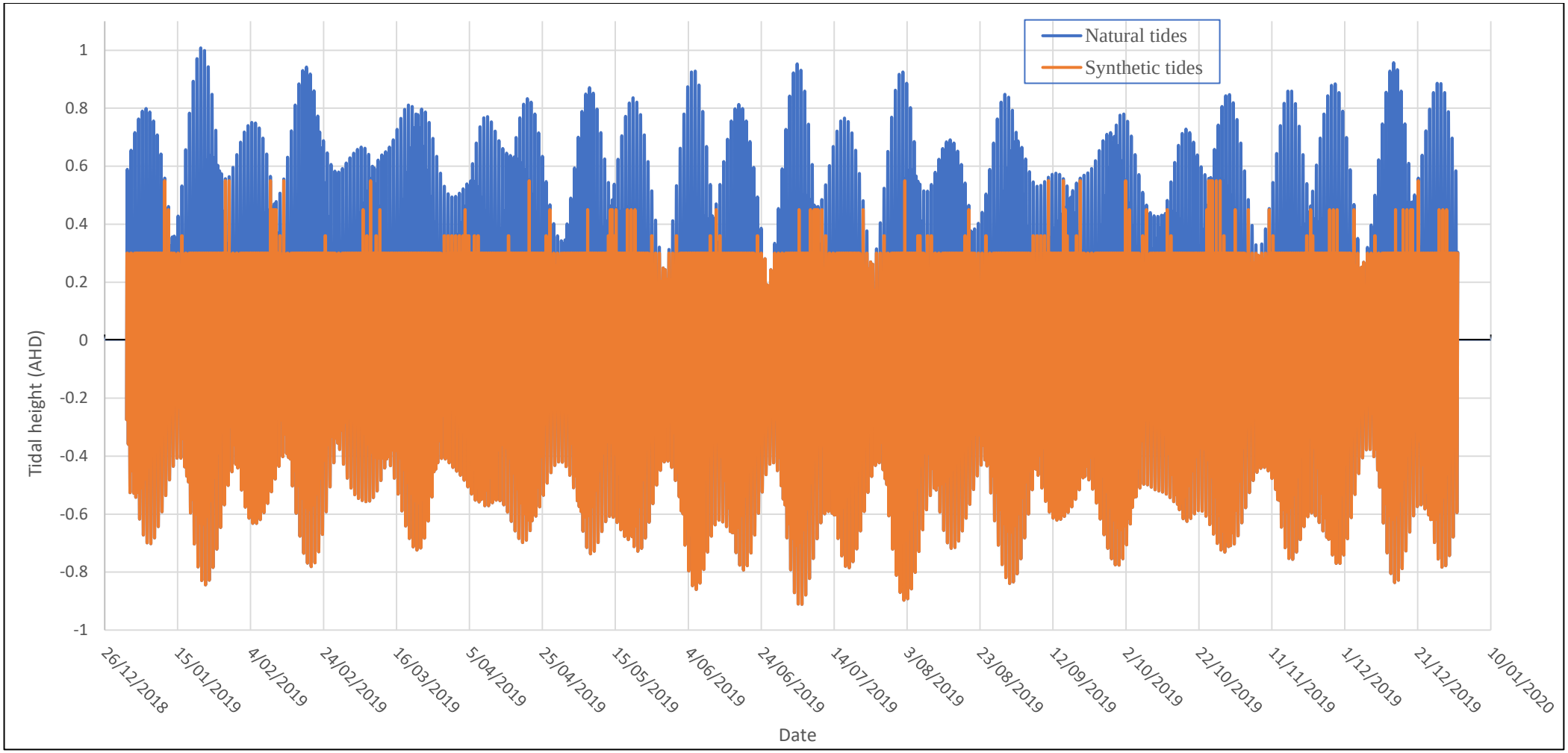

Figure 2. Newcastle natural and synthetic design tides for 2019

3. Hydrology Monitoring

3.1 Groundwater dynamics

Groundwater levels at Area E are continually recorded using Solinst pressure transducer loggers placed in piezometers that were installed in November 2017. Figure 3 shows the location of the piezometers at Area E. In additional to groundwater levels, five piezometers (1, 2, 14, 7, 8 and 15) log groundwater Electrical Conductivity (EC) or salinity. These piezometers were installed in a transect to cover groundwater dynamics on both sides of Fish Fry creek. Data from the loggers were extracted and average monthly groundwater level and conductivity times-series data plots were created for the year 2018 and the first half of 2019 for these piezometers.

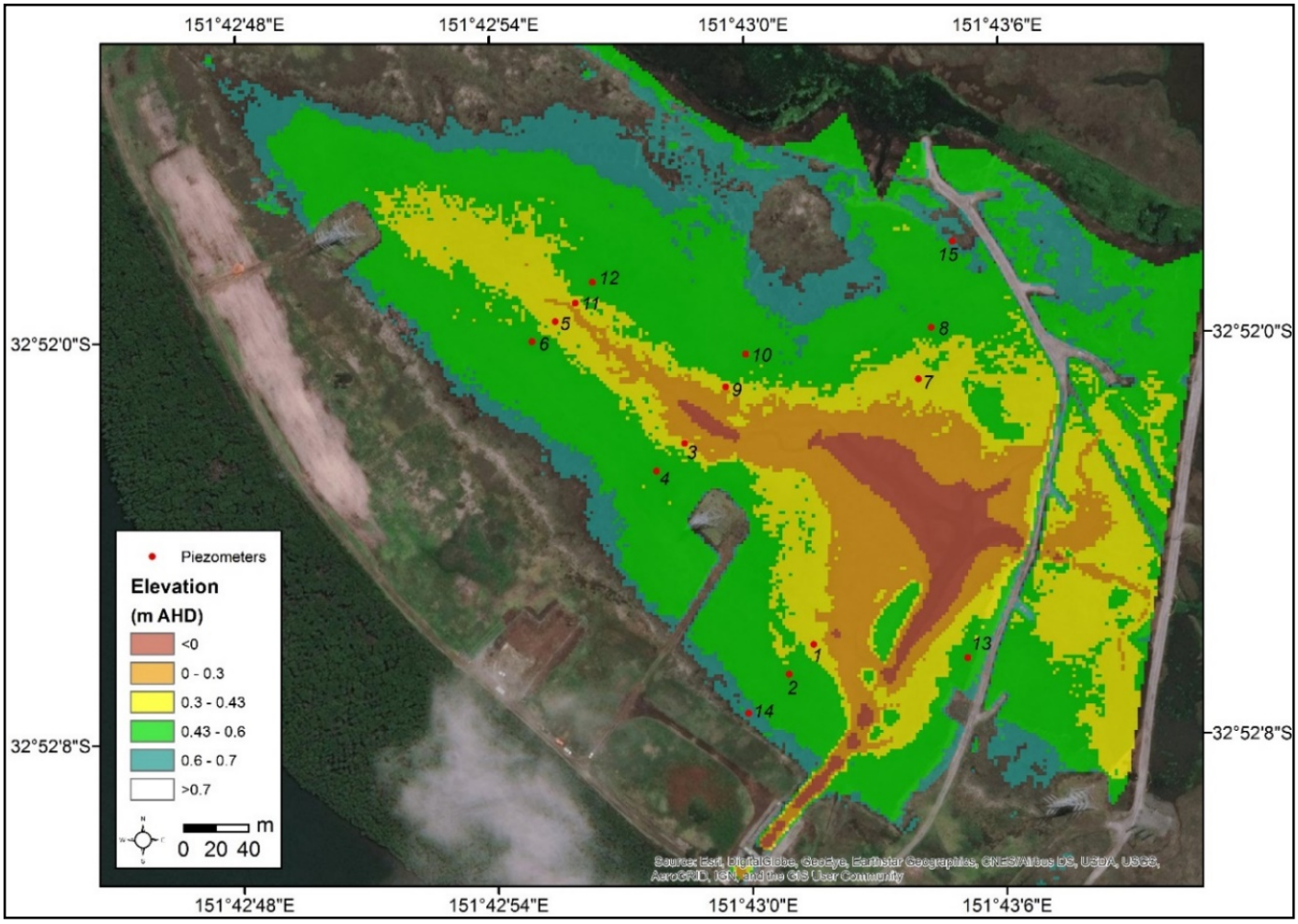

Figure 3. Location of the piezometers at Area E

3.2 Groundwater electrical conductivity (EC)

The average groundwater conductivity at the site was around 56,000 µS/cm for 2018 and 61,000 µS/cm for 2019 (expect for piezometers 1 which was slightly lower at 56,000 µS/cm). Typical ocean water conductivity is around 55,000 µS/cm, therefore the average conductivity of groundwater at the site is above oceanic values, indicating evaporation. The largest changes in conductivity since the start of the monitoring were observed in piezometer 14 (49,000 µS/cm in 2018 and 56,000 µS/cm in 2019). However, Figure 4 shows there is no significant difference in conductivity between the closest and furthest piezometer from the water body which indicates that the shallow groundwater system at the site (the location where the piezometers are installed) is closely connected.

A comparison between conductivity (salinity) levels for 2018 and 2019 in the piezometers show a slight increase for 2019 in all the piezometers. The observed increase is not significant and may be due to different rainfall amounts during 2018 and 2019. For example, the area has received significantly lower rainfalls in the first two months of 2019 which may have led to less flushing and hence a slight increase in conductivity levels. Based on the 2018 data that include every month of the year, a decrease in conductivity in the months of July and August is observed for all the piezometers, which may correspond to low rainfall. Further monitoring of groundwater conductivity and rainfall will facilitate identifying the possible relationship between these two parameters. Additionally, as the saltmarsh vegetation has started to develop at the site (shown later in this report), continues monitoring of groundwater dynamics can play an important role in identifying areas where vegetation may be groundwater dependent for development.

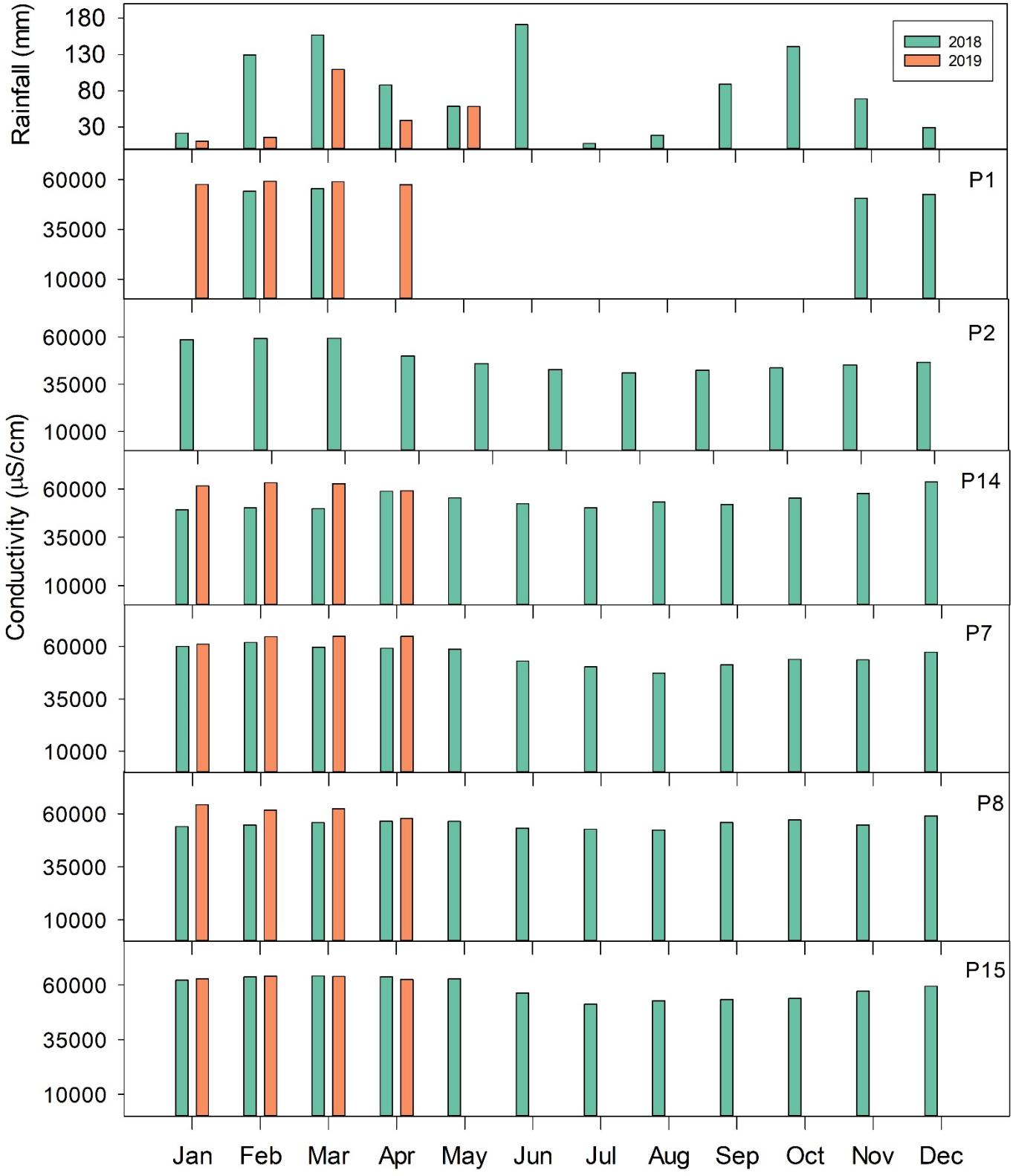

Figure 4. Average monthly conductivity for piezometers 1, 2, 14, 7, 8, and 15 transect.

3.3 Groundwater levels

Figure 5 shows the average monthly groundwater hydraulic heads for piezometers 1, 2, 14, 7, 8 and 15 for 2018 and 2019. Average groundwater hydraulic heads in the piezometers is around 0.6 m for both 2018 and 2019. Groundwater hydraulic heads in all piezometer show similar levels for both years except for piezometer 8 which shows an increase of 40 cm compared to 2018. Groundwater hydraulic heads data for the year 2018 and the first half of 2019 showed a general trend in which the groundwater hydraulic heads decrease in winter months (June, July and August) which may correspond to the lower rainfall in those months at the site.

Groundwater basically flows from locations with higher to lower hydraulic heads. The monitoring data shows that groundwater flow can change direction at the site at different times of the years depending on the rainfall amount, tides and hydraulic heads. For example, in the upper piezometer transect (7, 8, 15) in July 2018, groundwater flows from piezometer 7 to 15 away from the centre of the wetland, whilst the flow direction changes and groundwater moves from piezometer 15 towards 7 in September and/or October 2018. In the lower piezometer transect (1, 2, 14) the groundwater seems to generally flow towards piezometer 14 during all of the year.

In general, groundwater hydraulic heads at Area E are affected by rainfall events but mostly controlled by tides (follow the tidal regime). No obvious unnatural trend was observed in the data, indicating mostly stable conditions post removal of the mangrove vegetation. As the saltmarsh vegetation expansion is occurring at the site, further monitoring of groundwater hydraulic head (level) is necessary to stablish long term trends and links between groundwater dynamics and saltmarsh vegetation growth in such wetland restoration projects.

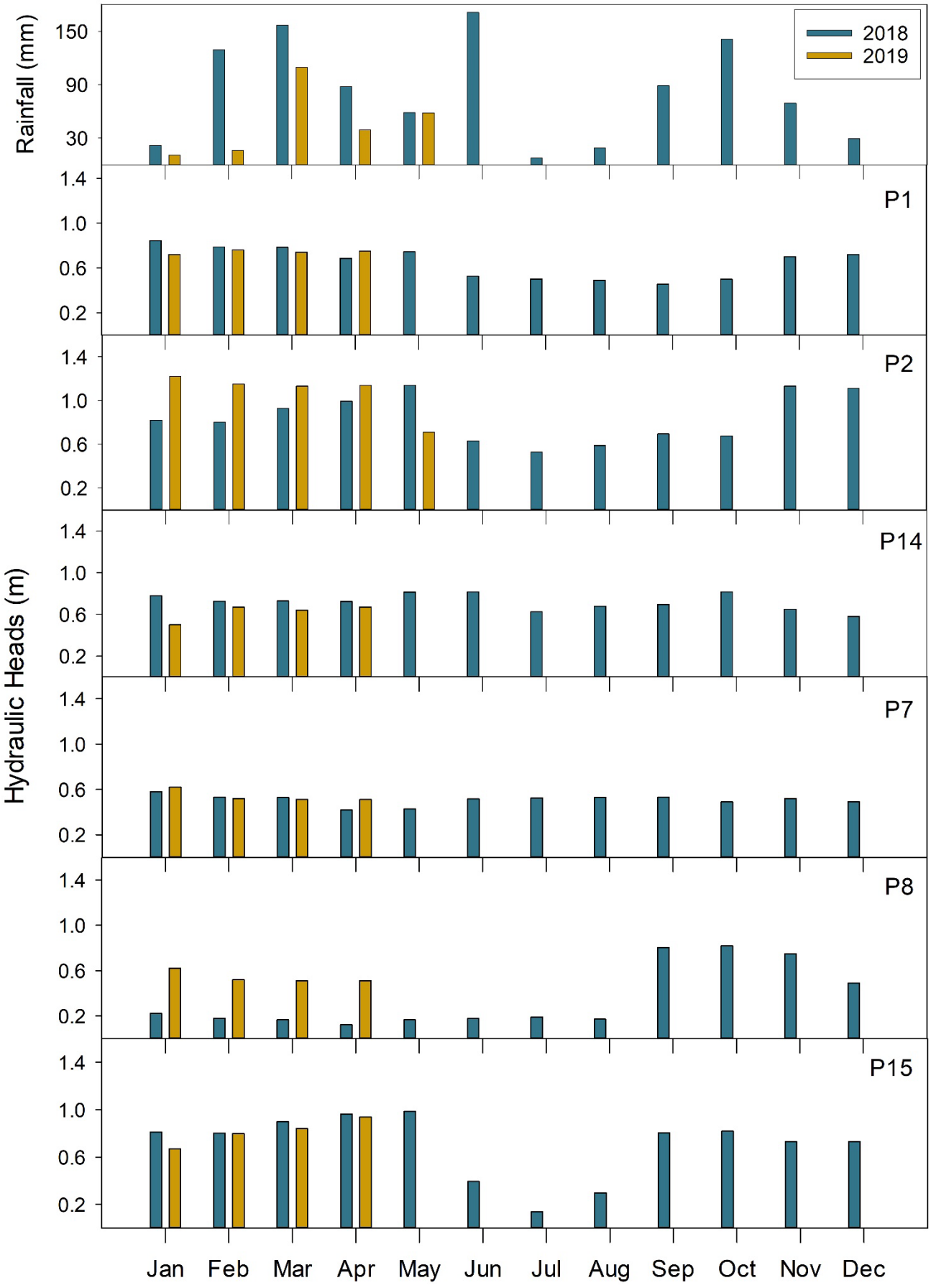

Figure 5. Average monthly hydraulic heads for piezometers 1, 2, 14, 7, 8, and 15 transect.

4. Drone Survey

4.1 Vegetation development

A total of six drone surveys have been conducted to date. Drone surveys were conducted on the 13th February, 5th July and 19th October in 2017, 5th April, 22nd August, and 9th August in 2018 and 30 April 2019. For each drone survey 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, geo-rectified ortho-mosiac was also produced.

Figure 6 shows the imagery for the six drone surveys and changes from February 2017 to April 2019. When comparing the images, distinct vegetation colour and coverage can be observed, however, this may be due to surveys conducted at different seasons in the year with varying factors that can affect vegetation growth and spatial cover. The average monthly rainfall and temperature in addition to date each survey was conducted are presented in Table 1.

Table 1. Date, season, average monthly rainfall and temperature for conducted drone surveys.

Survey	Date	Season	Temp (C)	Rainfall (mm)
1	Feb 2017	Summer	29	59
2	July 2017	Winter	12.4	28.5
3	October 2017	Spring	24.5	113.8
4	April 2018	Autumn	26.5	88
5	August 2018	Spring	19	18.9
6	April 2019	Autumn	24.7	39.4

The obvious change in these six images is the spatial cover of green area in the latest survey (April 2019) compared to images in 2017, suggesting that one-and-a-half-year post restoration, saltmarsh vegetation is developing and expanding in the wetland. The latest captured drone imagery form April 2019 shows saltmarsh vegetation developing along the high tide mark on the mudflats. This survey was conducted in autumn 2019 where average monthly temperature was similar to 2018 but the area received less rainfall compared to 2018 (Table 1). A visual comparison between the first and latest survey shows areas where saltmarsh has started to develop (Figure 7). It is recommended to continue the drone surveys to capture saltmarsh vegetation growth and expansion at the site.

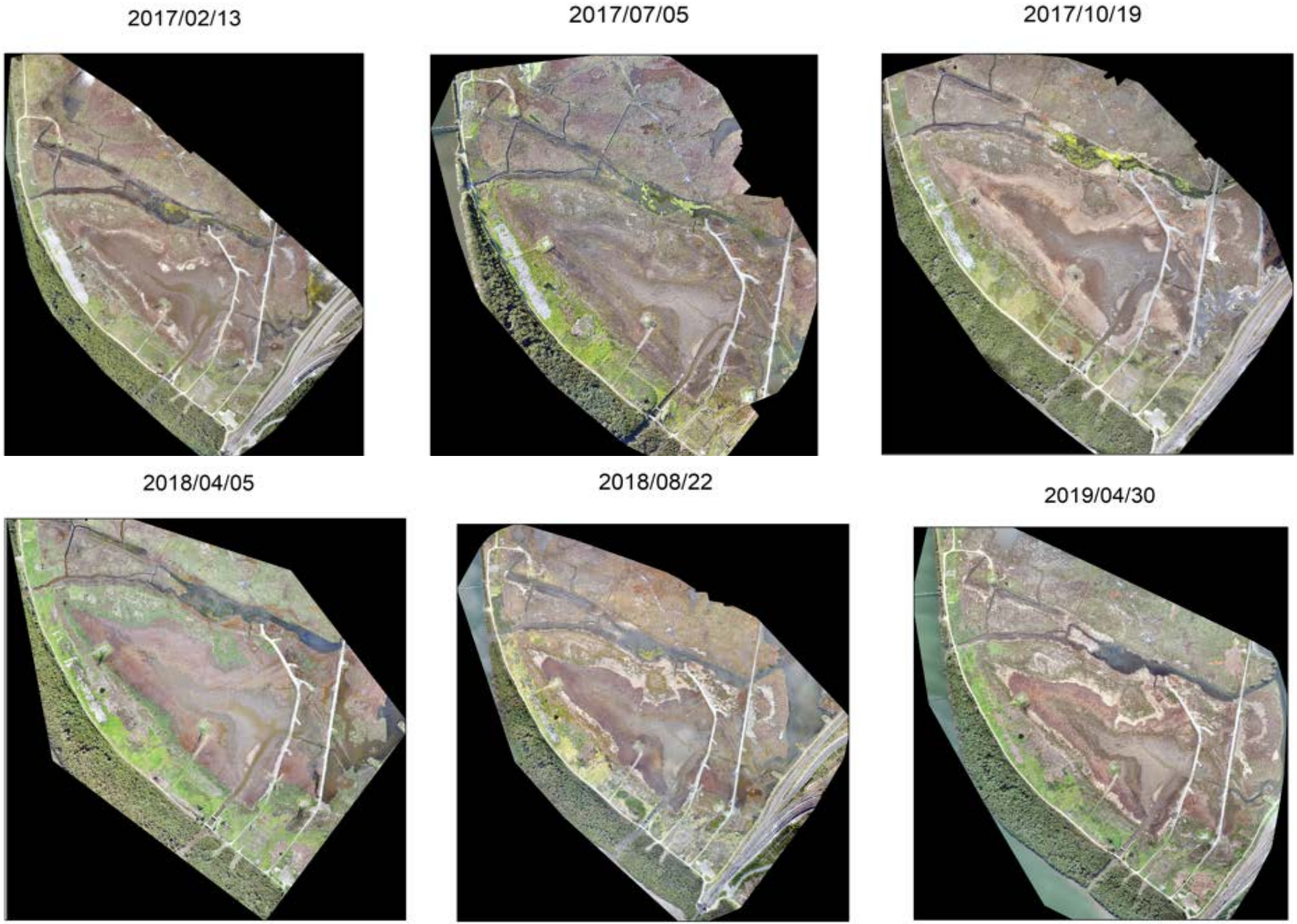

Figure 6. Drone imagery of Area E from February 2017 to April 2019

Figure 7. Drone imagery of Area E.

4.2 Elevation changes

To assess elevation changes at Area E the newest drone imagery (April 2019) was compared to the to the imagery obtained from the first drone survey in February 2017 which acts as baseline data. This analysis was done by creating cross-sections lines with in the wetland and comparing the land elevation. Figure 8 shows the location of the cross-section lines where elevations profile where created and assessed. These cross sections extend the width of the wetland and were selected based on the most assumed affected areas after restoration.

The elevation profile for cross-section 1 (Figure 9) shows a slight elevation reduction for mudflats areas towards the centre of the wetland for the April 2019 data in comparison to the baseline data from Feb 2017. This is also visible and confirmed by site inspections which indicate a ±5 cm surface elevation reduction over the last 1.5 year at the site. Cross-section 2 (Figure 10) shows a 5 cm decrease in elevation for areas north of Fish Fry Creek when comparing the data from April 2019 to baseline data (February 2017). However, April 2019 land elevation data for cross-section 2, show very similar elevations (within 5 cm variation) for areas west of the wetland (close to the power pole) in February 2017, indicating no major surface elevation changes for this area during the past year.

In general, elevation variation at Area E is around 0.05±0.1 meter, which is within the uncertainty of the measurement techniques used. Therefore, elevation changes at Area E 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.

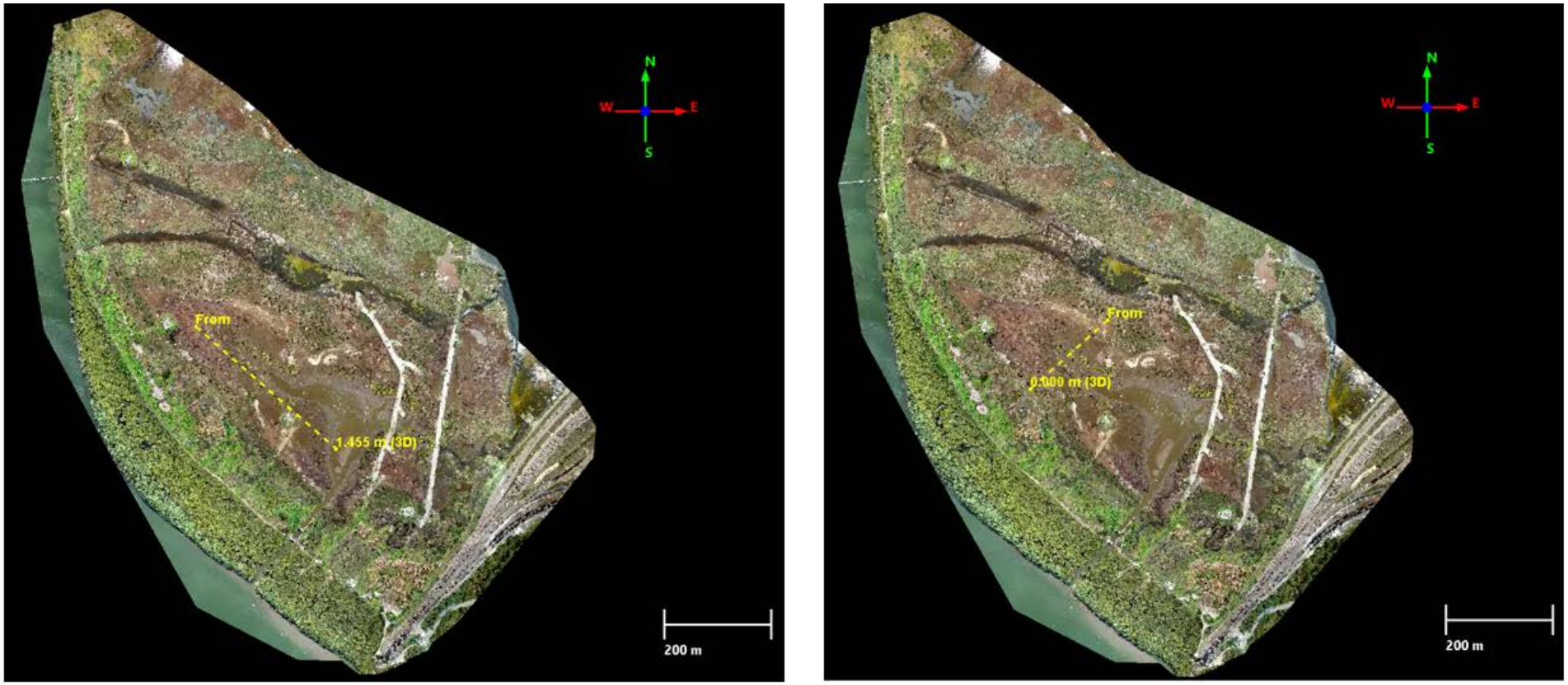

Figure 8. Location of cross section 1 (Left) and 2 (right)

Figure 9. Elevation profile for cross section 1 at Area E. Red line: April 2019; Green line: February 2017; Y and X axis indicate elevation (AHD) and length of the cross-section line, respectively.

Figure 10. Elevation profile for cross section 2 at Area E. Red line: April 2019; Green line: February 2017; Y and X axis indicate elevation (AHD) and length of the cross-section line, respectively

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30th January 2019

Philip Reid
Environmental Advisor
Newcastle Coal Infrastructure Group
30 Raven Street
Kooragang, NSW, 2304

Re: Report for Jan-Jun 2019 Area E shorebird monitoring

Philip

Please find below a report for shorebird monitoring surveys conducted during the January to June period of 2019 over sites at Area E of Kooragang Island.

Please note that the report refers collectively to 2017, 2018 and Jan-Jun 2019.

GFF Reference - GFF 19602

Thanking you

Greg Little
General Flora and Fauna

Introduction

This report documents the January to June 2019 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.

Background information to migratory shorebird presence in Area E is found in earlier 2017 (GFF 16467) and 2018 (GFF 19583) reports. Mangroves were completely cleared by NCIG from the Fish Fry Flat area (the activity area) in December 2016 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).

During 2017 and 2018 surveys 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.

Methods

During the January to June 2019 period, as per 2017-2018, 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 1st half 2019 shorebird survey, plus the 2017 and 2018 surveys, 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

22 shorebird species were recorded during Jan-Jun 2019 from all sites in Area E, as presented in **Appendix-A**. A total of 46 shorebird species have been recorded, by this survey project, for Area E during the 2017, 2018 and the Jan-Jun 2019 surveys. This includes a range of wetland and migratory shorebird species. No new species have been recorded for Area E so far in 2019.

At Fish Fry Flat the "all shorebird" species richness increases through each of the years 2017 and 2018 for Day High Tide surveys (**Fig-2**). Similar trends occur for the day low tide surveys. This trend appears to be a result of the "drying out" of the adjacent Area E reference site ponds during the hot dry months of summer and lower rainfall (**Fig-4**).

Species richness for the latter part of 2018 and early part of 2019 appears to be generally higher than the same 2017-2018 period. Records indicate that the Area E reference site ponds did not dry out during the 2018-2019 period to the same extent as they did during the same 2017-2018 period, probably due to slightly higher rainfall leading up to this period (**Fig-4**).

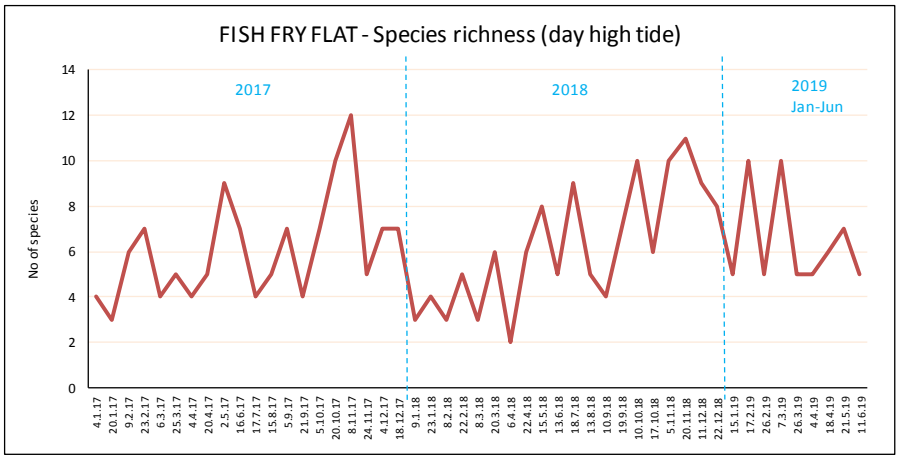


Figure – 2
In 2017-2018 Fish Fry Flat had a rising trend in species richness of all shorebird species through each year. Note that the number of species in the first half of 2019 are generally higher than previous years.

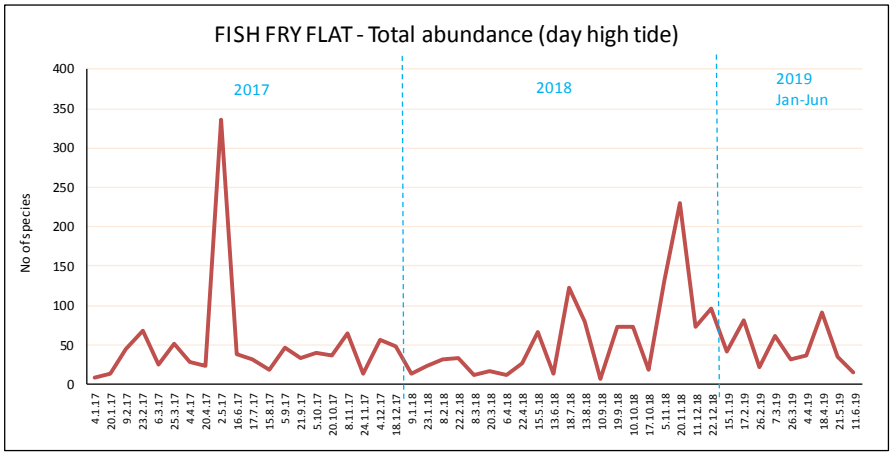


Figure – 3
Total abundance of all shorebird species at Fish Fry Flat during 2017-2018 and Jan-Jun 2019.

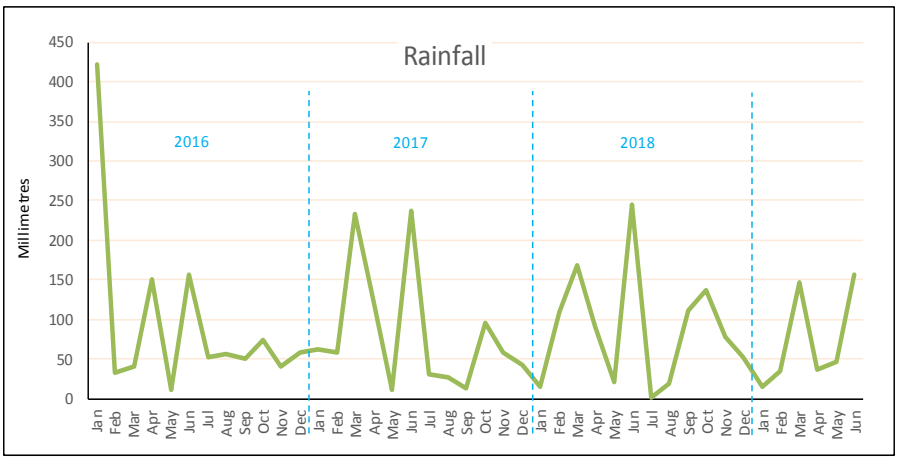
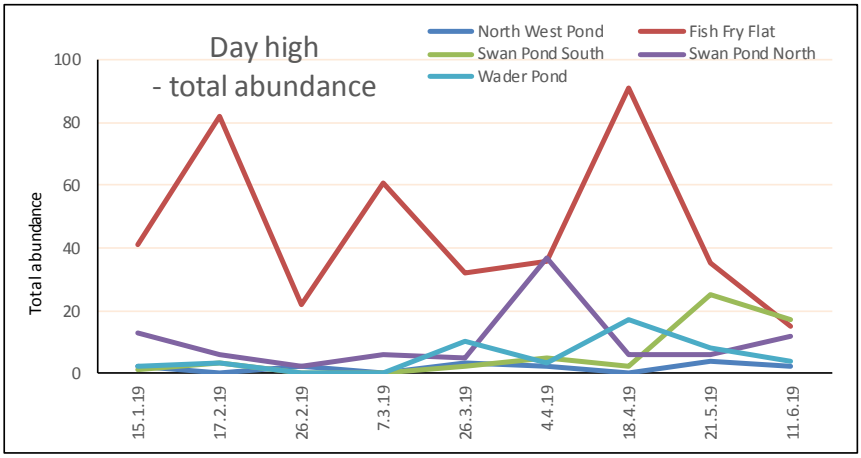


Figure – 4
BoM monthly rainfall data from nearby Williamtown for 2016 to June 2019.

While the adjacent reference site ponds dried out, either partially or completely, Fish Fry Flat retained regular tidal flows in Fish Fry Creek and Wader Creek during those dry periods. How the drying out of ponds elsewhere in Area E affects fluctuations in shorebird species richness at Fish Fry Flat is unknown.

Figure – 5
Total abundance of all shorebird species at all Area E survey sites during Jan-Jun 2019.



Total abundance of all shorebird species at Fish Fry Flat during day high tide appeared to rise through 2018 and fall during early 2019 (**Fig-3**). Similar total abundance results are observed for the day low tide. During 2017 and 2018 total abundance at Swan Pond North was higher through the year than at Fish Fry Flat. However, for the first half of 2019 total abundance for Fish Fry Flat is higher than at Swan Pond North (**Fig-5**).

Migratory Shorebirds

Four (4) migratory shorebird species were recorded at Fish Fry Flat during Jan-Jun 2019 (**Table-1**). No migratory shorebirds were recorded at other sites in Area E during the Jan-Jun 2019 survey period. It is likely that additional shorebird species will be recorded at all sites through the rest of 2019. **Table-1** below presents a summary of presence of migratory shorebird species (11 species) at all sites and Fish Fry Flat during 2017, 2018 and Jan-Jun 2019. Three species, the

Bar-tailed Godwit, Red Knot and Marsh Sandpiper, have not been recorded at Fish Fry Flat during these surveys.

Table - 1 Migratory shorebirds (p) at all sites and Fish Fry Flat during 2017, 2018 and Jan-Jun 2019

All sites	2017	2018	2019 Jan-Jun
Curlew, Eastern	p	p	p
Godwit, Bar-tailed	p		
Greenshank, Common	p		
Knot, Red	p		
Plover, Double-banded	p	p	
Plover, Pacific Golden	p	p	p
Sandpiper, Curlew	p	p	
Sandpiper, Marsh		p	
Sandpiper, Sharp-tailed	p	p	p
Snipe, Latham's		p	
Stint, Red-necked	p	p	p
	9	8	4

Fish Fry Flat	2017	2018	2019 Jan-Jun
Curlew, Eastern	p	p	p
Godwit, Bar-tailed			
Greenshank, Common	p		
Knot, Red			
Plover, Double-banded	p		
Plover, Pacific Golden	p	p	p
Sandpiper, Curlew		p	
Sandpiper, Marsh			
Sandpiper, Sharp-tailed	p	p	p
Snipe, Latham's		p	
Stint, Red-necked	p	p	p
	6	6	4

Activity and habitat use by migratory shorebirds at Fish Fry Flat during 2017 to Jan-Jun 2019 is presented in **Table-2**. There were no migratory shorebirds recorded roosting at night at Fish Fry Flat. Only two species, the Red-necked Stint and Sharp-tailed Sandpiper, were recorded on four occasions "apparently" roosting during the day at Fish Fry Flat. Results show that migratory shorebirds at Fish Fry Flat were foraging, day and night, mostly on the mud at high and low tide. It appears that Fish Fry Flat is not an important high tide roost location for migratory shorebirds.

Table – 2 Migratory shorebird activity and habitat use at Fish Fry Flat during 2017 to Jan-Jun 2019

Fish Fry Flat		DAY												NIGHT											
2017 to Jan-Jun 2019		High Tide						Low Tide						High Tide						Low Tide					
		Foraging			Roosting			Foraging			Roosting			Foraging			Roosting			Foraging			Roosting		
	Days recorded	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water	Saltmarsh	Mud	Water
Curlew, Eastern	14	1	5						5						2						1				
Greenshank, Common	1																					1			
Plover, Double-banded	1								1																
Plover, Pacific Golden	10		1											1	1	1				1	5				
Sandpiper, Curlew	1								1																
Sandpiper, Sharp-tailed	32		8	1					6	2		1			3	4				1	6				
Snipe, Lathams	2														1						1				
Stint, Red-necked	24		5	1	1	3			9	1		1				1					2				

The following observations are made of records of migratory shorebirds at Fish Fry Flat.

- Eastern Curlews - small numbers were recorded foraging mostly in damp mud during day and night surveys, on both high and low tides.

- Pacific Golden Plover – small numbers were recorded foraging mainly at night on the mud on both high and low tides
- Curlew Sandpiper – a single bird was recorded foraging on the mud during day low tide.
- Sharp-tailed Sandpiper - were not recorded during both day and night, mainly on the mud, on both the high and low tides
- Latham Snipe – a single bird was recorded in February on two occasions at night only, once on the low tide and once on the high tide
- Red-necked Stint - small numbers recorded through the year, during both day and night high and low tides. Were recorded apparently roosting during the day high and low tides but were not recorded roosting at night.

White-fronted Chats

During the Jan-Jun 2019 Area E survey period one White-fronted Chat was recorded at Fish Fry Flat only (**Table-3**). Interestingly, White-fronted Chats were not recorded in February at any of the Area E sites in 2017 or 2018.

Table – 3 White-fronted Chat sightings, showing date, location and number of individuals.

Year	2017													2018											2019 Jan-Jun					
Date/Month	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	Jan	Feb	Mar	Apr	May	13.6.18	Jul	Aug	10.9.18	10.10.18	Nov	Dec	Jan	17.2.19	Mar	Apr	May	Jun
Fish Fry Flat																			4			1	2				1				
Swan Pond North					2		4															2									
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 as forage and refuge (roost) habitat. Each species will disperse themselves on low tide into their various favoured foraging habitats including exposed mudflats, shallow water etc. However, all the 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 migratory shorebirds was observed using Fish Fry Flat as a high tide roost. However, a very small number of Red-necked Stints and one Sharp-tailed Sandpiper were observed during the survey apparently roosting at Fish Fry Flat but only during the day.

Most records of migratory shorebirds at Fish Fry Flat (**Fig-1**) were from the centre-north portion between Fish Fry Creek and Wader Creek and around the broad shallow section of Wader Creek.

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?
Shorebird abundance of all species was not negatively affected at ponds in Area E or elsewhere in the Hunter Estuary by mangrove removal from Fish Fry Flat in late 2016. At Fish Fry Flat all shorebird abundance was generally stable in 2017 and increased slightly through 2018 (**Fig-3**). All shorebird abundance at Fish Fry Flat decreased from late 2018 and into Jan-Jun 2019.

Did shorebird species diversity change?
Species diversity/richness of all shorebirds increased through 2017 and 2018 at Fish Fry Flat. There appears to be a trend of species diversity decreasing at the end of each year and then build up through the next year (**Fig-2**). While mangrove removal from Fish Fry Flat appears to have allowed use of this area by shorebird species there may be some other unobserved factor causing this rising trend through each year other than mangrove removal. Compared to data from 2015 surveys there is an increase in migratory species diversity at Fish Fry Flat during 2017 to Jan-Jun 2019.

Did shorebird behavior change?
Most recorded observations of migratory shorebirds at Fish Fry Flat were of birds foraging. There was no obvious large, mixed species, roosting aggregation of migratory shorebirds during day or night high tides. Fish Fry Flat does not appear to support an important high tide roost habitat for local or migratory shorebirds. However, a few records (**Table-2**) show Red-necked Stints and a single Sharp-tailed Sandpiper roosting (maybe just resting rather than roosting) on both the high and low tide during the day at Fish Fry Flat, but not at night. During 2017, 2018

and Jan-Jun 2019 migratory shorebirds are known 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?
There was no change in habitat for White-fronted Chats outside of the Fish Fry Flat area after removal of mangroves in late 2016 from Fish Fry Flat. There appears to be an increase in the extent of saltmarsh habitat in parts of Fish Fry Flat through 2017, 2018 and Jan-Jun 2019, however, this is addressed by a separate vegetation survey. A single White-fronted Chat was recorded at Fish Fry Flat during the Jan-Jun 2019 survey (**Table-3**) but not elsewhere in Area E. White-fronted Chats were not recorded at Fish Fry Flat during 2017 but were recorded in 2018. They have been recorded at Swan Pond North and Wader Pond during the 2017 and 2018 surveys.

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.

No new species were recorded for Area E in Jan-Jun 2019. Fourty six (46) shorebird species, including eleven (11) migratory shorebird species, were recorded from all sites in Area E during the 2017, 2018 and Jan-Jun 2019 surveys. For Jan-Jun 2019 total abundance of all shorebirds at Fish Fry Flat appears to be slightly higher than previous years for the same period. Four (4) migratory shorebird species were recorded at Fish Fry Flat during Jan-Jun 2019 but this is likely to increase through the rest of the year. A small number of Red-necked Stints and a single Sharp-tailed Sandpiper were observed to be roosting during a few visits to Fish Fry Flat in Jan-Jun 2019. However, there was no large mixed species aggregation of roosting migratory shorebirds recorded at Fish Fry Flat during the 2017, 2018 or Jan-Jun 2019 surveys.

Trends suggest from the 2017 and 2018 data that all shorebird species richness (**Fig-2**) increase through the year then crash when ponds dry out about December/January. Species richness numbers have started higher in early 2019 relative to 2017 and 2018. It will be interesting to see where this trend goes and why.

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 the Fish Fry Flat area is not being used as high tide roost habitat by large aggregations of migratory shorebirds.

Much of Fish Fry Flat is daily affected by tides through Fish Fry Creek from the south and Wader Creek from the west. 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 large aggregations of 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 reference sites of Area E. The expanding extent of saltmarsh through parts of the Fish Fry Flat area may have attracted White-fronted Chats. Only a single White-fronted Chats was recorded in Fish Fry Flat during this Jan-Jun 2019 survey.

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 Jan-Jun 2019 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*	P	Mar	Y	Y		Y	Y
Little Black Cormorant	*Phalacrocorax sulcirostris*	P			Y			
Little Pied Cormorant	*Microcarbo melanoleucos*	P			Y			
Eastern Curlew *	*Numenius madagascariensis*	P	Mig,CE,C,J,K		Y			
Black-fronted Dotterel	*Elseyornis melanops*	P			Y	Y	Y	Y
Red-kneed Dotterel	*Erythrogonys cinctus*	P				Y		
Pacific Black Duck	*Anas superciliosa*	P					Y	Y
Eastern Great Egret	*Ardea modesta*	P	Mar,C,J,		Y		Y	
Silver Gull	*Chroicocephalus novaehollandiae*	P					Y	
White-faced Heron	*Egretta novaehollandiae*	P		Y	Y	Y	Y	Y
Australian White Ibis	*Threskiornis molucca*	P		Y	Y			
Masked Lapwing	*Vanellus miles*	P		Y	Y	Y	Y	Y
Nankeen Night Heron	*Nycticorax caledonicus*	P			Y			
Australian Pelican	*Pelecanus conspicillatus*	P			Y			
Pacific Golden Plover *	*Pluvialis fulva*	P	Mig,C,J,K		Y			
Red-capped Plover	*Charadrius ruficapillus*	P	Mar	Y	Y	Y		Y
Sharp-tailed Sandpiper *	*Calidris acuminata*	P	Mig,C,J,K		Y			
Royal Spoonbill	*Platalea regia*	P			Y			
Black-winged Stilt	*Himantopus himantopus*	P	Mar		Y	Y	Y	Y
Red-necked Stint *	*Calidris ruficollis*	P	Mig,C,J,K		Y			
Chestnut Teal	*Anas castanea*	P		Y	Y	Y	Y	Y
Grey Teal	*Anas gracilis*	P		Y	Y	Y	Y	Y
White-fronted Chat	*Epthianura albifrons*	V, P			Y			
Totals -								
Shore/wetland birds -	22			7	19	8	10	9
Bush birds -	1			0	1	0	0	0

* = migratory shorebird

Y = Yes, recorded at that location

P = Protected under the BC Act

V = Vulnerable under the BC Act

E1 = Endangered under the BC Act

CE = Critically Endangered under the EPBC 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

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NCIG GGBF & Shorebird Compensatory Habitat Management

6 Month Works Overview – March 2019 - July 2019

Weed Control

- No weed control was undertaken this period.

Compensatory Habitat Maintenance

- Macrophyte removal was undertaken during March 2019, within Stages 3, 4, 5, and 7, to maintain sufficient open water coverage in ponds dominated by vegetation. Full details of this work are provided in 'Macrophyte Removal Summary Report – March 2019'.
- Slashing of tall weeds within 2m either side of the frog fence in Stage 1 was undertaken in June 2019. The density of weeds inside the fence, particularly Kikuyu, made the efficiency of slashing very slow. As a result less than 50% of the inside fence was slashed. It is proposed that spraying will be undertaken next period in place of slashing to improve efficiency.
- An inspection of trial pond plantings was undertaken during June 2019. Survival is high however smothering from weeds is suppressing growth in some areas, in particular dense Kikuyu. It is recommended that slashing is undertaken around the plantings to suppress competition from dense weeds.

6 month look ahead

The following investigations and preparatory works will need to be undertaken prior to the implementation of the next program of on-ground works:

- Survey weed densities within licence areas to inform the scope of weed control works required for next period.
- Survey mangrove density within Shorebird Compensatory Habitat (Area E) to inform scope of work required for next period.
- Prepare Fox Baiting Plan for submission and approval by NPWS.
- Stake surviving plants and pull weed growth away from plantings in preparation for slashing.

APPENDIX 7

NCIG AVIFAUNA SURVEYS

Hunter Bird Observers Club
Affiliated with BirdLife Australia

Hunter Bird Observers Club Inc
PO Box 24, New Lambton, NSW 2305
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DEEP POND (KOORAGANG ISLAND) AVIFAUNA DATA SUMMARY 2018

Surveys for waterbirds and shorebirds were conducted by the Hunter Bird Observers Club (HBOC) on Deep Pond during 2018, facilitated by the Newcastle Coal Infrastructure Group (NCIG). A summary of results of those surveys for this period is provided in this document. Significant observations of non-shorebirds/waterbirds are also included. Note that this is a broad overview summary and is not intended to be a detailed analysis of results. HBOC reserves the right to publish such analyses in the future.

As first noted in the 2014 report, due to the construction of a rail flyover over the southern part of Deep Pond, there is now 2 ponds that have been surveyed separately from the February 2014 survey onwards. The ponds are referred to as "Deep Pond South" and "Deep Pond North". The latter is the larger and more open of the two ponds and is likely to be of most importance to shorebirds in the future. For the purposes of this report, comments about the amalgam of the two ponds in a general sense refer to "Deep Pond" and where necessary for the sake of specificity, references to Deep Pond South ("DPS") and Deep Pond North ("DPN") have been made.

HBOC personnel that conducted field surveys in 2018 were Mick Roderick and Ian Benson.

BC Act = *Biodiversity Conservation Act* (NSW) 2016
EPBC Act = *Environment Protection and Biodiversity Conservation Act* (Commonwealth) 1999

Shorebirds

Water levels were extremely low early in the year, probably due to the dry conditions experienced in the region and elsewhere. Indeed, DPN was found to be almost completely dry during the February survey, improving only slightly for the March survey. By the time of the April survey some rains had brought a return of water to the ponds. Incidentally, Mick Roderick visited Ash Island on the 24th February 2018 and found that on that date DPN was actually completely dry (rain did fall the following day).

1. Migratory Shorebirds

Four species of migratory shorebird were recorded at Deep Pond during formal surveys in 2018, as listed below:

- Black-tailed Godwit ('Vulnerable' BC Act 2016) – present Jan/Feb and Apr/May, with peak count 71 birds in February
- Sharp-tailed Sandpiper – 15 birds in December only
- Common Greenshank – 29 birds in December only

- Red Knot ('Endangered' EPBC Act 1999) single bird in February

An additional three species were recorded by HBOC observer outside of survey times (on 1st February 2018; refer to notes about incidental records), being.

- Ruff – single bird (rare bird in the Hunter Estuary)
- Curlew Sandpiper ('Endangered' BC Act; Critically Endangered EPBC Act) – 4 birds
- Marsh Sandpiper -13 birds

See here for details https://ebird.org/view/checklist/S42393842

Including incidental observations, a total of twelve species of migratory shorebird have now been recorded on Deep Pond between 2008-2018 (with a total of fourteen species between 1993-2008). Red Knot was a new species recorded for the site during 2008.

Notes and Comments

- As mentioned above, water levels were extremely low at the beginning of the year. By April most ponds were close to capacity again. The benefit of these autumn rains were difficult to judge given that they came at a time when migratory shorebirds were not far from leaving the Hunter Estuary (generally speaking).
- Black-tailed Godwits continue to favour DPN when conditions are good there (or perhaps, less than optimal elsewhere). Once again these counts represented the majority count of Black-tailed Godwits in the Hunter Estuary during the early part of 2018, further confirming that that Deep Pond has particular appeal to Black-tailed Godwits (*contra* Lindsey 2008).
- At the back end of the year, the return of Sharp-tailed Sandpipers and Common Greenshank is very promising. These are two of the species that had been noted consistently during the early years of HBOC surveys in the Hunter Estuary (see Lindsey 2008). At the time of writing (March 2018) this has extended to Marsh Sandpipers as well; a species even more closely associated with Deep Pond during the early phase of shorebird monitoring.
- How the return of migratory shorebirds to Deep Pond has been influenced by conditions locally and/or conditions externally is difficult to be certain about. One would need to look at national shorebird and rainfall data to draw meaningful conclusions. However, it can be said with great confidence that when water levels in Deep Pond (North) are at an optimal level for shorebirds they will use the site if the species are present in the estuary at the time. Combined with the fact that it is often one of the last freshwater ponds in the estuary to completely dry out during drought conditions, the importance of Deep Pond cannot be understated for migratory shorebirds locally. The small numbers and infrequency of shorebirds recorded mostly for the period 2013 to 2017 is probably reflective of water levels being too high for anything but the longest-legged shorebirds to be able to use the site.

2. Resident Shorebirds

Five species of resident shorebird were recorded at Deep Pond during 2018, being:

- Masked Lapwing – several records from both DPN and DPS
- Black-fronted Dotterel – 14 birds in April, including one juvenile
- Black-winged Stilt – peak count of 650 birds in January but with 315 birds "returning" in December
- Red-capped Plover – a single bird during the April surveys
- Red-necked Avocet – peak count of 749 birds in January (this was the single largest count of any species during the year)

The above counts of resident shorebirds reinforces the point made about how shorebirds generally use Deep Pond. In simple terms, if the habitat is suitable on Deep Pond and less than optimal elsewhere the resident shorebirds will use the site.

Waterfowl and other waterbirds

Numerous waterfowl (e.g. ducks, swans, grebes etc) and other waterbirds (e.g. herons, egrets, ibis etc) utilise the Deep Pond area. With the water levels fluctuating as they did in 2018 (from almost dry in summer to returning to capacity through the middle of the year) there was a significant variation in the usage by waterbirds.

Notes

- Significant numbers of waterfowl were recorded at Deep Pond during the December survey. During this survey there were 450 Hardhead present, along with five Freckled Ducks ('Vulnerable' BC Act). Six Glossy Ibis were also present in December; a new species for Deep Pond at the time.
- In addition to the above, 105 Grey Teal and 130 Australasian Shoveler were recorded in May. This is a significant count of the latter for the Hunter Estuary.
- A single Whiskered Tern was present during the November survey; a species rarely recorded on Deep Pond (though possibly more common at nearby Swan/Wader Ponds on Ash Island).
- Black Swans again bred locally, with 6 active nests recorded on Deep Pond South in June.

Other birds

- White-bellied Sea-Eagles ('Vulnerable BC Act) are regularly seen in and around Deep Pond. A bird was observed perched on the bare exposed floor of DPN in February, presumably to look for fish herded into the last remaining puddles of the pond at the time.
- A Pallid Cuckoo was heard calling from east of DPN during the November. This species is not often recorded in this part of the estuary (if at all, it most often on the western side of Hexham Swamp).

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Summary

- The count of migratory and resident shorebirds using Deep Pond in 2018 were quite high, both in terms of the number of species and individual birds.
- Deep Pond (and in particular DPN) remains an important site for particular migratory shorebirds (and waterfowl), especially when conditions elsewhere in the region may not be favourable.
- Given the diversity of avifauna using the site, Deep Pond remains a unique and important habitat entity in the Hunter Estuary.

Prepared by Mick Roderick of the Hunter Bird Observers Club
13 March 2019

Reference

Lindsey, A. (2008). The Birds of Deep Pond – Kooragang Island 1993-2007. *The Whistler.* **2:** 1-12.

APPENDIX 8

COMMUNITY SUPPORT PROGRAM

Organisation	Project
September 2018 Community Support Program	
The Cove Men's Shed	Completion of creek bank stabilisation
Stockton Sharks Football Club	Funding for new POS system in canteen and training gear
Stockton Jellyblubbers	Funding to host Northern Districts Winter Swimming Carnival
Hunter Bible Church	Christmas Carols in Lambton Park
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 play equipment for disabled children
Multiple Sclerosis Limited	MS Symposium in Newcastle
March 2019 Community Support Program	
All Age 2 Team (Belmont Football Club)	New playing kits
Society of Artists Newcastle	Newcastle Art Prize
Hunter Simba Football Club	Hunter Simba FC Season 2019
Thornton Devils Junior Football Club	Install field PA system
Salt Ash Pony Club	Replacement of stolen equipment/uniforms
Multicultural Neighbourhood Centre	Hunter Multicultural Services Expo 2019
Stockton Women's Bowling Club	Surfside Fours Carnival
Mentor Support Network	Educational and Career Development Scholarships
Your Dream Schools	Student Wellbeing Program
Kiwanis Beachside Newcastle	Beachside Bags
Dudley Junior Rugby League Football Club	Goal post pads and gazebo
Variety	Variety Spin 4 Kids
TAD	Essential Volunteer Resources
Zara's House	Zara's House Access and Security
Shortland Waters Golf Club	Treatment of water weeds for preservation of wildlife
Stockton Public School P&C	Sensory Garden for Stockton Public School Stage 1 Play Area
South Newcastle Women's Hockey Club	Replace hockey playing socks for all junior players
Families Supporting Families	Family Support and Connection Program
Stockton Cricket Club	Replace wicket covers
Lifeline	World Suicide Prevention Walk
Surfing Newcastle	2019 NSW Junior Regional Titles