Floating Photovoltaic System on Kranji Reservoir – Environmental Impact Assessment (EIA)

Volume 4 – Appendix 7.2 to 7.7

Version 1.0 (Final)

May 2024

Project No.: 0566575

Sustainability is our business

ERM

1. This Report has been prepared exclusively for the use and benefit of Environmental Resources Management (S) Pte Ltd's ("ERM") Client, the Renewable Energy User selected by EDB ("Client"), to assist in determining the technical feasibility and environmental impact of the potential deployment of a large-scale floating photovoltaic system to generate renewable energy for private sector consumption in Singapore ("System"). A Developer/ Owner (to be selected and appointed) will own, design, install, operate and maintain the System.
2. This Report has been prepared by ERM in accordance with generally accepted consultancy principles and is subject to the scope, materiality, guidelines, qualifications, methodology and assumptions that are set out or otherwise referenced in the Report and the terms of reference agreed between ERM and the Client, and is published on the express condition that ERM, the Client and their respective affiliates, officers, employees, agents, representatives and advisors ("Disclaiming Parties") each fully disclaims all liabilities or responsibilities whatsoever for any use of or reliance on this Report by any third party. The Disclaiming Parties (a) make no representations or warranties (express or implied) to any third party as to the accuracy, reliability, currency, adequacy or completeness of the Contents or with respect to the use of or reliance on any Contents disclosed in this Report and (b) assume no liability whatsoever with respect to or arising from any error, omission, inadequacy, incompleteness or mis-statements in the Contents and/or the use of or reliance on any Contents disclosed in this Report. Any use of or reliance on this Report by any third party is solely at its own risk and the Disclaiming Parties are fully released from any and all liabilities for direct, indirect, consequential or special loss or damage whether arising in contract, warranty, express or implied, tort or otherwise, and irrespective of fault, negligence and strict liability.
3. Following the completion and approval of the Environmental Impact Assessment by the relevant statutory authorities, none of the Disclaiming Parties assume any obligation (expressed or implied) to update, correct or supplement any assumption, finding, statement, recommendation, method or information contained in this Report ("Contents") or to inform any third party of any revisions to or corrections of the Contents or any facts, events, matters or circumstances occurring after the date of this Report which may invalidate, affect or qualify any part of the Contents.
4. This Report includes forward-looking statements, plans or information. These forward-looking statements, plans or information reflect, amongst others, ERM's views as to how the implementation of the Project will affect Kranji Reservoir (as identified in the Report) ("Site") and are based on certain assumptions made by ERM based on consultations with and input from public stakeholders, nature groups and government agencies as well as assumptions with respect to certain future events projected as of the date of this Report. These forward-looking statements, plans or information are subject to, without limitation, future economic condition, future condition or intended use of the Site and other risks, events or factors and uncertainties that may arise during the course of the System's deployment, development and operation to be undertaken by the Developer/ Owner. Actual condition of the Site and impact of the Project on the Site could therefore differ materially from those set forth in such statements, plans or information.
5. This Report further includes recommendations, findings and plans made or proposed by ERM based on consultations with and input from public stakeholders, nature groups and government agencies. Nothing in this Report shall impose any obligation or duty on any of the Disclaiming Parties to implement (or procure any person to implement) any such recommendations, findings and/or plans and the Disclaiming Parties undertake no duty nor accept any responsibility to any third party with respect to the same.
6. Reproduction and redistribution of this Report without the prior written permission of ERM and the Client is strictly prohibited. No third party shall obtain any right or interest in or to the Report, or utilise, refer or otherwise use this Report for any purpose other than the sole purpose of understanding and reviewing the potential environmental impact of the System on the Site. By accessing or downloading this Report, the recipient acknowledges and agrees that it understands, accepts and agrees to the disclaimers and qualifiers herein.

Signature Page

May 2024

Version 1.0 (Final)

Floating Photovoltaic System on Kranji Reservoir – Environmental Impact Assessment (EIA)

Volume 4 – Appendix 7.2 to 7.7

Terence Fong
Partner

Mark Eisenegger
Partner

ERM Singapore Pte Ltd

20 Collyer Quay, #15-01/02

Singapore 049319

APPENDIX 7.2 AQUATIC BASELINE REPORT

CONTENTS

Appendices

List of Tables

List of Figures

Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profilers
Al	Aluminum
As	Arsenic
B	Boron
Ba	Barium
BOD5	Biological oxygen demand
BQI	Benthic Quality Index
Cd	Cadmium
Cl-	Chloride
CN	Cyanide
COC	Chain of Custody
Cr	Chromium
Cu	Copper
DO	Dissolved oxygen
DOC	Dissolved organic carbon
eDNA	Environmental DNA
EIA	Environmental Impact Assessment
Fe	Iron
FFG	Functional Feeding Guild
FPV	Floating Photovoltaic
Hg	Mercury
IUCN	International Union for Conservation of Nature
LOI	Loss On Ignition
Mo	Molybdenum
Mn	Manganese
NH3	Ammonia
Ni	Nickel
NO3	Nitrate
NO2-N	Nitrite
NParks	National Parks Board
PAR	Photosynthetically Active Radiation
Pb	Lead
PO4	Phosphate
PUB	Public Utilities Board
QA	Quality Assurance
QC	Quality Control
RPD	Relative Percent Difference
Sb	Antimony
Se	Selenium
Si	Silver
Sn	Tin
SO42-	Sulphate
S2-	Sulphide
TC	Total Carbon
TCM	Tilt Current Meters
TL	Total Length
TN	Total Nitrogen

TP	Total Phosphorous
TSP	Total Suspended Particulates
TSS	Total Suspended Solids
TOC	Total Organic Carbon
μm	Micrometre
Zn	Zinc

1. INTRODUCTION

Aquatic environment surveys have been conducted to establish the existing aquatic conditions within the Kranji Reservoir to inform the Environmental Impact Assessment (EIA) of the Floating Photovoltaic (FPV) System on Kranji Reservoir.

Hydrobiology Pte Ltd (Hydrobiology) were commissioned by Environmental Resources Management (S) Pte Ltd (ERM) to carry out the comprehensive aquatic baseline surveys.

The aquatic baseline surveys included:

- Aquatic biodiversity;
- Water quality and hydrology; and
- Reservoir bed sediment quality.

The coverage and methodologies of the aquatic baseline surveys were discussed and agreed with relevant Government agencies (e.g. PUB and NParks) and other stakeholders (e.g. Nature Groups).

Following this introduction, this Report sets out:

- Survey methodologies;
- Baseline findings; and
- Summary.

A number of Appendices are attached to this Report containing supplemental information.

2. METHODOLOGY

This Section outlines the agreed survey methodologies. The Reservoir Study Area was delineated to include:

i) Reservoir Project Site boundary; and

ii) Southern reservoir, beyond the Reservoir Project Site boundary but within the broader Kranji Reservoir.

All boat-based surveys were subject to health and safety considerations, actual site conditions and relevant Government approvals (including related to COVID-19).

A summary of the surveys is outlined in *Table 2-1*, and survey/ sampling locations are indicated in *Figure 2-1.*

Table 2-1: Summary of Aquatic Baseline Approach

Topic	Sampling & Data Collection	Transect/ Sampling Points	Frequency/ Duration
Light penetration [(a)]	■ Underwater Light penetration – Photosynthetically Active Radiation (PAR) Logger sampling ■ In-situ handheld LI-COR radiation sensor	■ Six locations	■ Over two weeks
Water quality	■ Water quality sampling	■ Five locations	■ Monthly for six months ■ One-time storm event
Reservoir bed sediment quality	■ Sediment sampling	■ Five locations	■ Once every two months over a period of six months
	■ Pore water and elutriate	■ Five locations	■ One-off
Aquatic Biodiversity	■ Benthic community analysis	■ Five locations (sediments) ■ Seven locations ■ Five locations (colonisers)	■ Sediments collected once every two months for six months ■ Sweep sample collection was a one-off event ■ Colonisers deployed in reservoir for four weeks
	Aquatic fauna fish distribution and biomass: ■ eDNA sampling for multi-species detection ■ Hydroacoustics	■ Five transects along reservoir edge ■ Transects over a period of 10 nights	■ One-off
	Aquatic vegetation sampling: ■ Sonar measurement and imaging along transects across Reservoir Study Area for habitat and aquatic vegetation mapping ■ Grab sampling/ Rake-dragging	■ Transects ■ Five locations, with 10 replicates per location	■ One-off

Topic	Sampling & Data Collection	Transect/ Sampling Points	Frequency/ Duration

Notes:

(a) Light assessment was initially proposed as a one-off event over a duration of 6 months with monthly maintenance to be carried out. However, it was noted that the data collected were unreliable due to rapid biofouling and overgrowth of water hyacinths. The deployment plan was changed to a rapid study carried out over a two- week duration from 26 Aug 2021 to 9 Sep 2021. This report only presents data collected and analysed from the rapid study.

2.1 Light Penetration

A consolidated light monitoring program was designed with the intention of measuring the baseline light condition (i.e., measure diffusion of sunlight through water) at various depths in the Kranji Reservoir. The methods used in the light measurement program included short-term deployment of Photosynthetic Active Radiation (PAR) loggers and in-situ light measurement by using a handheld LI-COR radiation sensor at various locations in the reservoir. An initial program of a long-term deployment of PAR loggers had been found to be unreliable and ineffective due to excessive biofouling on the sensors and overgrowth of water hyacinths during the initial deployment program. As such, the deployment plan was changed to a rapid study, the consolidated light measurement program took place over a period of 2 weeks (26 Aug 2021 to 9 Sep 2021). The planning and implementation of the light measurement as well as the analysis of the measurement data mainly followed the guidelines recommended by Department of Environment and Science (DES) (2018).

Three PAR loggers were submerged for a total duration of 7 days, approximately 1 m below the water surface at each of the three locations (*Figure 2-1*). Light intensities were continuously recorded at 1-minute intervals with the expectation that different light regimes (i.e., strong sunlight and overcast) could be captured during the deployment period. The PAR loggers were also serviced every 3 days to rule out the effect of biofouling. A PAR logger was also deployed on land in proximity to the reservoir to record the incident ambient light in the air before any attenuation in the water. The purpose of this was such that the light intensity could be recorded continuously and compared to the values above and below the water surface.

In-situ light measurements were also undertaken by using a handheld LI-COR radiation sensor every 50 cm throughout the water column at 6 selected locations in the reservoir (*Table 2-2*). The light intensity above the water surface were also recorded before measuring the light intensity in the water. Measurements were carried out at noon up to mid-afternoon when the sun provided the strongest light. This, coupled with the deployment of the PAR loggers, provided a comprehensive approach to fully investigate light attenuation throughout the water column instead of just 1m depth below water surface. Furthermore, in-situ measurements were able to be carried out at more locations and depths due to the intrinsic flexibility of using handheld devices.

Table 2-2: Light Measurement Deployment Locations

Location	Coordinates (WGS84)		Description
	x	y	
PAR1 LI-COR1	103.727500	1.410261	■ South of Reservoir Project Site ■ Water depth: approximately 6m ■ South-west where tributaries feed into the reservoir
PAR2 LI-COR2	103.732250	1.416611	■ Within Reservoir Project Site ■ Water depth: approximately 6m ■ West near the PUB Kranji bund
PAR3 LI-COR3	103.741839	1.425281	■ Within Reservoir Project Site ■ Water depth: approximately 10m ■ Deeper part of reservoir
LI-COR4	103.738822	1.426667	■ Within Reservoir Project Site ■ Water depth: approximately 1m ■ Shallower western portion towards the PUB Kranji bund

Location	Coordinates (WGS84)		Description
	x	y	
LI-COR5	103.737931	1.423031	■ Within Reservoir Project Site ■ Water depth: approximately 1m ■ Shallower western portion towards the PUB Kranji bund
LI-COR6	103.740994	1.436072	■ Northern boundary of Reservoir Project Site ■ Water depth: approximately 3m ■ Northern extent nearer to Kranji tidal gates
PAR (Land)	103.736102	1.437534	■ On land ■ Measuring incident ambient light

2.2 Water Quality

Monthly water quality sampling was carried out at 5 pre-selected locations within Kranji Reservoir from December 2020 to June 2021. These locations were pre-determined by PUB and the Project engineers. Note that some ex-situ parameters were not measured in December 2020 and were therefore resampled in June 2021. An additional reservoir water sampling event was also carried out in September 2021 after a storm event to capture baseline conditions for runoff water analysis. The rationale for the water sampling locations is presented in *Table 2-3* and are shown in *Figure 2-1*.

Relevant water quality measurements and samples were collected and parameters were analysed at various depths. In-situ water profiles were taken at 0.5m below the water surface, mid-depth and 0.5m above reservoir bed with a calibrated sonde YSI ProDSS; while water samples were collected at mid-depth and 0.5m above reservoir bed with a Van Dorn water sampler for laboratory analysis. The collected water samples were chilled and sent to a SINGLAS accredited laboratory with a completed Chain of Custody (COC) form. The results were compared against the allowable limits of NEA Allowable Limits for Trade Effluent Discharge to Controlled Watercourse or against PUB's internal limits where available. Where no allowable limits are provided, the results from this baseline study may be used as a comparison criterion for future testing in subsequent phases of this Project. *Table 2-4* provides a summary of the water quality parameters, test methods, sampling depths and allowable limits for the water quality sampling program.

Phytoplankton and zooplanktons are also considered an indicator of water quality, and hence were collected using a tow net of 53 µm and 250 µm respectively at 0.5 m below the water surface at the 5 locations. Both phytoplankton and zooplankton were analysed for count and species. The Shannon-Biodiversity Index was applied, which accounts for both abundance and evenness of species present in the community to calculate the diversity of the species within the reservoir. More details on the Shannon-Biodiversity Index can be found in *Section 2.4.4*.

Table 2-3: Water Quality Sampling Locations

Location	Coordinates (WSG84)		Rationale
	x	y	
WQ01	103.74095	1.43116	To establish baseline water quality within the Reservoir Project Site
WQ02	103.73972	1.42146	To establish ambient conditions from drainage outfall (Pang Sua Diversion Canal) on the eastern reservoir bank; within the Reservoir Project Site
WQ03	103.73124	1.41421	To establish ambient conditions from drainage outfall on the

Location	Coordinates (WSG84)		Rationale
	x	y	
			eastern reservoir bank; within the Reservoir Project Site
WQ04	103.7177	1.41087	To establish ambient conditions from Kangkar River; south (upstream) of the Reservoir Project Site
WQ05	103.72826	1.40577	To establish ambient conditions from Sungei Peng Siang and Sungei Tengah; south (upstream) of the Reservoir Project Site

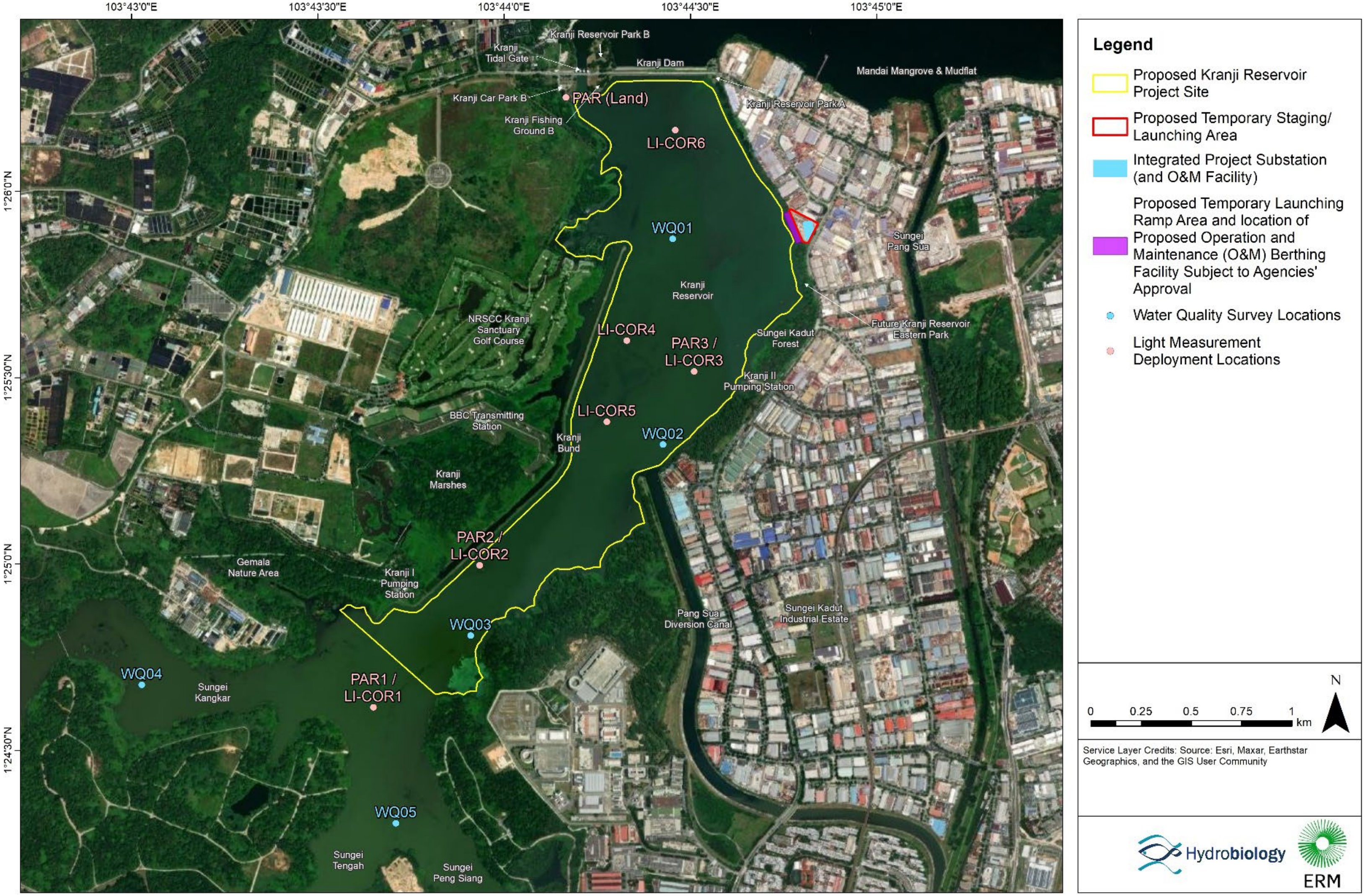


Figure 2-1: Water Quality Survey Locations

Table 2-4: Water Quality Parameters, Test Methods, Sampling Depths and Allowable Limits

Parameters	Test Method	Unit	Sampling Depth	NEA Allowable Limit for Trade Effluent Discharge[a]
Temperature	In-situ measurement via calibrated YSI probe	°C	■ 0.5 m below water surface; ■ Mid-depth; and ■ 0.5 m above reservoir bed.	-
pH		-		6 to 9
Conductivity		µs/cm		-
Turbidity		NTU		-
Dissolved oxygen (DO)		mg/L		-
Secchi depth	-	m	■ Water column	-
Total organic carbon (TOC)	APHA 5310B / C	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	10[b]
Dissolved organic carbon (DOC)	APHA 5310B	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	-
Ammonia as NH_3-N	APHA 4500-NH3 (H)	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	0.5[b]
Nitrate as NO_3	APHA 4500-NO3 (I)	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	-
Total nitrogen (TN)	APHA 4500-P (J)	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	-
Dissolved phosphorous	APHA 4500-P (J)	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	-
Total phosphorous (TP)	APHA 4500-P (J)	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	-
Phosphate as PO4	APHA 4500-P (G)	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	2
Sulphide	APHA 4500-S2- (D)	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	0.2
Microcystin-LR	LCMS-MS	µg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	1[b]
Chlorophyll-a	APHA 10200H (2) (Spectrophotometric)	µg/L	■ Mid-depth	-
2-Methylisoborneol (MIB)	APHA 6040D	ng/L	■ Mid-depth	100
Geosmin	APHA 6040D	ng/L	■ Mid-depth	100
Total Microcystins	LCMS-MS	µg/L	■ Mid-depth	-
Clindrospermopsin	LCMS-MS	µg/L	■ Mid-depth	-

Parameters	Test Method	Unit	Sampling Depth	NEA Allowable Limit for Trade Effluent Discharge[(a)]
Chloride as Cl	APHA 4110B	mg/L	■ Mid-depth	250
Oil & Grease (Total)	In-house method - MLS-SOP-WQ-033 Rev 0 (adapted from APHA 5520C)	mg/L	■ Mid-depth	1
Colour	-	Lovibond	■ Mid-depth	7
Biochemical Oxygen Demand as BOD_5	APHA 5210B	mg/L	■ Mid-depth	20
Chemical Oxygen Demand as COD	APHA 5220D	mg O2/L	■ Mid-depth	60
Total Suspended Solids (TSS)	APHA 2540D	mg/L	■ Mid-depth	30
Total Dissolved Solids (TDS)	APHA 2540C	mg/L	■ Mid-depth	1,000
Sulphate as SO4	APHA 4110B	mg/L	■ Mid-depth	200
Cyanide as CN	APHA 4500-CN (N)	mg/L	■ Mid-depth	0.1
Detergents (LAS as MBAS)	APHA 5540C	mg/L	■ Mid-depth	5
Sulphide as Sulphur	APHA 4500-S2- (D)	mg/L	■ Mid-depth	0.2
Antimony as Sb	APHA 3125B	mg/L	■ Mid-depth	-
Molybdenum as Mo	APHA 3125B	mg/L	■ Mid-depth	-
Arsenic as As	APHA 3125B	mg/L	■ Mid-depth	0.01
Aluminium as Al	APHA 3125B	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	-
Barium as Ba	APHA 3120B	mg/L	■ Mid-depth	1
Tin as Sn	APHA 3125B	mg/L	■ Mid-depth	5
Iron as Fe	APHA 3125B	mg/L	■ Mid-depth; and ■ 0.5 m above reservoir bed.	1
Beryllium as Be	APHA 3125B	mg/L	■ Mid-depth	0.5
Boron as B	APHA 3120B	mg/L	■ Mid-depth	0.5
Manganese as Mn	APHA 3120B	mg/L	■ Mid-depth	0.5
Phenolic compounds (as Phenols)	APHA 5530D (Determination)	mg/L	■ Mid-depth	-
Cadmium as Cd	APHA 3125B	mg/L	■ Mid-depth	0.003
Chromium as Cr (trivalent and hexavalent)	APHA 3125B	mg/L	■ Mid-depth	0.05
Copper as Cu	APHA 3125B	mg/L	■ Mid-depth	0.1
Lead as Pb	APHA 3125B	mg/L	■ Mid-depth	0.1
Mercury as Hg	USEPA 245.1 (FIMS) (1994)	mg/L	■ Mid-depth	0.001
Nickel as Ni	APHA 3125B	mg/L	■ Mid-depth	0.1

Parameters	Test Method	Unit	Sampling Depth	NEA Allowable Limit for Trade Effluent Discharge[(a)]
Selenium as Se	APHA 3125B	mg/L	■ Mid-depth	0.01
Silver as Ag	APHA 3125B	mg/L	■ Mid-depth	0.1
Zinc as Zn	APHA 3120B	mg/L	■ Mid-depth	0.5
Metals in total	By calculation	mg/L	■ Mid-depth	0.5
Free Chlorine as Cl_2	Lovibond Test Kit (DPD) Rev 1.0	mg/L	■ Mid-depth	1
Phosphate as PO_4	APHA 4500-P (G)	mg/L	■ Mid-depth	2
Calcium as Ca	APHA 3120B	mg/L	■ Mid-depth	150
Magnesium as Mg	APHA 3120B	mg/L	■ Mid-depth	150
Nitrate as NO_3	APHA 4500-NO3 (I)	mg/L	■ Mid-depth	20
Phytoplankton – species and counts	APHA 10200F (2017)	-	■ 0.5 m below water surface	-
Zooplankton – species and counts.	APHA 10200G (2017)	-	■ 0.5 m below water surface	-

Notes:
(a) NEA Allowable Limits for Trade Effluent Discharge to Controlled Watercourse, unless stated otherwise
(b) PUB's internal alert levels for reservoir water quality

2.2.1 QA/QC Program

A Quality Assurance and Quality Control (QA/ QC) program was implemented to detect if any contamination was introduced during the field sampling and transport. In addition, field duplicate samples were also sent to an independent laboratory for analysis for inter-laboratory quality control and assurance purposes. Replicate samples were collected once every month, making up 10% of the monthly water samples. This allowed for the detection of natural variation. The QA/ QC test program is presented in *Table 2-5*.

The detailed QA/ QC program was designed as follows, described as two approaches:

1. Aimed at detecting contamination within lab-provided bottles, conducted in December 2020, January 2021 and February 2021. Field duplicate samples (rinsed and without rinsed bottles) were obtained by collecting two samples from the same sampling site at the same time, using exactly the same methods to represent the same environmental condition. The grab sampler and lab bottles were rinsed with de-ionised water before filling with a single grab water sample from the same location. A second sample was collected and put into an unrinsed bottle. This program was used to identify potential errors or contamination (if any) in sample collection and analysis.

2. Aimed at detecting inter-laboratory differences, conducted: in March 2021, April 2021 and May 2021. Field replicate samples were obtained by collecting two samples from the same sampling site at the same time, using exactly the same methods to represent the same environmental condition. These samples were sent to two different laboratories for analysis. In addition, field blank samples of de-ionised water were also analysed as if they were a sample.

   The assessment of duplicates is commonly undertaken by expressing duplicate results as Relative Percent Difference (RPD). A RPD of ≤20% may indicate an acceptable result for duplicate aqueous samples (DES, 2018). RPD is calculated as follows, and RPD results are presented in *Section 3.2.3.*

$$RPD = \frac{|C_1 - C_2|}{\left(\frac{C_1 + C_2}{2}\right)} \ x\ 100$$

Where:

C_1 = concentration of analyte from Sample 1; and

C_2 = concentration of analyte from Sample 2.

Table 2-5: Water Quality Parameters and Respective Test Methods for QA/QC Program

Parameters	Test Method
Ammonia as NH_3	APHA Pt 4500-NH_3 (H)
Nitrate as NO_3^-	APHA Pt 4500-NO_3 (I)
Phosphate as PO_4	APHA Pt 4500-P (G)
Sulphide as S^{2-}	APHA Pt 4500-S^{2-} (D)
Iron as Fe	APHA Pt 3120B
Aluminium as Al	APHA Pt 3120B
Chloride as Cl^-	APHA Pt 4110B
Sulphate as SO_4^{2-}	APHA Pt 4110B
Cyanide as CN-	APHA Pt 4500-CN- (N)
Arsenic as As	APHA Pt 3120B
Barium as Ba	APHA Pt 3120B
Tin as Sn	APHA Pt 3120B
Iron as Fe	APHA Pt 3120B
Beryllium as Be	APHA Pt 3120B
Boron as B	APHA Pt 3120B
Manganese as Mn	APHA Pt 3120B
Cadmium as Cd	APHA Pt 3120B
Chromium as Cr	APHA Pt 3120B
Copper as Cu	APHA Pt 3120B
Lead as Pb	APHA Pt 3120B
Mercury as Hg	APHA Pt 3112B
Nickel as Ni	APHA Pt 3120B
Selenium as Se	APHA Pt 3120B
Silver as Ag	APHA Pt 3120B
Zinc as Zn	APHA Pt 3120B
Notes: Units are in mg/L unless stated otherwise. All samples were collected at mid-depth at each location.	

2.3 Sediment

The purpose of the sediment (including pore water and elutriate) sampling was to provide important input on the sources from the reservoir bed which may affect the water quality in the reservoir. These results were also required for input to the bed-characteristics description for the water quality assessment efforts.

Sediment samples were collected at five locations (*Table 2-6*) within the Reservoir in January 2021, March 2021 and May 2021 (*Figure 2-2*) as sampling efforts were only scheduled to be carried out once every two months over a period of six months (three sampling times). Samples were collected from the reservoir bed surface via an Ekman grab sampler which allowed a maximum penetration of approximately 20 cm and up to 3 kg of sample to be collected per location. Sediment samples were also collected on a one-time basis for pore water and elutriate processes which are designed to estimate the potential availability of contaminant release in the water when the (bulk) sediment is disturbed during construction. These samples were collected by grab sampling of the reservoir bed surface via the use of a Van Veen grab sampler together with a Van Dorn water sampler to collect source water samples from each location.

The sediment and water samples collected were chilled and sent to a SINGLAS accredited laboratory with a completed Chain of Custody (COC) form. As there are no local sediment quality regulations to classify the results, the 2009 Dutch Soil Quality Standard was adopted for comparison. No QA/ QC program for sediment, pore water or elutriate was implemented.

Table 2-7 provides a summary of the sediment quality parameters, test methods and allowable limits for sediment characteristics; while *Table 2-8* and Table 2-9 outline the parameters, test methods and sampling frequency for pore water and elutriate sampling programs, respectively.

Table 2-6: Sediment Quality Sampling Locations and Selection Rationale

Location	Coordinates (WSG84)		Rationale
	x	y	
SS01	103.74095	1.43116	To establish ambient conditions within the Reservoir Project Site.
SS02	103.73972	1.42146	To establish ambient conditions from drainage outfall (Pang Sua Diversion Canal) on the eastern reservoir bank; within the Reservoir Project Site.
SS03	103.73124	1.41421	To establish ambient conditions from drainage outfall on the eastern reservoir bank; within the Reservoir Project Site.
SS04	103.7177	1.41087	To establish ambient conditions from Kangkar River; south (upstream) of the Reservoir Project Site.
SS05	103.72826	1.40577	To establish ambient conditions from Peng Siang River and Sungei Tengah; south (upstream) of the Reservoir Project Site.

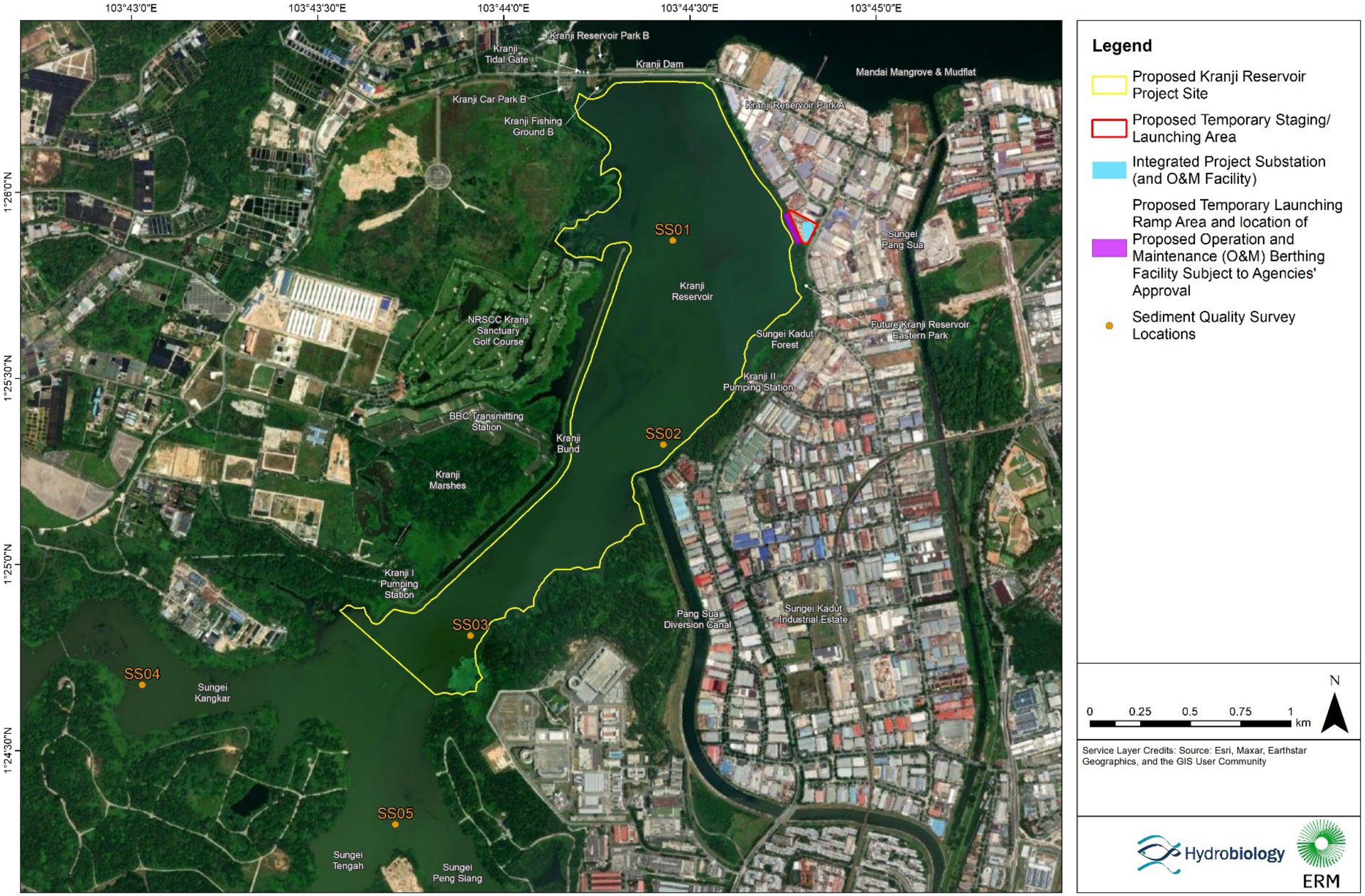


Figure 2-2: Sediment Quality Survey Locations

Table 2-7: Sediment Quality Parameters, Test Methods and Allowable Limits for Sediment Characteristics

Parameters	Test Method	Unit	Sampling frequency	Soil (mg/kg dry matter)	
				Target	Intervention
Total Nitrogen, TN	APHA 4500-Norg (D)/4500-NO3 (I)	mg/kg	Once every two months	-	-
Total Phosphorus, TP	APHA 3120B	mg/kg	Once every two months	-	-
Loosely bound P	APHA 3120B	mg/kg	Once every two months	-	-
Fe/Al bound P	APHA 3120B	mg/kg	Once every two months	-	-
Ca bound P	APHA 3120B	mg/kg	Once every two months	-	-
Organic bound P	APHA 3120B	mg/kg	Once every two months	-	-
Organic matter as LOI	BS 1377: Part 3 :2018	%	One time	-	-
Total organic carbon, TOC	BS EN 13137: 2001	%	One time	-	-
Aluminium, Al	APHA 3120B	mg/kg	Once every two months	-	-
Antimony, Sb	APHA 3120B	mg/kg	Once every two months	3	15
Arsenic, As	APHA 3120B	mg/kg	Once every two months	29	55
Barium, Ba	APHA 3120B	mg/kg	Once every two months	160	625
Boron, B	APHA 3120B	mg/kg	Once every two months	-	-
Cadmium, Cd	APHA 3120B	mg/kg	Once every two months	0.8	12
Chromium, Cr	APHA 3120B	mg/kg	Once every two months	100	380
Copper, Cu	APHA 3120B	mg/kg	Once every two months	36	190
Iron, Fe	APHA 3120B	mg/kg	Once every two months	-	-
Lead, Pb	APHA 3120B	mg/kg	Once every two months	85	530
Manganese, Mn	APHA 3120B	mg/kg	Once every two months	-	-
Mercury, Hg	USEPA 245.1 (1994)	mg/kg	Once every two months	0.3	10
Molybdenum, Mo	APHA 3120B	mg/kg	Once every two months	3	200
Nickel, Ni	APHA 3120B	mg/kg	Once every two months	35	210
Selenium, Se	APHA 3120B	mg/kg	Once every two months	0.7	100

Parameters	Test Method	Unit	Sampling frequency	Soil (mg/kg dry matter)	
				Target	Intervention
Zinc, Zn	APHA 3120B	mg/kg	Once every two months	140	720
Lead, Pb	APHA 3125B	mg/kg	Once every two months	85	530

Table 2-8: Pore water Parameters, Test Methods and Sampling Frequency

Parameters	Test Method	Unit	Sampling frequency
pH	APHA 4500-H^+ (B)	-	One time
Total Organic Carbon, TOC	APHA 5310B	mg/L	One time
Phosphate as PO_4-P	APHA 4500-P (G)	mg/L	One time
Nitrate as NO_3-N	APHA 4500-NO_3 (I)	mg/L	One time
Total Nitrogen, TN	APHA 4500-P (J)	mg/L	One time
Total Phosphorus, TP	APHA 4500-P (J)	mg/L	One time
Ammonia as NH_4-N	APHA 4500-NH_3 (H)	mg/L	One time
Aluminium, Al	APHA 3120B	mg/L	One time
Antimony, Sb	APHA 3125B	mg/L	One time
Arsenic, As	APHA 3125B	mg/L	One time
Barium, Ba	APHA 3120B	mg/L	One time
Boron, B	APHA 3120B	mg/L	One time
Cadmium, Cd	APHA 3125B	mg/L	One time
Chromium, Cr	APHA 3125B	mg/L	One time
Copper, Cu	APHA 3125B	mg/L	One time
Iron, Fe	APHA 3120B	mg/L	One time
Lead, Pb	APHA 3125B	mg/L	One time
Manganese, Mn	APHA 3120B	mg/L	One time
Mercury, Hg	USEPA 245.1 (FIMS) (1994)	mg/L	One time
Molybdenum, Mo	APHA 3125B	mg/L	One time
Nickel, Ni	APHA 3125B	mg/L	One time
Selenium, Se	APHA 3125B	mg/L	One time
Zinc, Zn	APHA 3120B	mg/L	One time

Table 2-9: Elutriate Parameters, Test Methods and Sampling Frequency

Parameters	Test Method	Unit	Sampling frequency
pH	APHA 4500-H^+ (B)	-	One time
Phosphate as PO_4-P	APHA 4500-P (G)	mg/L	One time
Nitrate as NO_3-N	APHA 4500-NO_3 (I)	mg/L	One time
Nitrite as NO_2-N	APHA 4500-NO_3 (I)	mg/L	One time
Total Nitrogen,TN	APHA 4500-P (J)	mg/L	One time
Total Phosphorus,TP	APHA 4500-P (J)	mg/L	One time
Ammonia as NH_4-N	APHA 4500-NH_3 (H)	mg/L	One time
Arsenic as As	APHA 3125B	mg/L	One time

Parameters	Test Method	Unit	Sampling frequency
Cadmium as Cd	APHA 3125B	mg/L	One time
Lead as Pb	APHA 3125B	mg/L	One time

2.4 Benthic Communities

Two sets of surveys were conducted for benthic macroinvertebrate sampling.

For the first set, standardised benthos samples were collected using an Ekman grab with volumes of up to 5kg per grab to retrieve a fixed volume of benthic sediment. Sediments were dug out to a depth of up to 20cm and sieved to retain fauna > 0.25mm. To assess fauna heterogeneity, triplicate samples were collected at each site within and south of the Reservoir Project Site (i.e. BC01 – BC05 in *Figure 2-3)* and were preserved and transferred to 95% ethanol for identification. These benthos samples were sorted into functional group, then identified to family level or morphospecies under a stereomicroscope. Existing ecological health of the benthic communities was then determined using the scoring method Shannon-Biodiversity Index. However, resulting baseline data revealed a gap: macroinvertebrate communities present in the potentially impacted shoreline area had not been represented.

A twofold approach was hence carried out in a second set of surveys to fully characterise the assemblages in Kranji Reservoir.

2.4.1 Sweep Sampling of Edge Habitat (trailing vegetation, macrophytes and shoreline)

Triplicate samples were collected from seven locations agreed with PUB within the reservoir (Edge 1 to Edge 7) including the proposed temporary Launching Ramp Area and proposed O&M Berthing Facility area (Edge 3); and two reference sites (Edge 6 and 7) (see *Table 2-10* and *Figure 2-3*). Edge 1 and 2 also provide a measure of regular disturbance via public access in these designated fishing areas. Each triplicate involved active sweep and kicknet style sampling of the habitat niches along a composite 10m reach using a D-shaped kicknet with 250 µm mesh. Sampling methods conform to techniques used in Blakely et al., 2014 and Ho et al., 2018, identified as the most appropriate techniques for this habitat type in Singapore. The shallow submerged bank was physically disturbed using the net and pole then swept to collect disturbed biota and sediment. The trailing vegetation was sampled by sweeping the net through the macrophytes. At each site, the net was brushed against surfaces of boulders, sand, vegetation and leaf packs to ensure a full range of microhabitats were sampled. This increases the likelihood of collecting rare and habitat-specific benthic macroinvertebrates.

2.4.2 Colonisers – Deployment of 5 x Colonisers

Colonisers were constructed in the manner described in Loke et al. (2010), namely stainless-steel cages (Ø 20cm; height 10cm, 1.2cm^2 mesh size) filled with coconut brushes and palm fronds as artificial substrate. As per Clews et al (2014), 5 colonisers were deployed at an approximate depth of 1.2 m, at 2 m intervals along a 10 m transect roughly 5 m from shore (*Figure 2-3*). Colonisers were deployed at the same location used in the Clews et al (2014) study, as advised by PUB (see *Table 2-10* and *Figure 2-3*).

This area was composed of a rocky rip-rap protecting the bund near the mouth of the intake channel. Colonisers were retrieved after four weeks of deployment.

Samples were first transferred into a container and preserved with 90% ethanol. In the laboratory, they were then rinsed through an Endecott sieve of 250 µm mesh. Large substrates (i.e. stones, plant debris) were then rinsed and removed from the macroinvertebrate residue. All aquatic macroinvertebrates were picked from the residue and identified under a 100x magnification. Specimens were identified to family-level, except for Ostracoda, Copepoda, Isopoda, Amphipoda, Acari and Collembola. Statistical analyses were then undertaken.

Table 2-10: Benthic Community Sampling Locations and Sample Method

Location	Coordinates (WSG84)		Sample Method Description
	x	y	
BC01	103.74095	1.43116	Standardised benthos sampling via grab
BC02	103.73972	1.42146	
BC03	103.73124	1.41421	
BC04	103.71770	1.41087	
BC05	103.72826	1.40577	
Edge 1	103.73778	1.43796	Sweep and kick sampling of edge habitat
Edge 2	103.74290	1.43791	
Edge 3	103.74641	1.43134	
Edge 4	103.74441	1.42551	
Edge 5	103.74099	1.42139	
Edge 6	103.73871	1.41750	
Edge 7	103.73282	1.41786	
Colonisers	103.73822	1.42994	Colonisation sampling

Figure 2-3: Macrobenthos Sampling Locations

2.4.3 Benthic Quality Index (BQI_{SING})

Benthic Quality Index (BQI_{SING}) was used in the analysis of the macroinvertebrate communities collected using colonisers following the method used by Clews et al., 2014. For this index, benthic macroinvertebrates act as bioindicators to reflect the level of ecological stressors experienced by the water body.

$$BQI_{SING} = \frac{\sum \text{BQIW of each taxon} \times \text{abundance of each taxon}}{\sum \text{Total abundance of invertebrates}}$$

In this formula, $BQIW_{SING}$ are weights that have been assigned to benthic macroinvertebrate families that are more common in Singapore than the rest of the world. A higher weight (i.e. 5) is assigned to the taxon with higher tolerance to organic pollution and a lower weight (i.e. 1) to the taxon more sensitive to organic pollution.

This metric was chosen due to its relative success in distinguishing Singapore's reservoirs of various trophic status, as compared to the many other metrics.

2.4.4 Shannon – Biodiversity Index

Biodiversity and biotic indices (the biodiversity index that measures species diversity in a given community), were calculated from the results of the survey. These indices are different from species richness because they show community composition and take into account the relative abundance of species that are present in the community. The Shannon-Biodiversity Index that takes into account both abundance and evenness of species present in the community for the samples, was used to calculate biodiversity of the reservoirs (Shannon, 1948; Shannon & Weaver, 1949; Wiener, 1939).

The Shannon-Biodiversity Index is explained by the formula:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where:

H' = the Shannon-Biodiversity Index;

Pi = fraction of the entire population made up of species I;

S = numbers of species encountered; and

∑ = sum from species 1 to species S.

The score range for Biodiversity Index (H') is:

- Very low diversity (H' < 0.5);
- Low diversity (0.5 ≤ H' < 1.0);
- Medium diversity (1.0 ≤ H' < 2.0);
- High diversity (2.0 ≤ H' < 2.5); and
- Very high diversity (H' ≥ 2.5).

This Shannon-Biodiversity Index is commonly applied in diversity studies and unlike BQI_{SING}, this index is not limited to macroinvertebrates and have been used for different types of organisms and in various studies, under a wide range of environmental conditions. As such, the use of the Shannon-Biodiversity

Index allows a better understanding of the diversity of benthic macroinvertebrates in Kranji Reservoir as compared to other water bodies around the world.

2.5 Submerged Aquatic Vegetation

The purpose of the aquatic vegetation sampling was to better understand the biomass of vegetation present in the Kranji Reservoir at the time of sampling. A combination of two methods – sonar measurement and imaging, and grab/ rake dragging sampling method for sample collection was used for this survey. The initial survey over the Reservoir Project Site was extended to the south to further support the understanding of vegetation biomass in Kranji Reservoir.

2.5.1 Sonar Measurement and Imaging

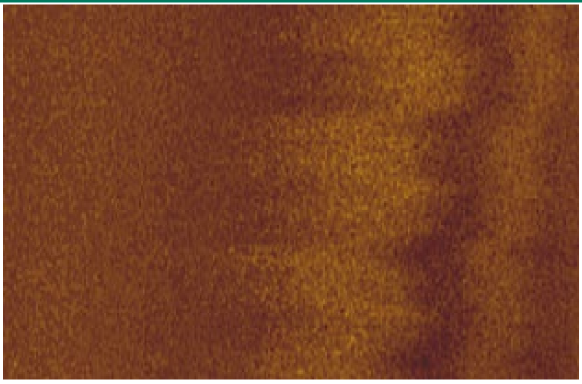
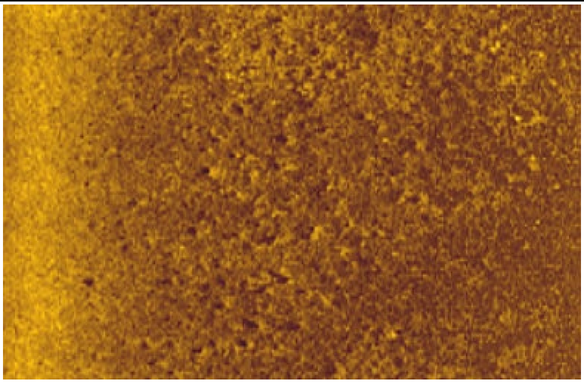
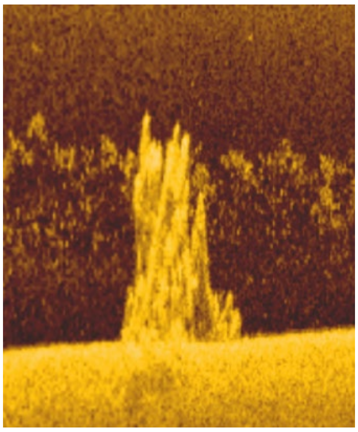
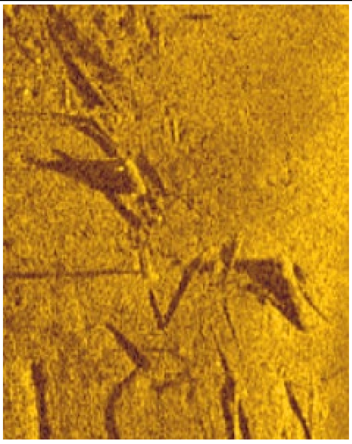
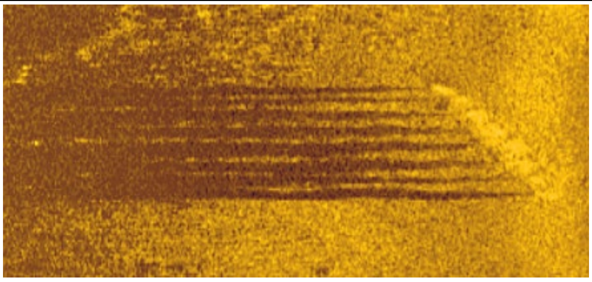
The use of the sonar measurement and imaging was to identify underwater habitat features and areas of high vegetation concentrations as it was anticipated that there may be high variability in the density of submerged vegetation due to varying light and substrate conditions at different water depths.

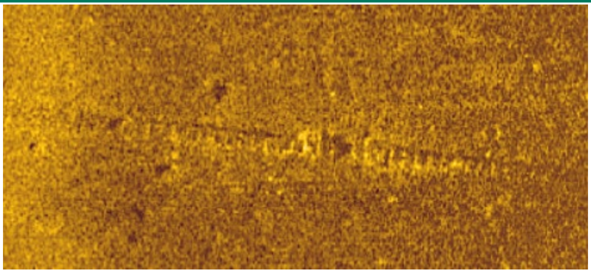
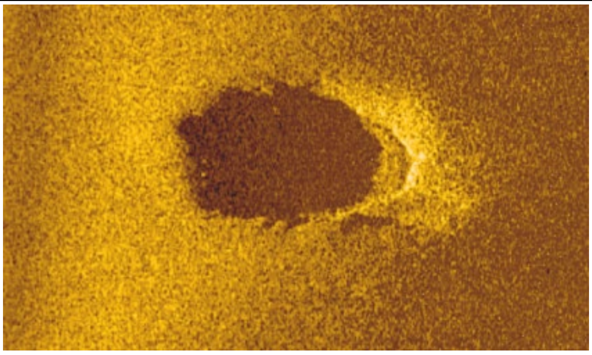
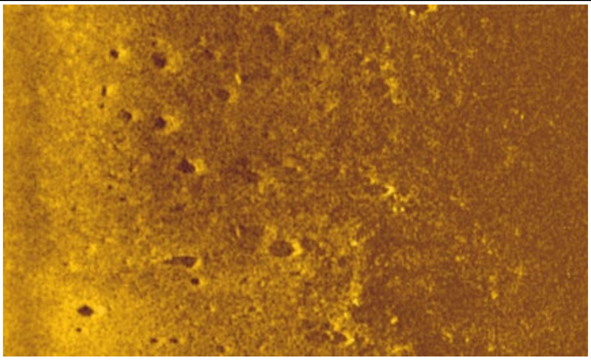
Micro-habitats are smaller scale features and are defined here as relatively homogenous areas, approximately the same scale as used by an individual fish engaged in a specific activity, such as feeding or spawning. Tree snags and submergent vegetation are examples of reservoir habitat units at the micro-habitat scale.

The aquatic habitat assessment method involved sonar measurement of water depth, bottom roughness and bottom hardness using a side scan sonar and imaging of habitat features using a high-resolution side-scan and downward imaging sonar. The data collected in the field were then overlaid with the bathymetry to produce a geo-referenced image of the reservoir bed. These provide a comprehensive characterisation of the reservoir's aquatic environment. The proportion of each aquatic habitat type (e.g. rocky substrate, boulders, mud, woody debris, vegetation, etc) were identified by an experienced professional, quantified and reported. In order to provide a better understanding of the spatial distribution of habitats, main habitat features observed are identified on the map and classified into the following categories (see *Table 2-11*):

- Smooth sand/ mud (no vegetation);
- Vegetation;
- Woody debris;
- Artificial structure;
- Large hole/ pool; and
- Smooth sand/mud with small holes.

Table 2-11: Summary of Different Features Displayed on the Sonar Viewer

Features	Examples of feature as shown on sonar imaging from Kranji Reservoir
■ Smooth Sand/ Mud (no vegetation) The typical habitat on the reservoir bed. This appears as an untextured layer on the sonar viewer and is dominant in areas with deeper depths.	
■ Vegetation This habitat appears as dark and light dots on the sonar viewer and is dominant in areas with shallower depths.	
■ Woody debris This category consists of features that appear to be tree stumps (right) and branches (far right). Branches seen under the sonar viewer appear as irregular straight lines.	 
■ Artificial Structure Artificial structures under the sonar viewer typically appear with regular shapes and straight lines.	

Features	Examples of feature as shown on sonar imaging from Kranji Reservoir
	
■ Large hole/ pool Large holes and pools on the reservoir bed appear as dark circles with lighter regions around the circumference furthest from the source of sonar beam.	
■ Smooth sand/ mud with small holes Small round holes appear as dark circles.	

2.5.2 Grab sampling/ Rake-dragging

The grab sampling or rake-dragging method was used to grab vegetation samples at identified locations/ clusters of vegetation within the reservoir based on sonar imaging maps. The map was categorised into 5 zones (within the Reservoir Project Site) where 10 samples were collected from each zone (see *Figure 3-33*), via either an Ekman grab sampler (15cm^3) or rake dragging of the reservoir bed. Aquatic plants were collected and identified primarily using the rake sampling approach (Johnson and Newman, 2011), where the rake was dragged along the bed and any collected vegetation was retrieved from the rake. After the visual inspection of the sampling location, the rake was extended off the boat, lowered vertically to the sediment and dragged towards the boat for about 1.5 m while holding the handle firmly to keep the rake head in contact with the sediment. Alternatively, aquatic vegetation was sampled using vertical spot sampling. Before the rake was pulled off the bottom, the rake was flipped 180° to minimise the loss of plants snagged on the rake teeth. Each sample were retrieved from a quadrat of 23 cm x 23 cm. The sampling locations were chosen based on criteria determined by sonar imaging (see *Section 2.5.1*), which included areas where water depth was relatively shallow (< 3 m) and vegetation was abundant. Once a vegetated area was identified, aquatic vegetation samples were collected and subsequently washed to remove residual sticks or other impurities. The wet and dried weight of each plant was weighed, recorded, and analysed for nutrients - percent (%) of total carbon (TC), total nitrogen (TN) and total phosphorus (TP). Any emergent/ floating, partially submerged and submerged aquatic plants were also directly observed and recorded. Plants present along the reservoir shoreline were also identified and recorded based on available references for local flora, where possible.

Where possible, aquatic vegetation that was sampled and observed were identified with its conservation status referred to the 2nd Edition of the Singapore Red Data Book (Davison et al., 2008) and Red List of Threatened Species by the International Union for Conservation of Nature (IUCN, 2012).

2.6 Aquatic Fauna

Aquatic fauna sampling was proposed as part of this study to establish the fish species and biomass in the Kranji Reservoir at the time of sampling. A combination of hydroacoustics and eDNA techniques were used for the purpose of this study. As these methods are non-invasive, they were selected over the more invasive sampling techniques like fish netting or electrofishing.

2.6.1 Hydroacoustics

The hydroacoustic technique is a well-established survey technique developed for fisheries research and stock assessment and allows for the rapid and remote assessment of biomass density without the need to capture and handle the fish. It was used to determine fish biomass across the Reservoir Project Site to assess the distribution and abundance of fish. Hydroacoustic monitoring involves transmitting a precise acoustic pulse into the water. The transducer then receives acoustic echoes from targets (such as fish or the reservoir bed) and converts them into electrical signals that can be digitally processed.

The hydroacoustic surveys were conducted using a Biosonics DT-X echosounder with a 6.4° split beam transducer operating at 201 kHz. The transducer was positioned facing downwards (or slightly angled forward depending on the bathymetry of the area) and the top was approximately 0.3 m below the water surface. Acoustic pulses were transmitted at a ping rate of 10 per second, with a pulse length of 0.4 milliseconds (ms), and with a data collection threshold of -130 dB (decibels). Data was not collected in the first 0.99 m of the signal as this is the minimum transducer blanking distance. This means that the surveyed volume of water was between approximately 1.3m below the surface and the reservoir bottom. The detection of fish in the water column was enumerated using echo detections which relate target strengths to biomass. The hydroacoustic field methodology used has been developed by Hydrobiology, based on approaches such as Kubecka and Duncan (1998), Matveev (2007) and Matveev and Steven (2014) and extensive Hydrobiology field experience since 1990.

The hydroacoustic data processing was performed using Sonar5-Pro (Balk and Lindem, 2018) and aimed to count individual fish detected and estimate fish biomass (in g/m^2 and g/m^3). Hydroacoustic instruments cannot identify or distinguish between species, therefore these data are not species-specific. The algorithm used to estimate biomass values was a generic algorithm (referred to as 'All_Species_1' in Sonar5-Pro). This generic algorithm provides an appropriate estimate when dealing with mixed fish assemblages for which a site-specific algorithm has not been developed. Noise and interference were removed by using a minimum target threshold for processing of -65 dB. This threshold corresponds to fish of approximately 9 mm total length (TL) according to the equation of Love (1977), hence only fish greater than 9 mm will be effectively captured in the data. This threshold provides a high-quality dataset with minimal exclusion of biomass. Further processing was also performed manually to remove all backscatter and other noise on the echograms.

Apart from noise and interference, other unwanted detections include echoes from the bottom and submerged vegetation. These were removed during data processing by filtering them from the resulting echogram. The blanking distance was also adjusted to remove noise caused by vibrations at the surface of the echogram. To optimise data collected from the fishes in the reservoir, surveys were conducted at night when fish emerge from under macrophytes to feed, making them more acoustically detectable at night (Ye et al., 2013). However, due to logistical constraints of night survey deployments (health and safety, increasing risk of macrophytes entangling to the engine turbines or damage to the boat and instrument in shallow waters etc) and limitations from the instruments (blanking distance), a large area of the reservoir could not be surveyed. Unscanned areas for hydroacoustic surveys were estimated at approximately 66.5 ha out of 160 ha.

Data were extracted for every 15 m of transect (*Figure 2-4*) to obtain the number of fish tracks detected, average fish weight (g), fish biomass per surface area (g/m^2) and volume density. Due to the conical shape of the transducer's emissions, there is a greater likelihood of encountering fish in deeper sections associated with the larger volume of water surveyed at depth. The biomass per surface area provides a standard estimate for temporal comparisons of the reservoir, however biomass per volume provides a more standardised estimate that aims to reduce the bias introduced by the sampling method for interpretation purposes as it takes into account the density estimate. The volumetric fish biomass (g/m^3) was calculated using the below equation:

$$Volumetric\ biomass\ (g/m^3\ ) = Average\ weight\ (g) \times Volume\ Density\ (\#/1000m^3)\ \times\ 0.001$$

2.6.2 Fish species

Methods of fish detection also included the implementation of environmental DNA (eDNA) sampling techniques. eDNA was included in the field program as it is non-invasive, and to increase the likelihood of detecting cryptic species[1], which are particularly important for this study. Uncovering a wider spectrum of species present in the reservoir allows for a more complete study on the fish biodiversity and the discovery of species with high ecological value or high conservation status.

The eDNA technique involves capturing fish DNA contained in the water column to determine the presence of fish species without needing to physically capture the fish. In order to maximise the chances of detecting fish DNA in the samples, water was collected predominantly from areas of likely fish habitat (amongst snags, large woody debris, macrophytes, undercut banks, etc.) but also from central areas of the water body to include species residing in open water habitat.

DNA sequences were clustered into Operational Taxonomic Units (OTUs) based on sequence similarity. Taxonomic assignment was made with VSEARCH software (Rognes et al., 2016) whereby each OTU cluster was assigned a species identity using a 95% threshold by comparing against a reference sequence database built using sequences from the public repository Genbank (https://www.ncbi.nlm.nih.gov/genbank/). Despite being a novel technology, eDNA methods are a well-recognised and widely used non-invasive forensic technique. The latter is necessary both for the accuracy of biodiversity methods and for the delimitation of critical habitat (Olds et al., 2016).

Environmental (e)DNA was obtained from water samples collected from five (5) transect locations on the reservoir (*Figure 2-4*) to complement the hydroacoustics and historical data collected during previous surveys (e.g. Ng et al., 2010). Unlike most eDNA studies that use small amounts of water for sampling (e.g. Valdez-Moreno et al., 2019; Kutty et al., 2022), this sampling program at Kranji Reservoir processed 10 litres of water from each sampling site (from varying water depths) in order to increase the probability of capturing fish DNA for species found in the reservoir. For each transect location, a drill pump was used to pump water through 0.45µm cannister filters. In total, five cannister filters were prepared for the five sampling locations and preserved in 95% ethanol. The samples were sent to a commercial eDNA lab in Australia (EnviroDNA), where each of the filters were processed by opening up the filter, cutting a section of the filter (3 sections per filter), bead beating each section in lysis buffer and then proceeding with the DNA extraction on each section.

[1] i.e. species that might evade other sampling methods due usually to their habitat preferences and behaviour.

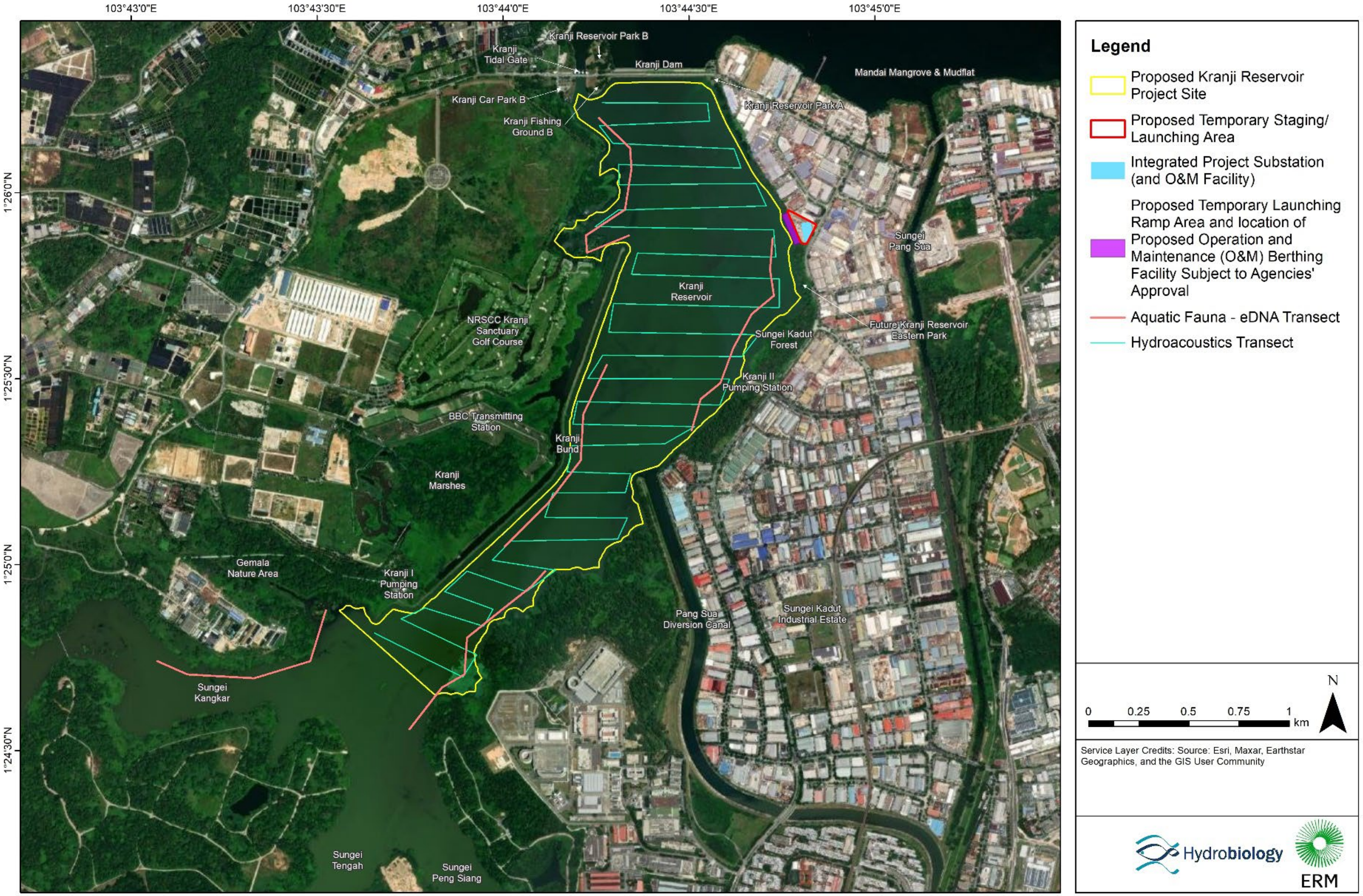


Figure 2-4: Hydroacoustic & eDNA Transects

3. BASELINE FINDINGS

3.1 Light Measurement

A summary of the data recorded by the PAR loggers and in-situ light (LI-COR) measurement observations can be found in *Table 3-1* and *Table* 3-2 respectively. The deployment of PAR loggers was to assess the daily light measurements at 1 m below water surface, while the in-situ measurements was to allow for measurement of light attenuation profiling throughout the water column. Note that the stations of LI-COR1, LI-COR2 and LI-COR3 are at the same stations of PAR1, PAR2 and PAR3.

Table 3-1: Summary of Data Recorded by PAR Loggers

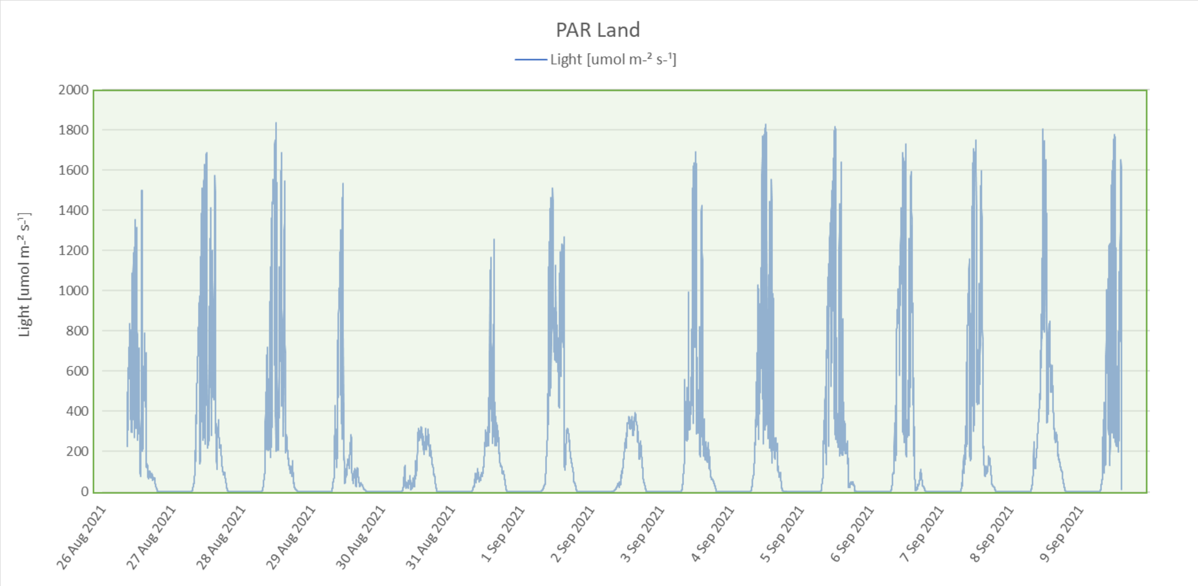
Location	Deployment record	Data recorded
PAR Land	■ Deployed on 26 Aug 2021 ■ Retrieved on 09 Sep 2021	■ Reliable data available from 26 Aug 2021, 08:41 AM to 09 Sep 2021, 14:21 PM
PAR1	■ Deployed on 26 Aug 2021 ■ Sensor servicing carried out on 27 Aug 2021 - no biofouling observed on the sensor ■ Floating water vegetation found entangled on the PAR1 buoy during sensor servicing on 30 Aug 2021 ■ Sensor service on 03 Sep 2021 - no biofouling observed on the sensor ■ Sensor was retrieved on 09 Sep 2021	■ Data available from 26 Aug 2021, 10:25 AM to 09 Sep 2021, 10:23 AM ■ Reliable data from 26 Aug 2021, 10:25 AM to 29 Aug 2021, 23:55 PM and from 30 Aug 2021, 15:48 PM to 09 Sep 2021, 10:23 AM
PAR2	■ Deployed on 26 Aug 2021 ■ Sensor servicing carried out on 27 Aug 2021 - no biofouling observed on the sensor ■ Sensor service on 03 Sep 2021 - no biofouling observed on the sensor ■ Sensor was retrieved on 09 Sep 2021	■ Reliable data available from 26 Aug 2021, 20:06 PM to 09 Sep 2021, 10:27 AM
PAR3	■ Deployed on 26 Aug 2021 ■ Sensor servicing carried out on 27 Aug 2021 - no biofouling observed on the sensor ■ Sensor service on 03 Sep 2021 - no biofouling observed on the sensor ■ Sensor was retrieved on 09 Sep 2021 and it was observed that during retrieval, water vegetation was found entangled on the PAR3 sensor and the ropes but no bio-fouling observed on the sensor.	■ Data available from 26 Aug 2021, 12:10 PM to 09 Sep 2021, 13:40 PM ■ Reliable data from 26 Aug 2021, 12:10 PM to 04 Sep 2021, 23:55 PM

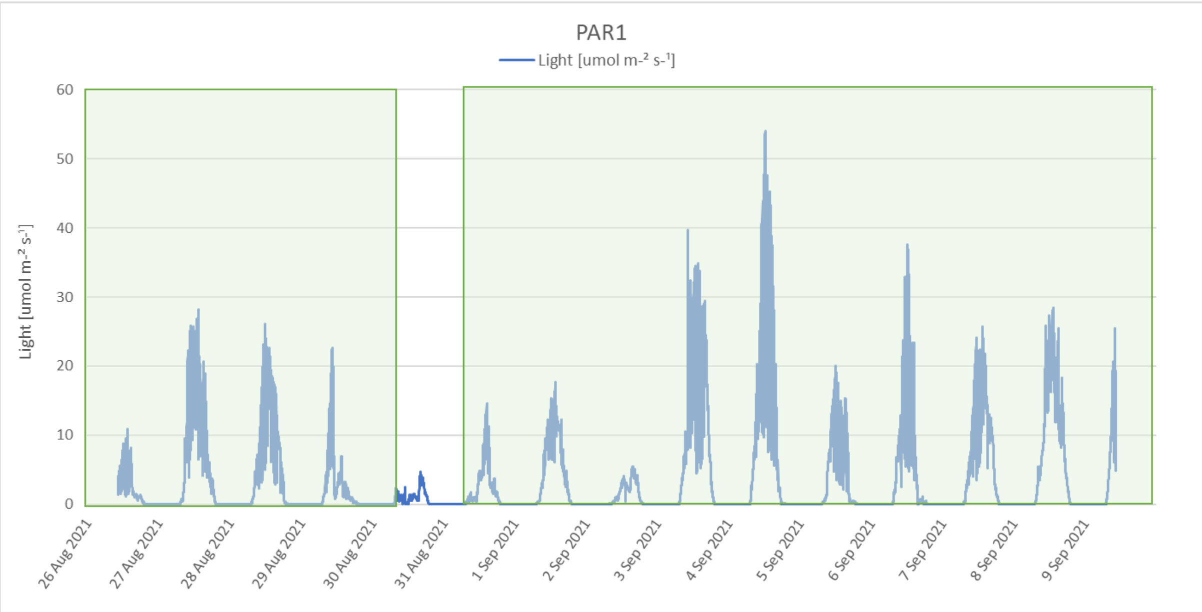
Table 3-2: Summary of In-Situ LI-COR Measurement Observations

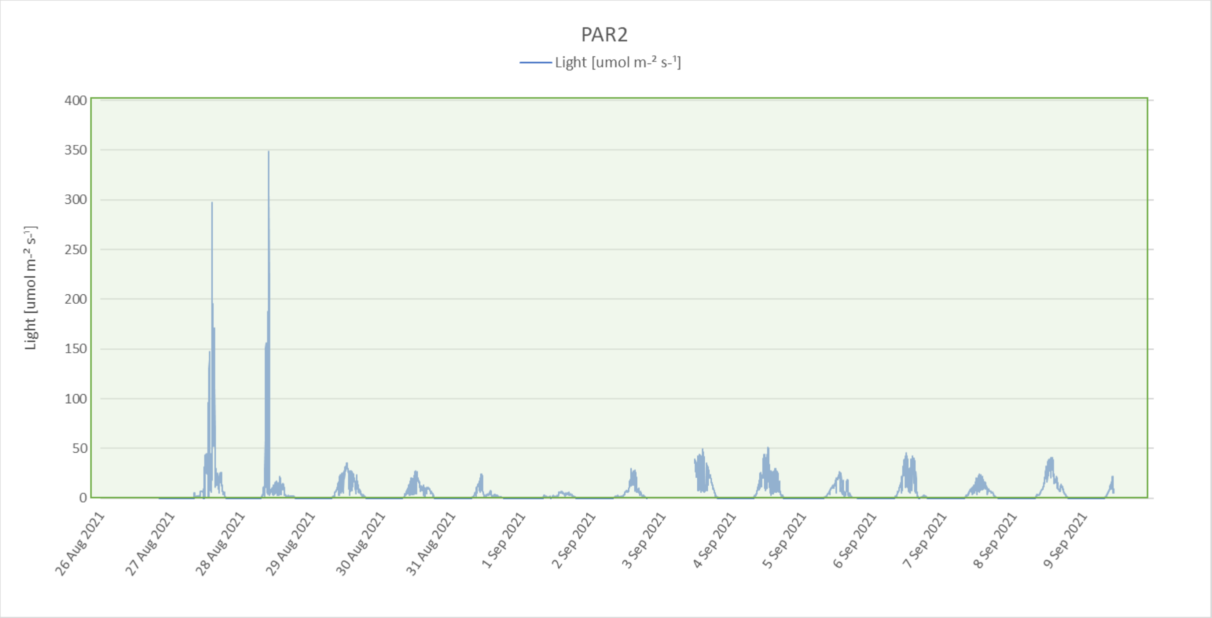
Round	Sampling date	Site Observations
Round 1	26 Aug 2021	Survey conducted from morning to noon. Fair weather; no strong sunlight; relatively calm reservoir water; greenish and turbid water; 60% cloud cover. Strong flow at LI-COR4.
Round 2	27 Aug 2021	Survey conducted in the morning. Sunny but sunlight was not that strong in the morning; calm reservoir water; greenish and turbid water; 30% cloud cover. Strong flow at LI-COR4 and LI-COR5.
Round 3	27 Aug 2021	Survey conducted near noon. Sunny; strong sunlight; smooth reservoir water surface; greenish and turbid water; 40% cloud cover. Strong flow at LI-COR4 and LI-COR5.
Round 4	27 Aug 2021	Survey conducted in the afternoon. Sunny; strong sunlight; smooth reservoir water surface; greenish and very turbid water; 50% cloud cover. Strong flow at LI-COR4 and LI-COR5.

Round	Sampling date	Site Observations
Round 5	27 Aug 2021	Survey conducted in the afternoon. Sunny; strong sunlight but dark clouds gradually coming over reservoir; smooth reservoir water surface; greenish and very turbid water; 70% cloud cover. Strong flow at LI-COR4 and LI-COR5.
Round 6	30 Aug 2021	Heavy rain in the morning. Survey conducted in the afternoon. Fair weather; no strong sunlight; relatively calm reservoir water; 70% cloud cover. Greenish water at all stations except LI-COR1 where the water was very yellowish and turbid perhaps due to the inflow from nearby tributaries after heavy rain event; Strong flow at LI-COR4 and LI-COR5.
Round 7	30 Aug 2021	Heavy rain in the morning. Survey conducted during sunset. Fair weather; weaker and weaker sunlight; relatively calm reservoir water; 70% cloud cover. Greenish water at all stations except LI-COR1 where the water was very yellowish and turbid perhaps due to the inflow from nearby tributaries after heavy rain event; Strong flow at LI-COR4.
Round 8	2 Sep 2021	Rain in the morning. Survey conducted in the afternoon. Fair weather; no strong sunlight; relatively calm reservoir water; 80% cloud cover; breezy. Fair water quality condition at all stations except LI-COR1 where the water was brownish perhaps due to the inflow from nearby tributaries after rain event.
Round 9	3 Sep 2021	Survey conducted in the morning. Sunny but sunlight was not that strong in the morning; smooth reservoir water surface; 50% cloud cover. Greenish water at all stations except LI-COR1 where the water was yellowish perhaps due to the inflow from nearby tributaries after heavy rain event days ago.
Round 10	3 Sep 2021	Survey conducted at noon. Sunny and strong sunlight; smooth reservoir water surface; 30% cloud cover. Greenish water at all stations except LI-COR1 where the water was yellowish perhaps due to the inflow from nearby tributaries after heavy rain event days ago.
Round 11	3 Sep 2021	Survey conducted in the afternoon. Sunny; sometimes strong sunlight but sometimes blocked by clouds; smooth reservoir water surface; 60% cloud cover. Greenish water at all stations except LI-COR1 where the water was yellowish perhaps due to the inflow from nearby tributaries after heavy rain event days ago.
Round 12	9 Sep 2021	Survey conducted from morning to noon. Sunny; no wind; smooth water surface; greenish water; 30% cloud cover.

Graphical representations of the PAR and LI-COR readings recorded can be found in *Figure 3-1* and *Figure 3-2,* respectively below. Highlighted green boxes represent reliable data. The following sections provide a summary of the findings related to light penetration at the sampling locations.


PAR Land
Light [umol m-2 s-1]
Light [umol m-2 s-1]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
26 Aug 2021
27 Aug 2021
28 Aug 2021
29 Aug 2021
30 Aug 2021
31 Aug 2021
1 Sep 2021
2 Sep 2021
3 Sep 2021
4 Sep 2021
5 Sep 2021
6 Sep 2021
7 Sep 2021
8 Sep 2021
9 Sep 2021


PAR1
Light [umol m-2 s-1]
Light [umol m-2 s-1]
60
50
40
30
20
10
0
26 Aug 2021
27 Aug 2021
28 Aug 2021
29 Aug 2021
30 Aug 2021
31 Aug 2021
1 Sep 2021
2 Sep 2021
3 Sep 2021
4 Sep 2021
5 Sep 2021
6 Sep 2021
7 Sep 2021
8 Sep 2021
9 Sep 2021



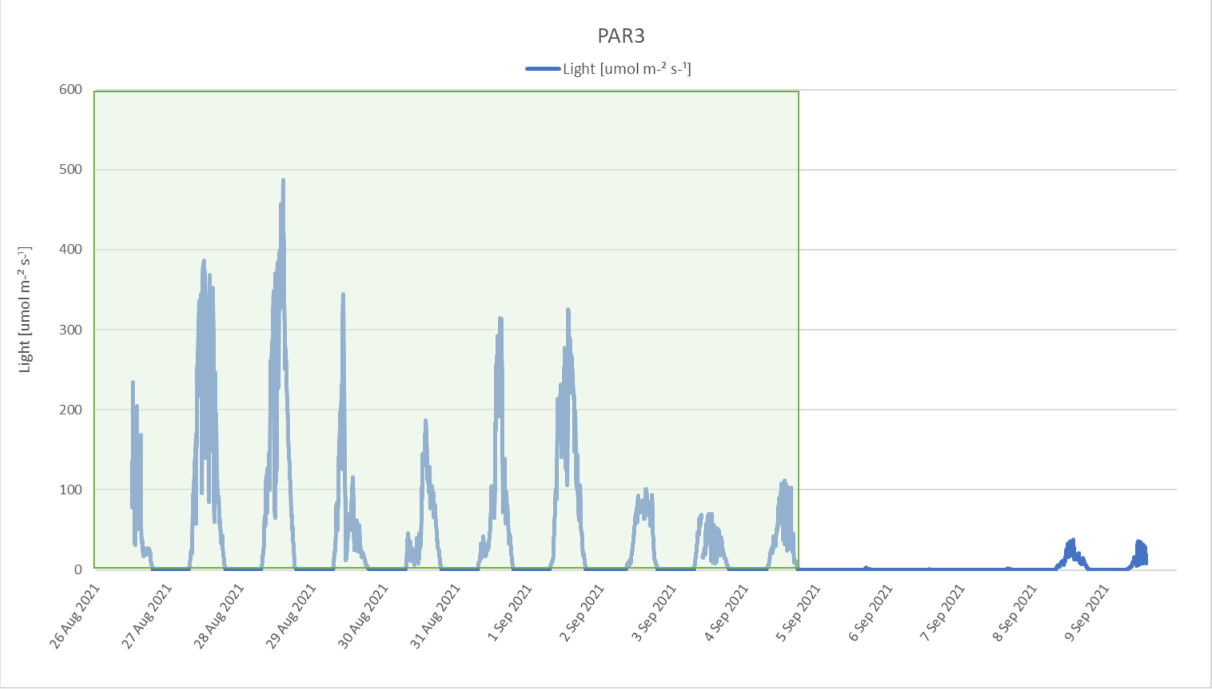
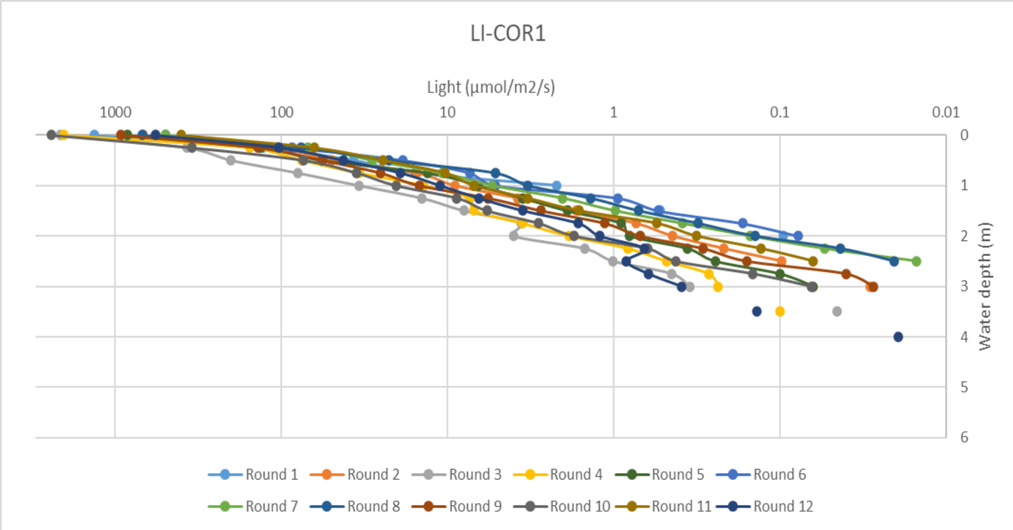
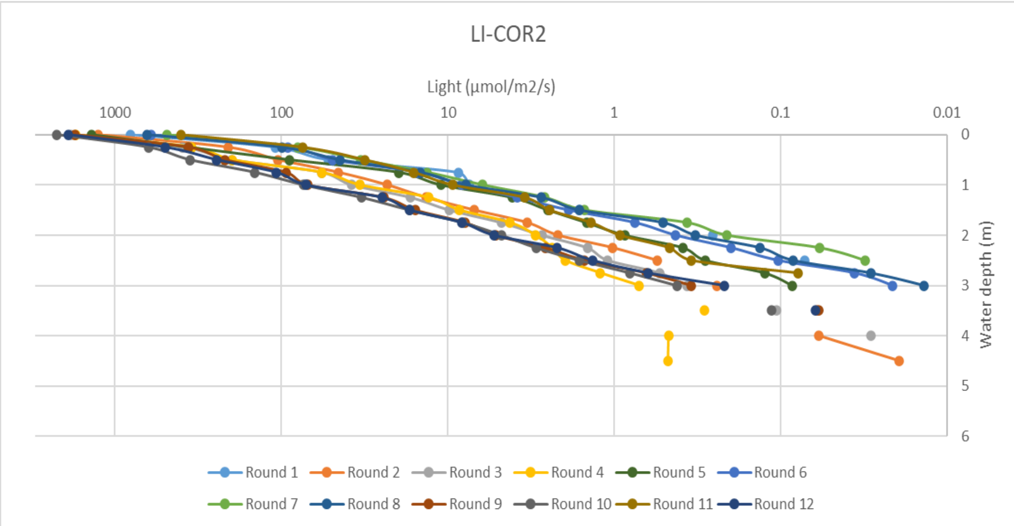
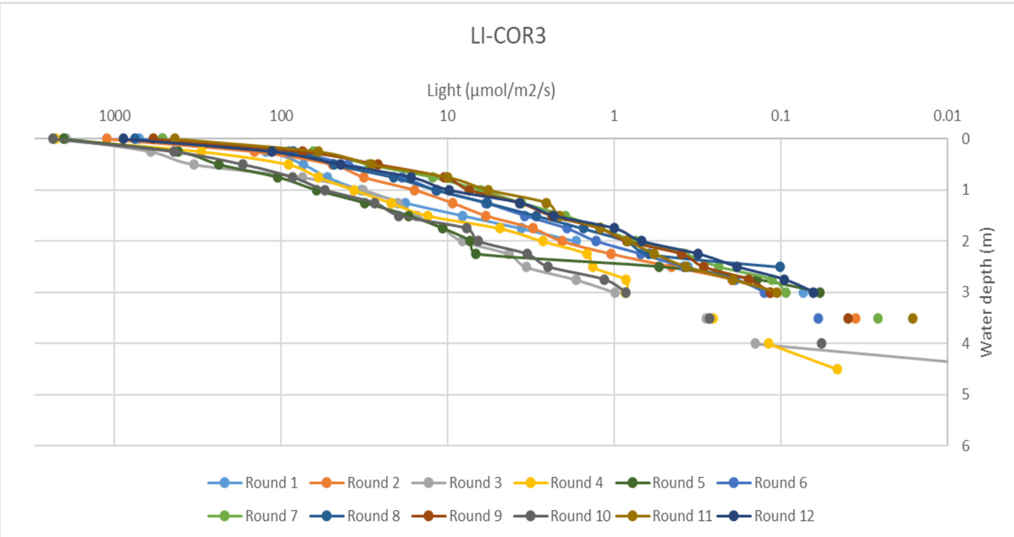
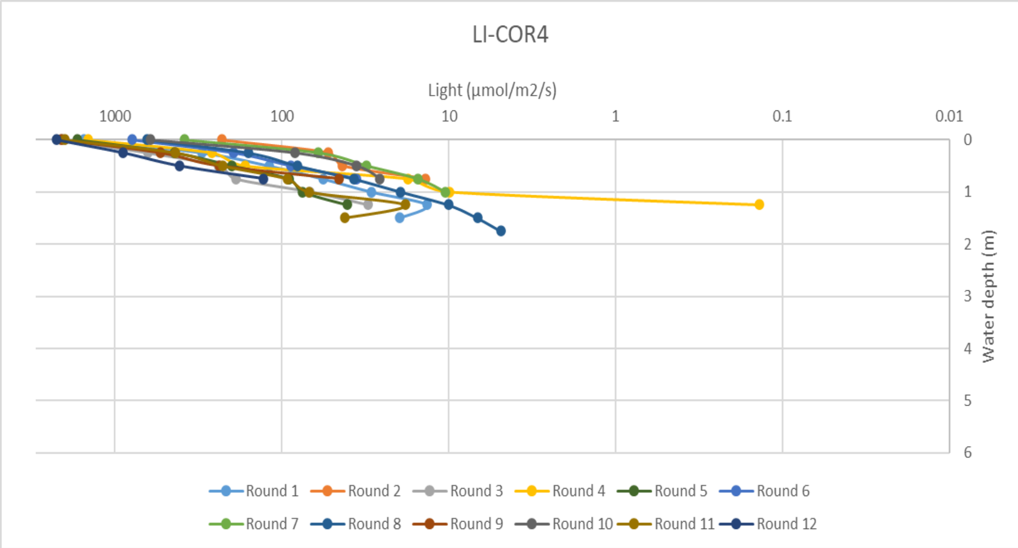


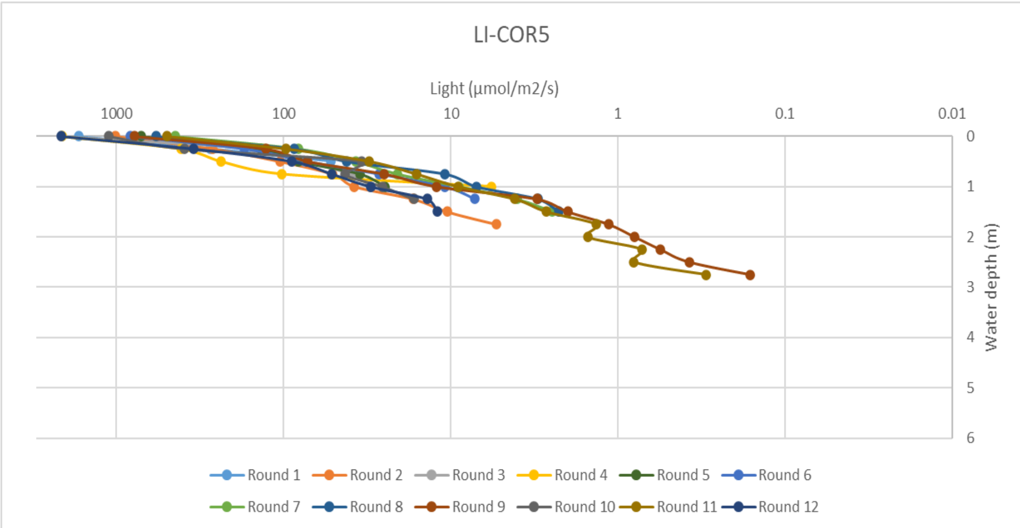
Figure 3-1: PAR Logger Data Recorded (green box = reliable data)


LI-COR1
Light (µmol/m2/s)
1000
100
10
1
0.1
0.01
0
1
2
3
4
5
6
Water depth (m)
Round 1
Round 2
Round 3
Round 4
Round 5
Round 6
Round 7
Round 8
Round 9
Round 10
Round 11
Round 12


LI-COR2
Light (µmol/m2/s)
1000
100
10
1
0.1
0.01
0
1
2
3
4
5
6
Water depth (m)
Round 1
Round 2
Round 3
Round 4
Round 5
Round 6
Round 7
Round 8
Round 9
Round 10
Round 11
Round 12


LI-COR3
Light (µmol/m2/s)
1000
100
10
1
0.1
0.01
0
1
2
3
4
5
6
Water depth (m)
Round 1
Round 2
Round 3
Round 4
Round 5
Round 6
Round 7
Round 8
Round 9
Round 10
Round 11
Round 12





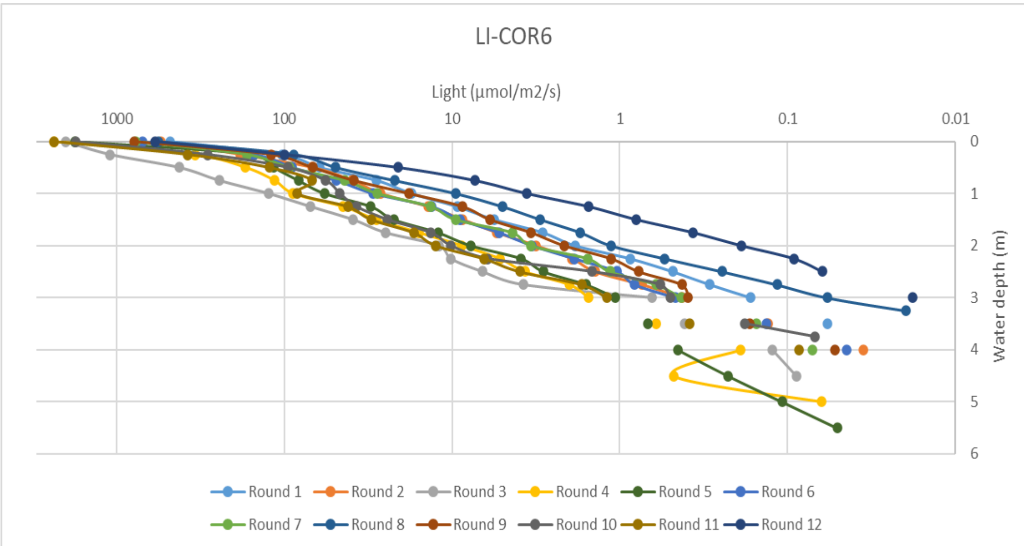


Figure 3-2: In-Situ Light (LI-COR) Data Recorded

3.1.1 Daily Light Irradiance (in Air, on land)

Light is measured as instantaneous irradiance (μmol m^{-2} s^{-1}). Accumulation of instantaneous irradiance should be calculated as daily irradiance (mol m^{-2} d^{-1}), which is standard practice and a useful way of expressing the PAR data for management of photosynthetic benthic light. Environmental Protection (Water) Policy - Monitoring and Sampling Manual: Biological assessment (2018) recommends a close approximation to convert a daily series of regularly measured instantaneous irradiance readings to daily light integrated irradiance using the following equation:

$$l_d = \frac{\sum PAR \times 24 \times 60 \times 60}{1{,}000{,}000 \times N \times D}$$

Where l_d is the daily light integrated irradiance (mol m^{-2} d^{-1}), $\sum PAR$ is the sum of all instantaneous readings in the complete days of logger deployment (μmol m^{-2} s^{-1}), N is the number of readings taken in one day and D is number of complete days of logger deployment.

Utilising the data recorded at PAR Land from 27 Aug 2021 to 8 Sep 2021 (days with complete data) where N=1,440 and D=13, the daily light irradiance in Kranji Reservoir $\boldsymbol{l_d = 16.68\ \mathrm{mol} \cdot m^{-2} d^{-1}}$.

3.1.2 Daily Light at 1m below Water Surface

Similar to the calculation of daily light irradiance in air, the same method was used to calculate the daily light received at 1 m below the water surface at the sample locations in Kranji Reservoir.

- **PAR1**: Utilising the data recorded from 27 Aug 2021 to 29 Aug 2021 and from 31 Aug 2021 to 8 Sep 2021 (days with complete data) where N=1,440 and D=13, the daily light received at 1 m below the water surface is $\boldsymbol{0.32\ \mathrm{mol} \cdot m^{-2} d^{-1}}$.
- **PAR2:** Utilising the data recorded from 27 Aug 2021 to 1 Sep 2021 and from 4 Sep 2021 to 8 Sep 2021 (days with complete data) where N=1,440 and D=11, the daily light received at 1 m below the water surface is $\boldsymbol{0.49\ \mathrm{mol} \cdot m^{-2} d^{-1}}$.
- **PAR3:** Utilising the data recorded from 27 August 2021 to 4 September 2021 (days with complete data) where N=288 and D=9, the daily light received at 1 m below the water surface is $\boldsymbol{3.91\ \mathrm{mol} \cdot m^{-2} d^{-1}}$.

For simplicity, arithmetic averaging was applied for the above three daily light received at 1 m below the water surface at three locations and this will give an overall daily light received at 1 m below the water surface in Kranji Reservoir, at. $\boldsymbol{1.57\ \mathrm{mol} \cdot m^{-2} d^{-1}}$ (noting the notable site-based variations found in the sampling effort).

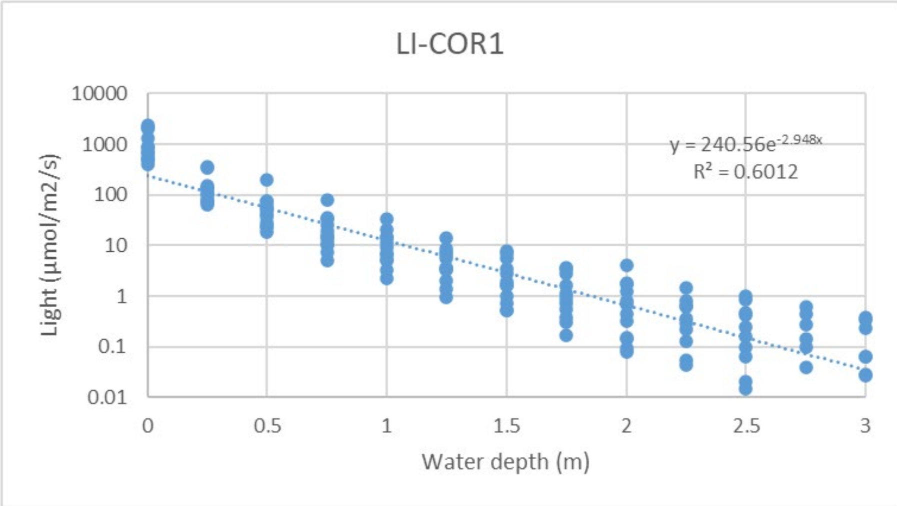
3.1.3 Light Attenuation throughout Water Column

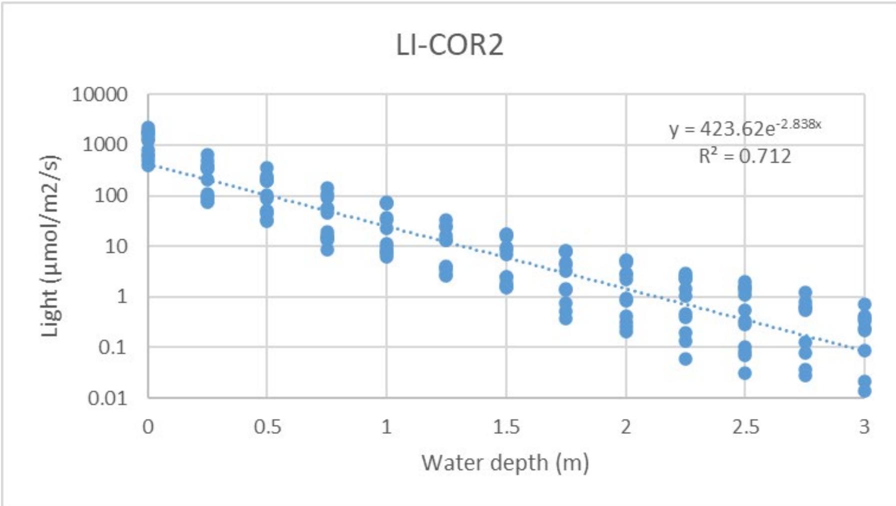
It can be seen from the LI-COR in-situ measurement data plotted in *Figure 3-2*, the light attenuation throughout water column in Kranji Reservoir follows exponential decay and can be expressed as the following equation:

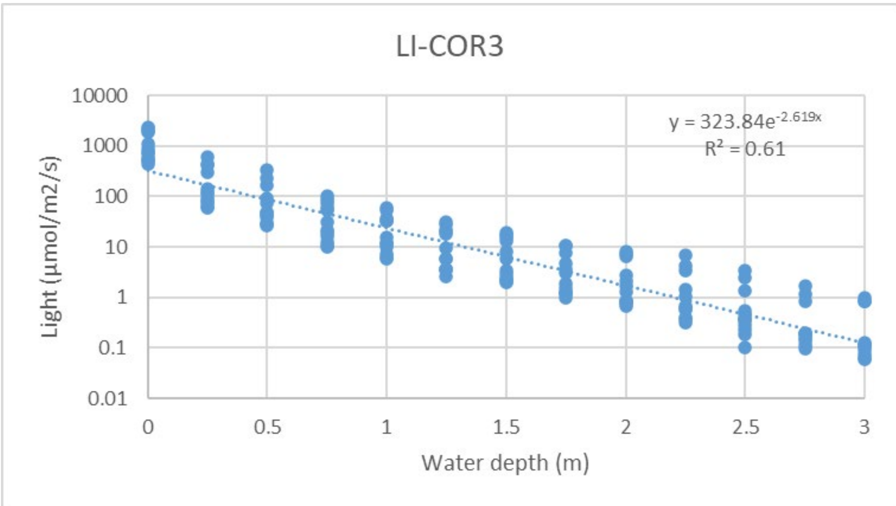
$$Light = a \cdot e^{-b \cdot H}$$

Where Light is the instantaneous light throughout the water column depth counted from water surface (μmol m^{-2} s^{-1}), H is the water depth, and a and b are the constants in exponential formula.

In processing the LI-COR in-situ measurement data at each location, the trendline function in Excel was used to produce the site-specific regression equation for each location (*Figure 3-3*). Note that only the data in the range of 0 to 3 m water depth was used in the data processing as the light below 3 m water depth was negligible in Kranji Reservoir. The regression analysis produced the light attenuation equations in the exponential form for locations from LI-COR1 to LI-COR6 respectively is presented in *Table 3-3*. Similarly, such regression analysis was also undertaken for overall LI-COR in-situ measurement data presented in *Figure 3-4* and resulted in a representative light attenuation equation in the exponential form for Kranji Reservoir in *Table 3-3.*


LI-COR1
y = 240.56e-2.948x
R² = 0.6012
Light (µmol/m2/s)
10000
1000
100
10
1
0.1
0.01
0
0.5
1
1.5
2
2.5
3
Water depth (m)


LI-COR2
y = 423.62e-2.838x
R² = 0.712
Light (µmol/m2/s)
10000
1000
100
10
1
0.1
0.01
0
0.5
1
1.5
2
2.5
3
Water depth (m)


LI-COR3
y = 323.84e-2.619x
R² = 0.61
Light (µmol/m2/s)
10000
1000
100
10
1
0.1
0.01
0
0.5
1
1.5
2
2.5
3
Water depth (m)

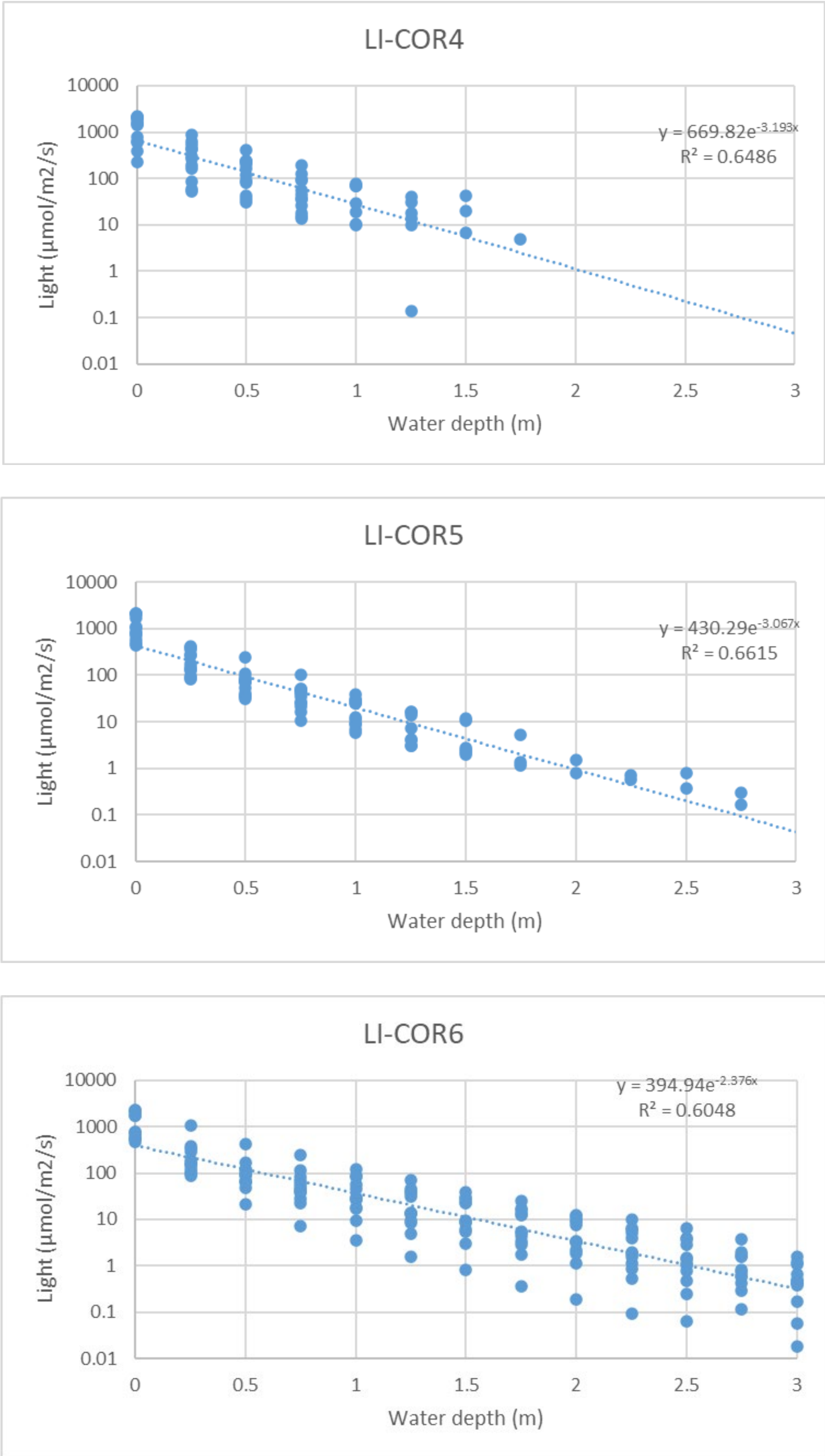


Figure 3-3: Exponential Regression Analysis for the LI-COR In-Situ Measurement Data

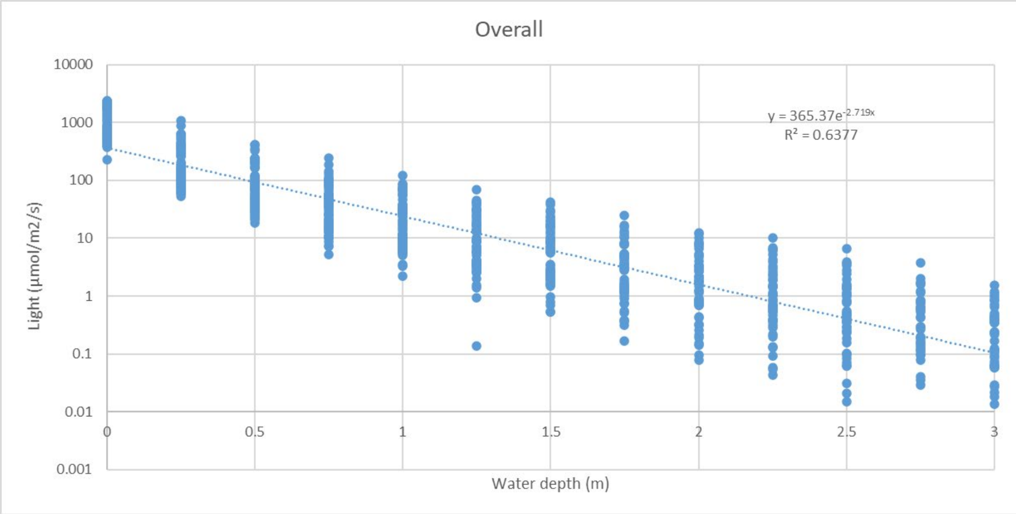


Figure 3-4: Exponential Regression Analysis for All LI-COR In-Situ Measurement Data

3.1.4 Summary

Based on the light data collected from 26 August 2021 to 9 September 2021 in Kranji Reservoir, it was found that the light attenuation throughout the water column in Kranji Reservoir followed exponential decay and the light below 3 m water depth was negligible in Kranji Reservoir. The values and light attenuation relations throughout water depths, either location specific or overall, can be used as the indicators reflecting the light condition in Kranji Reservoir during this period before the future development is in place (*Table 3-3*). Note that the current dataset was collected over a relatively short period and does not account for the intra- and inter-annual variation. Therefore, it can only serve as a part of baseline condition, not to represent a complete baseline condition.

Table 3-3: Overall Summary of Light Conditions in Kranji Reservoir in August/September 2021

Condition	Value / Equation
Daily light irradiance (in Air)	$16.68\ \mathrm{mol} \cdot m^{-2} d^{-1}$
Daily light at 1m below water surface at Location PAR1	$0.32\ \mathrm{mol} \cdot m^{-2} d^{-1}$
Daily light at 1m below water surface at Location PAR2	$0.49\ \mathrm{mol} \cdot m^{-2} d^{-1}$
Daily light at 1m below water surface at Location PAR3	$3.91\ \mathrm{mol} \cdot m^{-2} d^{-1}$
Overall daily light at 1m below water surface in Kranji Reservoir	$1.57\ mol \cdot m^{-2} d^{-1}$
Light attenuation equation along water depth at Location LI-COR1	$Light = 240.56 \cdot e^{-2.948 \cdot H}$
Light attenuation equation along water depth at Location LI-COR2	$Light = 423.62 \cdot e^{-2.838 \cdot H}$
Light attenuation equation along water depth at Location LI-COR3	$Light = 323.84 \cdot e^{-2.619 \cdot H}$
Light attenuation equation along water depth at Location LI-COR4	$Light = 669.82 \cdot e^{-3.193 \cdot H}$
Light attenuation equation along water depth at Location LI-COR5	$Light = 430.29 \cdot e^{-3.067 \cdot H}$

Light attenuation equation along water depth at Location LI-COR6	$Light = 394.94 \cdot e^{-2.376 \cdot H}$
Overall light attenuation equation along water depth in Kranji Reservoir	$Light = 365.37 \cdot e^{-2.719 \cdot H}$

3.2 Water Quality

3.2.1 *In-situ Profiling*

Figure 3-5 presents the in-situ water quality data carried out over 6 months from December 2020 to May 2021, across 5 locations, with an additional sampling event carried out in September 2021 to capture reservoir water conditions after a storm. The main observations and summary for in-situ parameters are as follow:

3.2.1.1 Temperature

Average water temperatures were consistent at each sampling location during each sampling monthly, ranging from 25.7 °C to 31.7 °C. Higher water temperature was observed at WQ01 in the month of May 2021, where the temperature was recorded at 35.7 °C at water surface and 35.4 °C at 0.5 m above reservoir bed. This appeared to be a one-time occurrence and could be attributed to the time of sampling during the day.

3.2.1.2 pH

The pH of a sample is a measure of the amount of free hydrogen ions in the water and neutral levels have a pH of 7. The typical pH range for freshwater is between 6 to 9. pH readings over the monitoring months ranged between 6.9 and 10.3, suggesting that the water was alkaline in nature. The geology of the catchment is alkaline by nature due to the presence of clay deposits in the sediments (Gin and Gopalakrishnan, 2010), but increased shoreline runoff, eutrophication and the proliferation of algae and aquatic plants have likely increased the alkalinity of the reservoir further (e.g. Verspagen et al., 2014). A one-off exceedance was observed in reservoir samples at WQ01 after a storm event in September 2021, with pH levels of up to 10.4.

3.2.1.3 Secchi Depth

Secchi depth provides an indication of the water clarity, which is influenced by various factors including turbidity and light. Secchi depth in the reservoir generally ranged from 0.3 m to 1.0 m while it ranged from 0.1 m to 0.5 m after the storm.

3.2.1.4 Turbidity

Turbidity levels typically ranged from 4.5 NTU to 47.4 NTU. High turbidity levels of up to 256.4 NTU were recorded in reservoir samples after the storm event at WQ04. The higher turbidity levels observed in WQ04 compared to the other locations is considered to be due to the proximity of this site to shallow waters and shorelines where surface runoff or rain/ storm discharges often result in higher suspended solids.

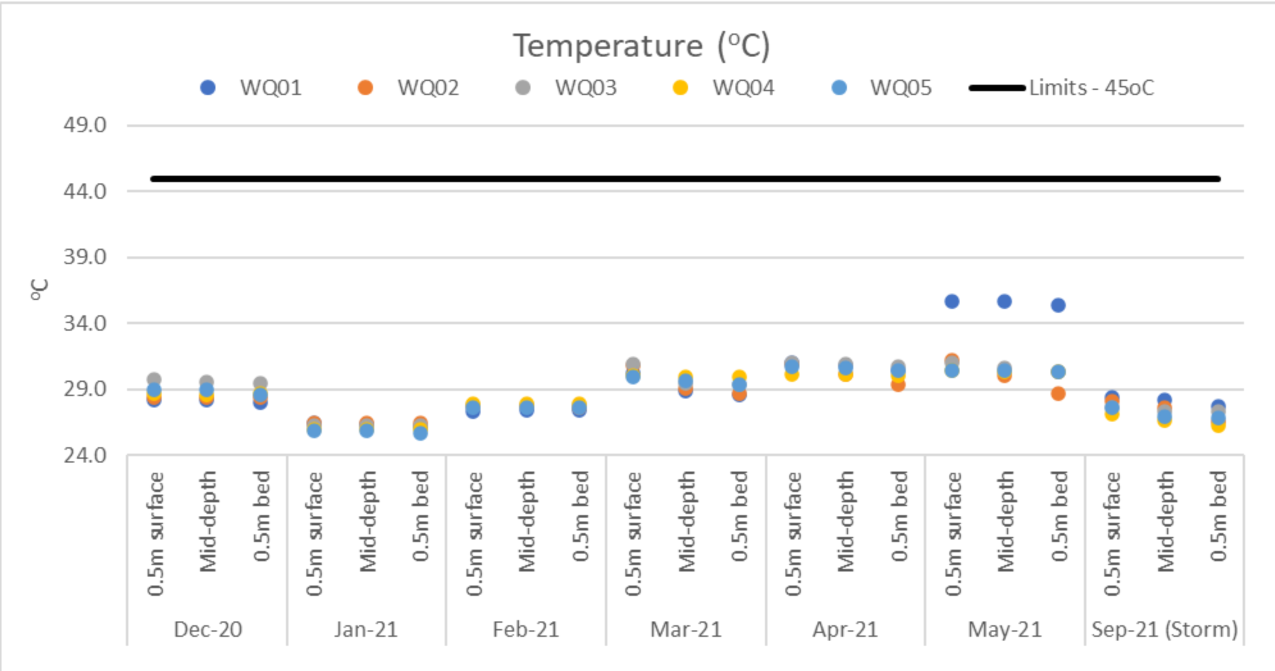
3.2.1.5 Dissolved Oxygen (DO)

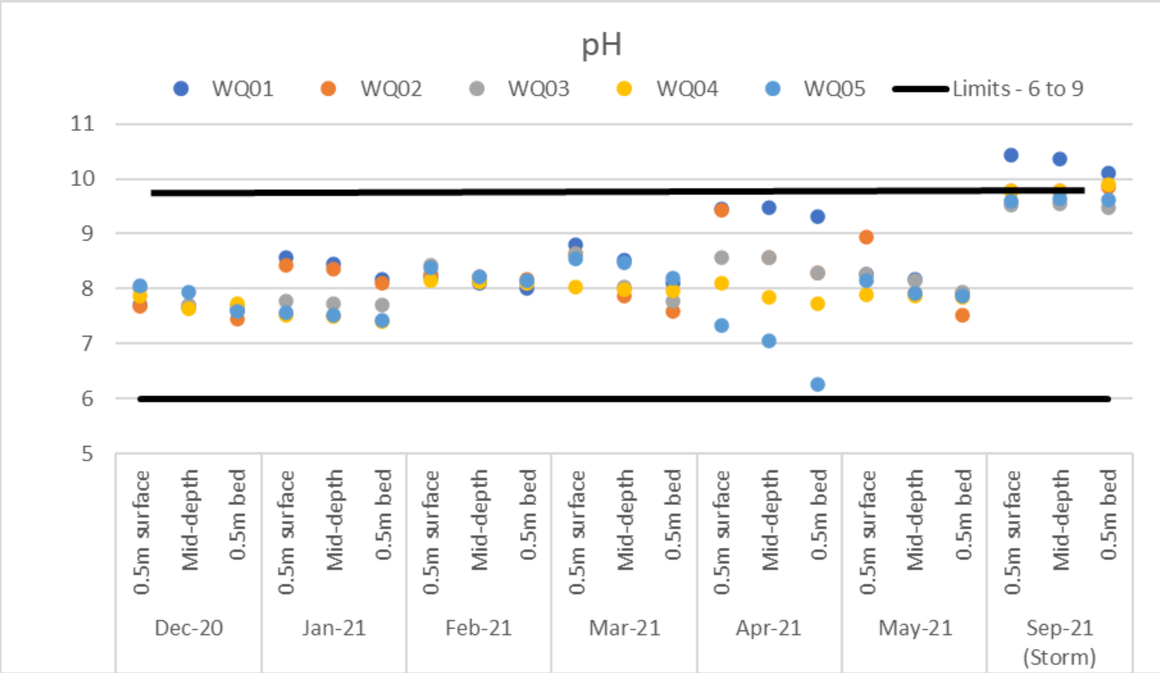
Dissolved oxygen measures the amount of oxygen dissolved in the water and is an indicator of water quality whereby higher DO levels usually indicate better water quality. The solubility of oxygen in water increases as temperature decreases which can influence DO levels. Levels can also change throughout the course of a day depending on respiration rates of submerged or partially submerged aquatic vegetation. Mean concentrations of DO (by stations per survey event) were relatively consistent, ranging between 4 mg/L to 11 mg/L. For surface measurements, the average DO across the sampling events was 7.6 mg/L and measurements ranged between 4.6 mg/L - 10.9 mg/L. For mid-depth measurements, the average DO was 6.9 mg/L and ranged between 4.05 mg/L - 11.07 mg/L. For measurements 0.5 m above the reservoir bed, the average DO across the sampling events was 6.0 mg/L and measurements ranged between 1.6 mg/L and 10.1 mg/L. There was a significant decrease in DO levels to <3 mg/L at WQ02 in May 2021 at 0.5 m above the reservoir bed, which may suggest organic decomposition on the reservoir bed at this time. DO measurements were less variable at WQ01 and WQ03, where habitat mapping indicated submerged and emergent/ floating vegetation were abundant. At these two locations, DO values were relatively consistent and did not decline below 5 mg/L.

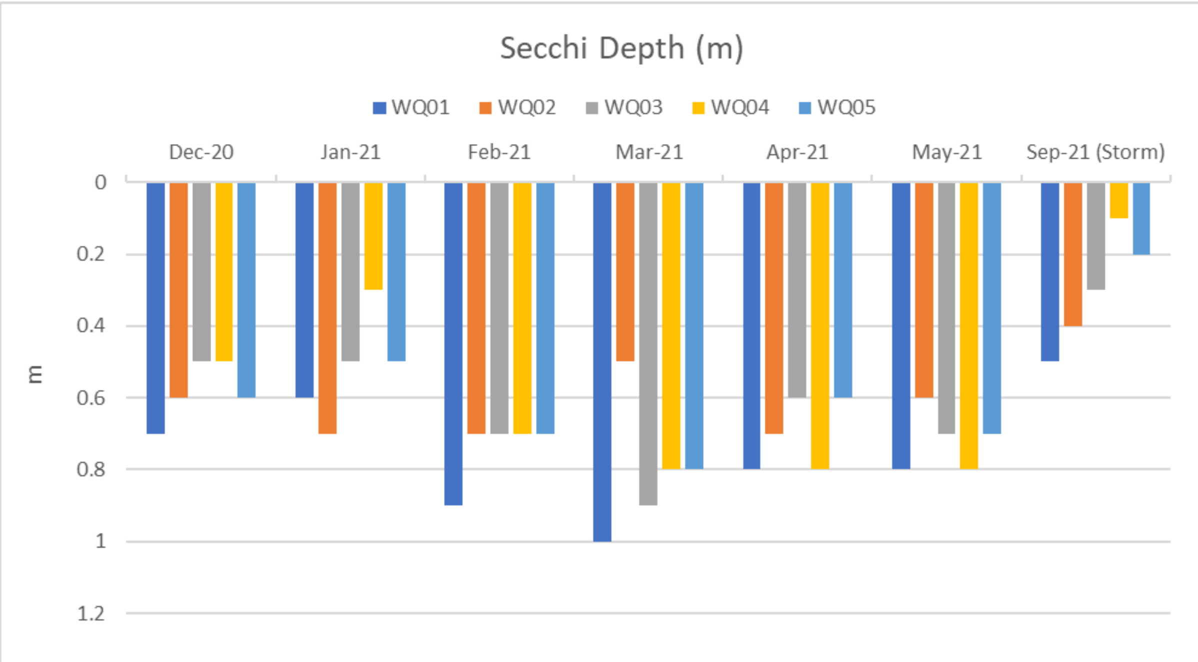
3.2.1.6 Conductivity

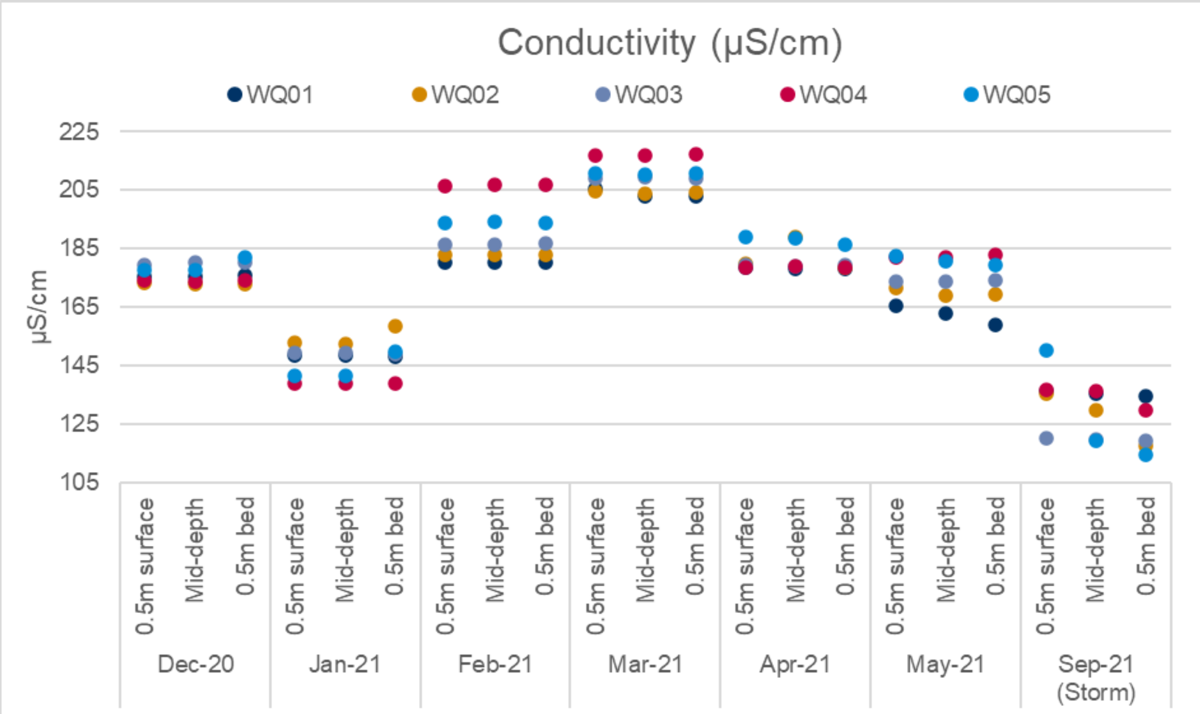
Conductivity is the ability of the water to conduct electricity. The more dissolved salts there are in the water, the higher the conductivity levels as dissolution converts salts into its constituent ions which enhance electric flow. The conductivity levels ranged between 105 µS/cm to 225 µS/cm. Lower conductivity levels were observed in reservoir samples after the storm event compared to the other sampling events. Concentrations were also relatively consistent throughout the water column at each of the survey stations. Freshwaters tend to have a conductivity level within the range of 30 – 500 µS/cm.

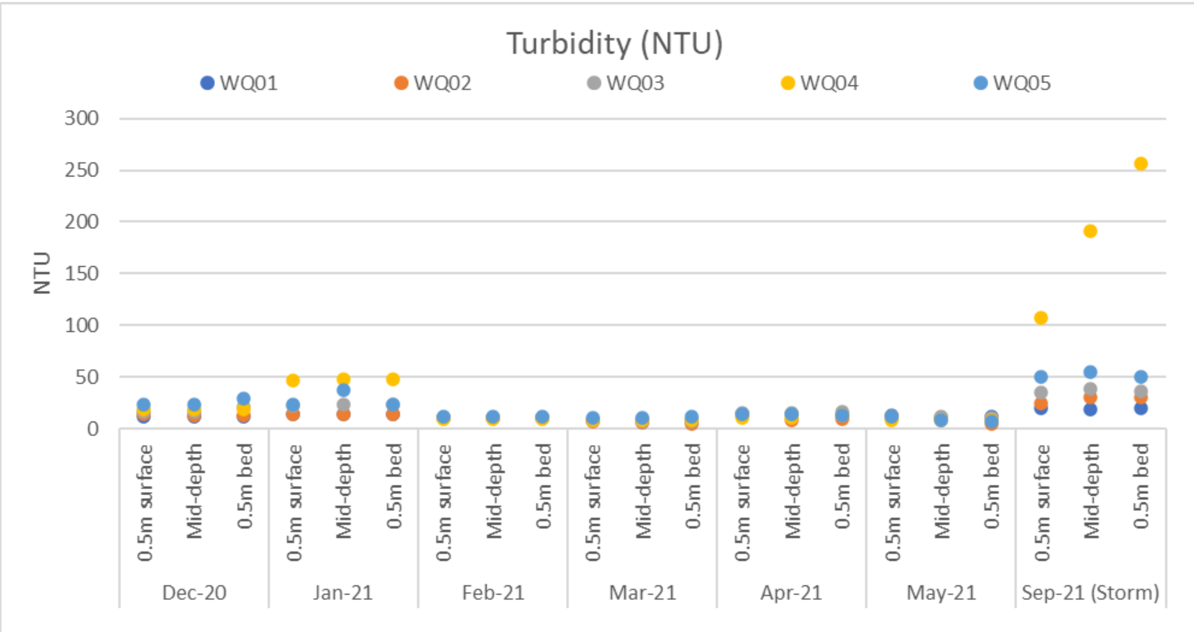
Figure 3-5 below presents the in-situ water quality data across the 5 sampling locations, and after one storm event.




pH
WQ01
WQ02
WQ03
WQ04
WQ05
Limits - 6 to 9
11
10
9
8
7
6
5
0.5m surface
Mid-depth
0.5m bed
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)


Secchi Depth (m)
WQ01
WQ02
WQ03
WQ04
WQ05
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
m
0
0.2
0.4
0.6
0.8
1
1.2


Conductivity (µS/cm)
WQ01
WQ02
WQ03
WQ04
WQ05
µS/cm
225
205
185
165
145
125
105
0.5m surface
Mid-depth
0.5m bed
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)


Turbidity (NTU)
WQ01
WQ02
WQ03
WQ04
WQ05
NTU
300
250
200
150
100
50
0
0.5m surface
Mid-depth
0.5m bed
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

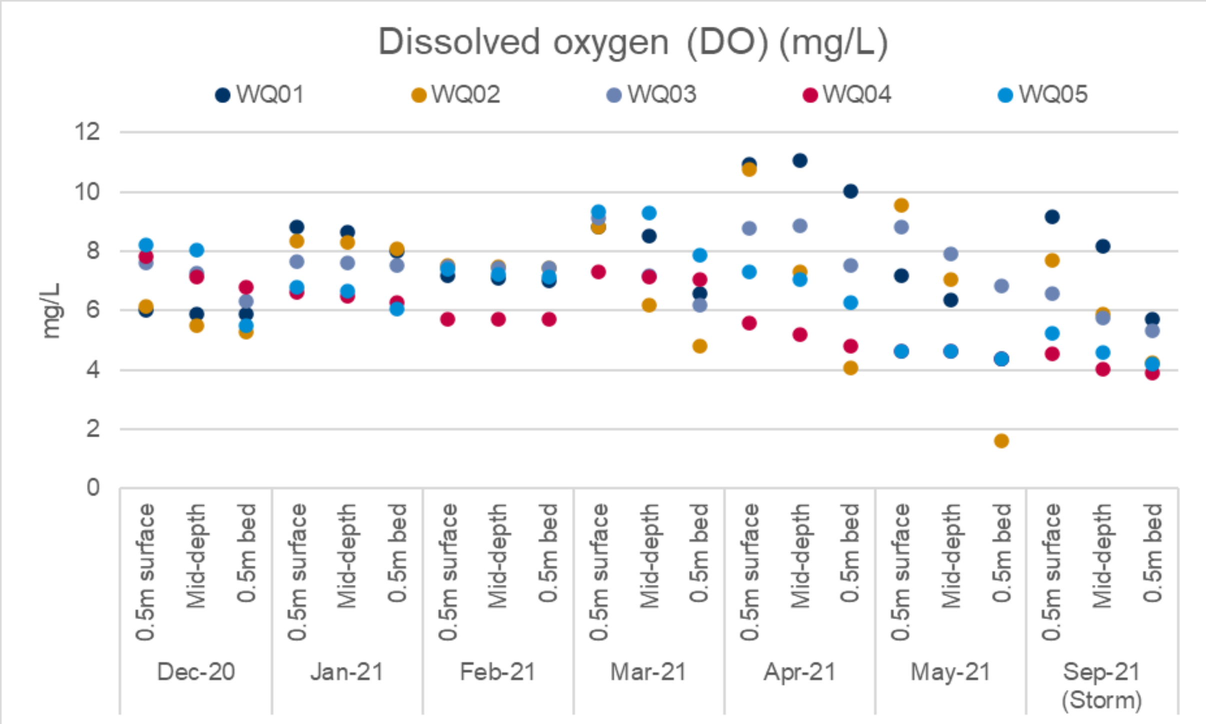


Figure 3-5: Water Quality – In-Situ Profiling at Varying Depths

3.2.2 Water Samples

Water samples were taken at 2 depths at each of the 5 locations. Limited number of exceedances of relevant criteria was observed for some parameters at specific sampling periods. These are described in *Section 3.2.2.1* and *Section 3.2.2.2* below.

3.2.2.1 Exceedances at Mid-Depth

The main observations and summary for water parameters analysed at mid-depth are as follows (also see *Figure 3-6*):

Total Suspended Solids (TSS)

TSS is a measure of suspended solids within the water column, and it affects the clarity of the water. TSS levels were generally below NEA's allowable limit for discharge to controlled watercourse (30 mg/L), except sampling in the reservoir after the storm event (September 2021) at WQ04 when TSS levels increased to 81 mg/L at this site. The TSS levels were observed to be higher at WQ04 at mid-depth compared to the other sampling locations throughout the sampling months. This could be due the shallow depth (<1.2 m) at WQ04 where reservoir bed sediments are easily stirred.

Arsenic (As)

Arsenic can be released into freshwater naturally from natural deposits in the earth or from industrial and agricultural pollution. An exceedance in As level was observed at WQ01 at mid-depth in December 2021 at 0.012 mg/L. This appeared to be a one-off occurrence (and not occurring during/ after a storm event) as As levels in sampling months thereafter were below 0.004 mg/L, well below the NEA's allowable limits (0.01 mg/L).

3.2.2.2 Exceedances at 0.5m Above Reservoir Bed

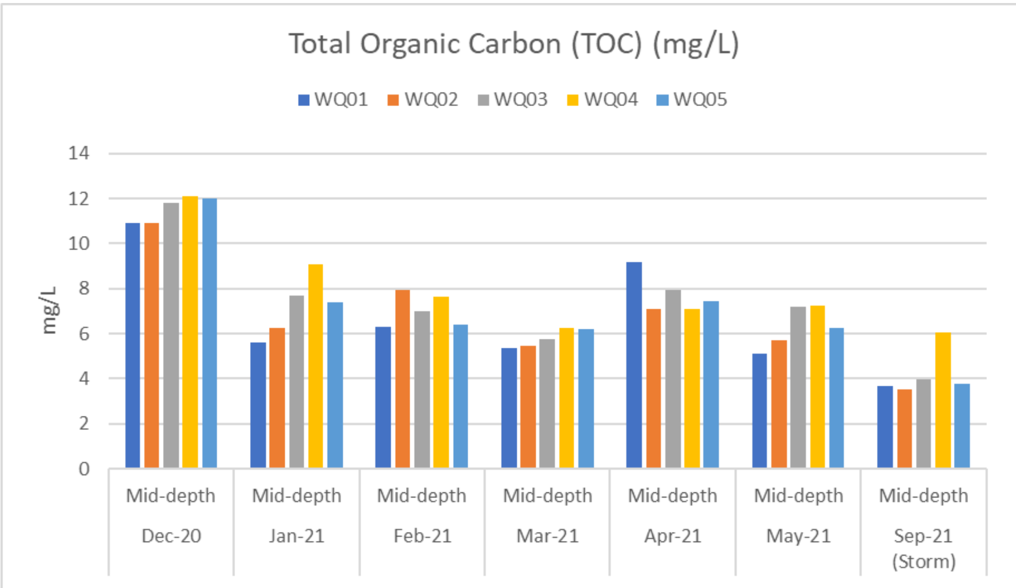
The main observations and summary for water parameters analysed at <u>0.5 m above reservoir bed</u> are as follow (*Figure 3-7*):

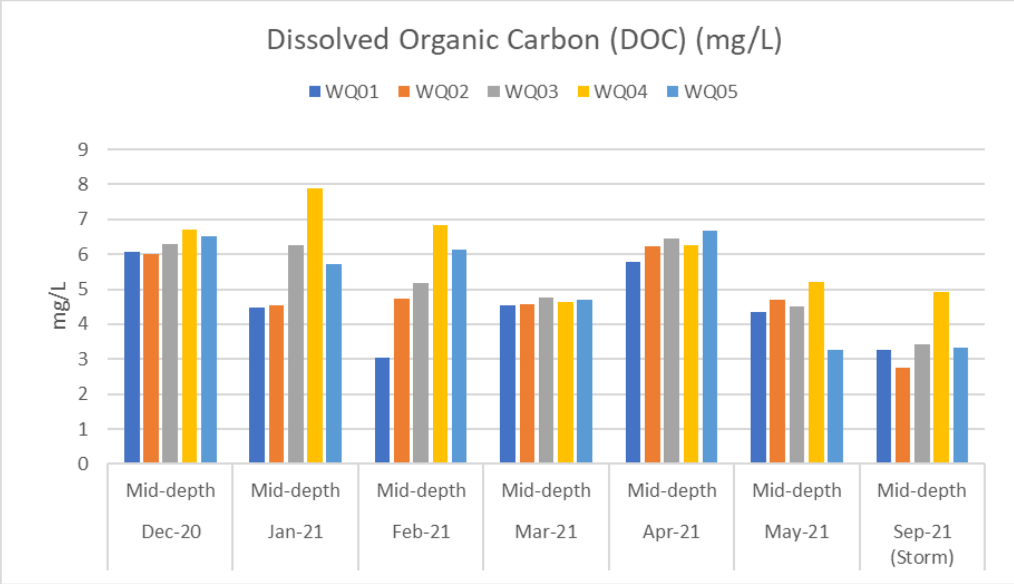
Iron (Fe)

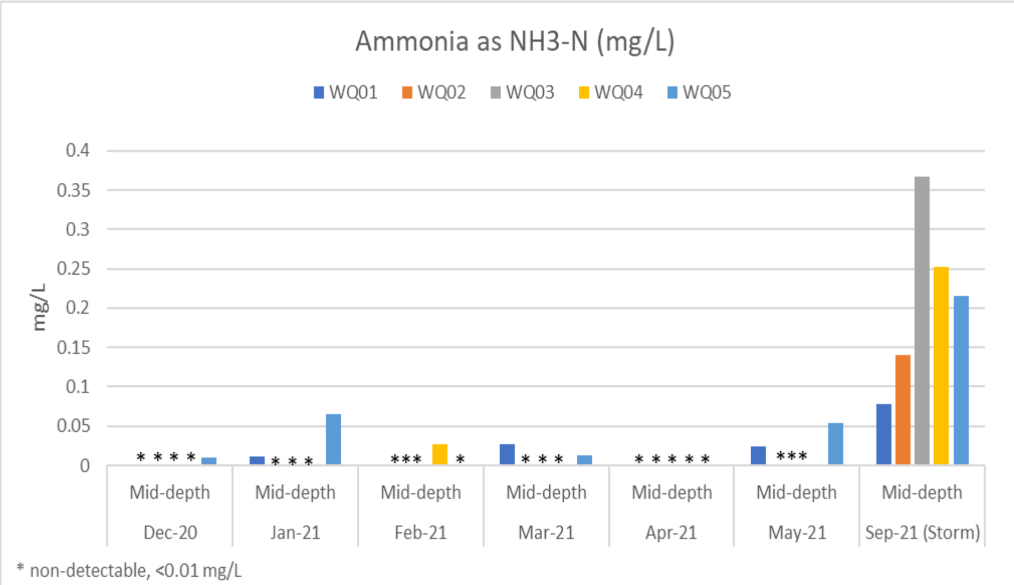
Iron exists naturally in rivers, lakes, and underground water and may be released from natural deposits. High level of iron can also be found in areas with combination of naturally occurring organic material in shallow or surface water. Fe levels were observed to exceed NEA's allowable limits (1 mg/L) at WQ05 in February and May 2021 (2.9 mg/L and 2.8 mg/L, respectively), as well as at WQ04 in September 2021 (2.1 mg/L) at 0.5m above reservoir bed.

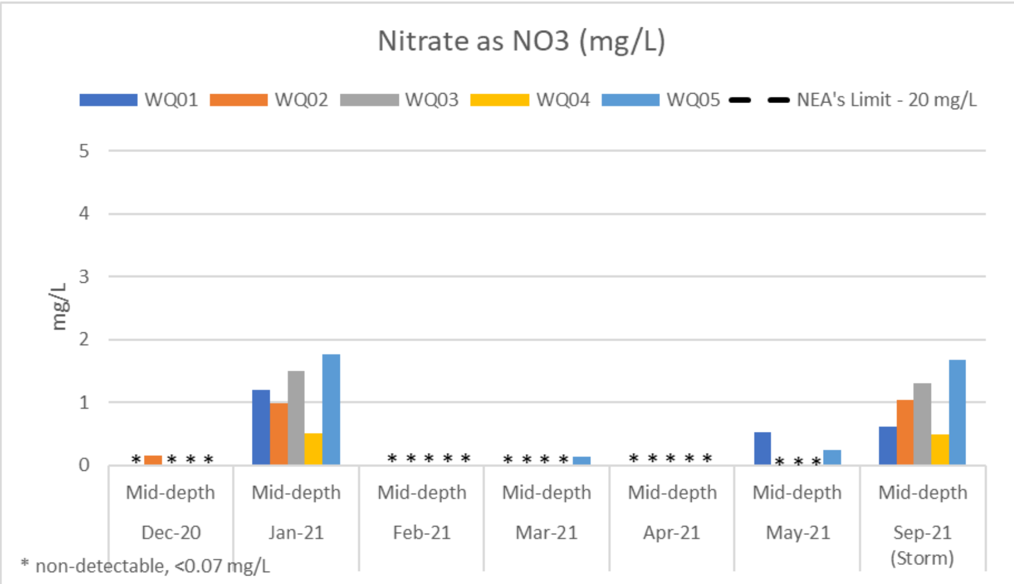
3.2.2.3 Water Quality Parameters

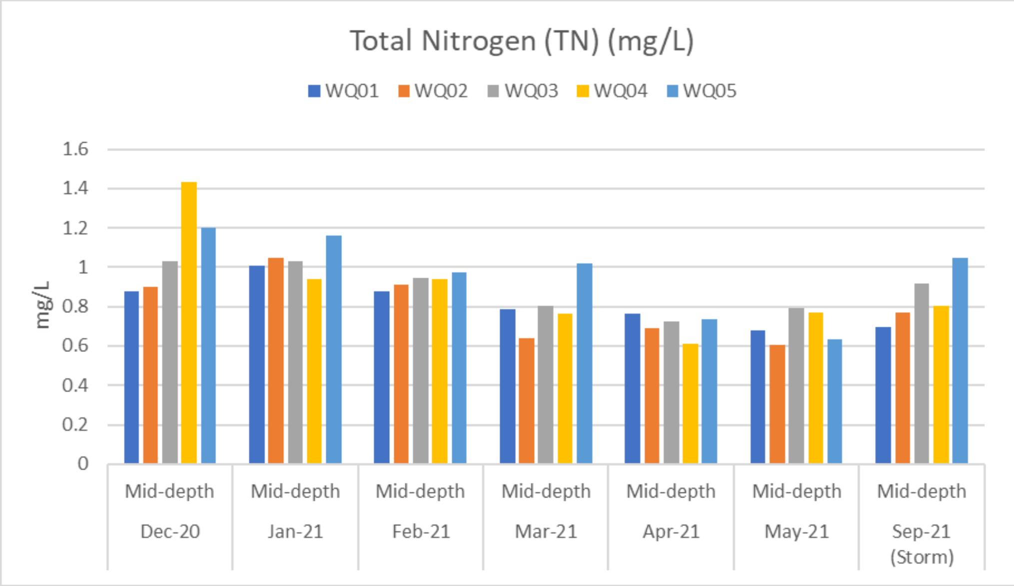
Figure 3-6 and *Figure 3-7* presents the lab results for water samples taken at mid-depth and 0.5 m above reservoir bed respectively; where detectable, parameter concentrations were generally below NEA's allowable limits for trade effluent discharge to controlled watercourse. Where detectable and without target or intervention limits, these results serve as a benchmark for future monitoring purposes. It is noted, that in some cases for metals there was a change in detection limit from February 2021, this is a result of these metals not being detected, thus a lower detection limit was applied for the analysis of these metals.

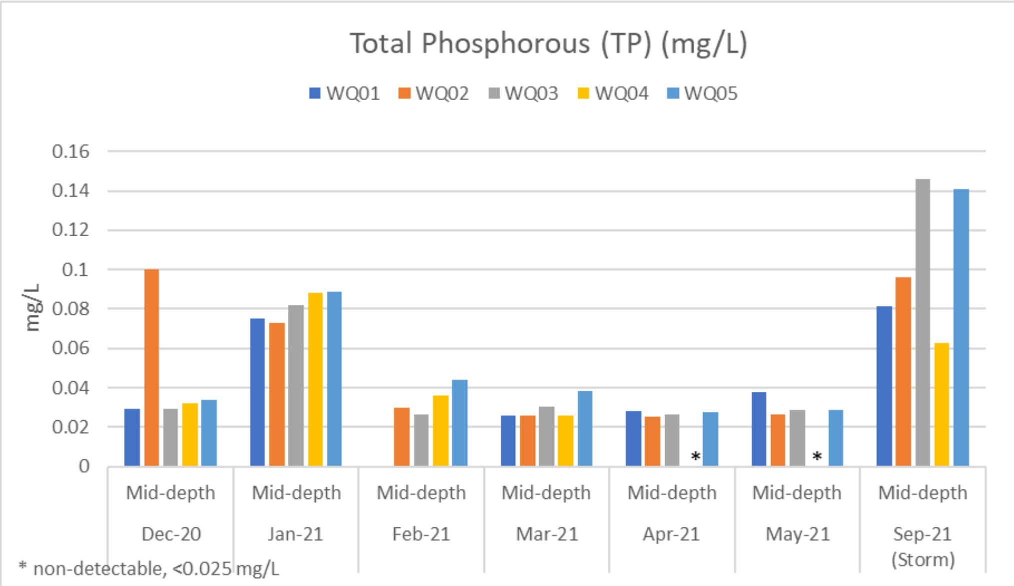


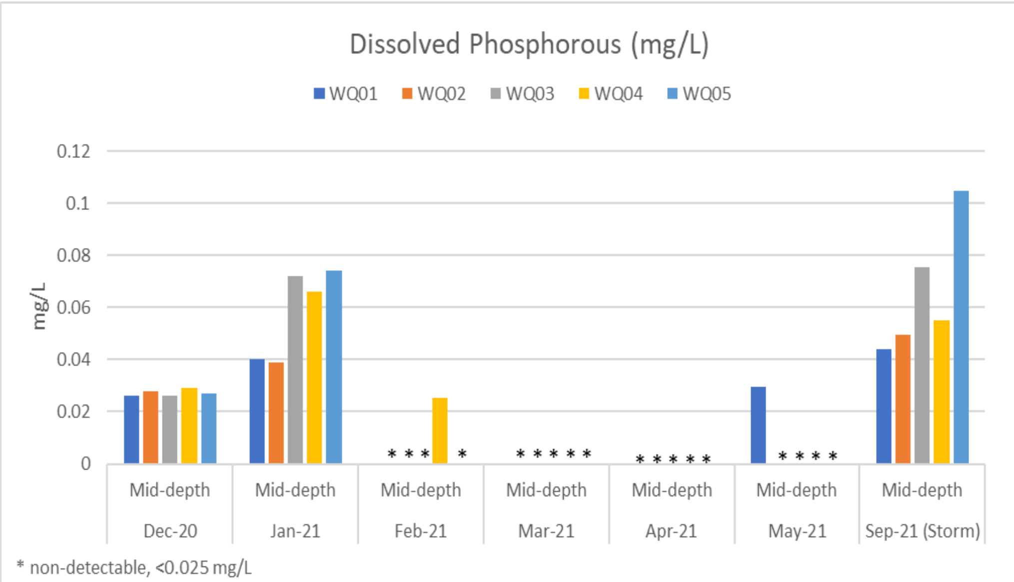

Dissolved Organic Carbon (DOC) (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)

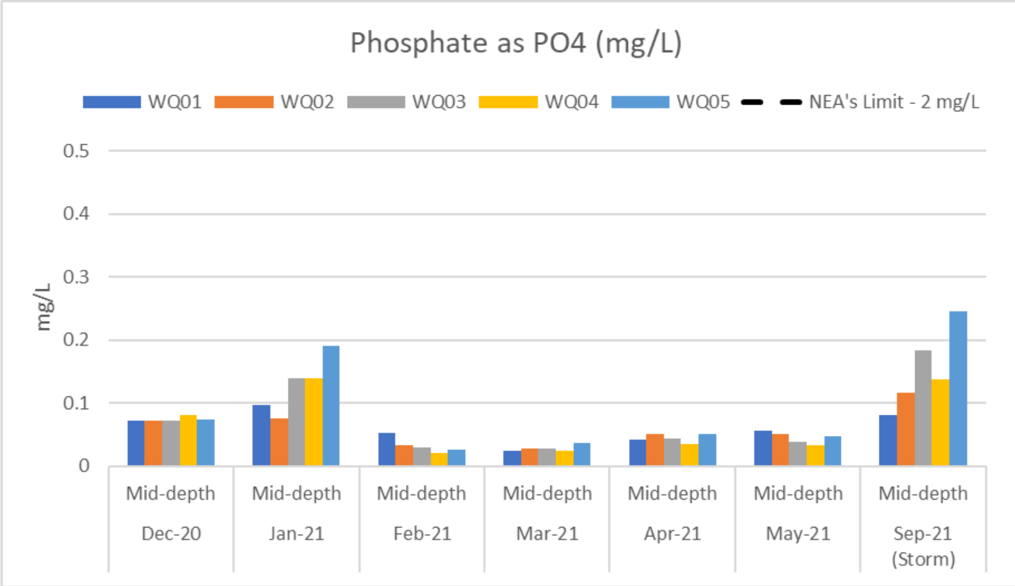

Ammonia as NH3-N (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)
* non-detectable, <0.01 mg/L

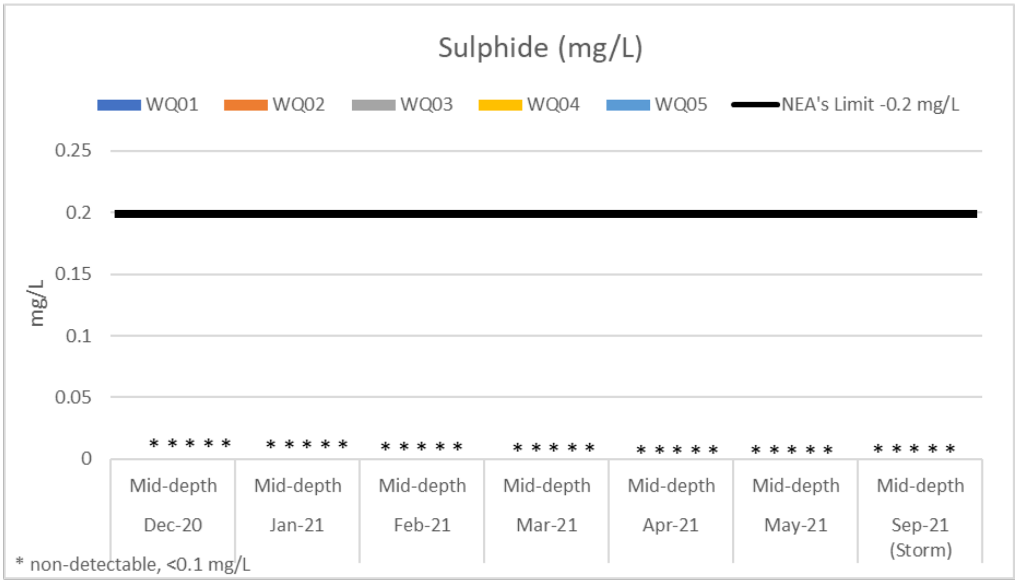

Nitrate as NO3 (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 20 mg/L
mg/L
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)
* non-detectable, <0.07 mg/L

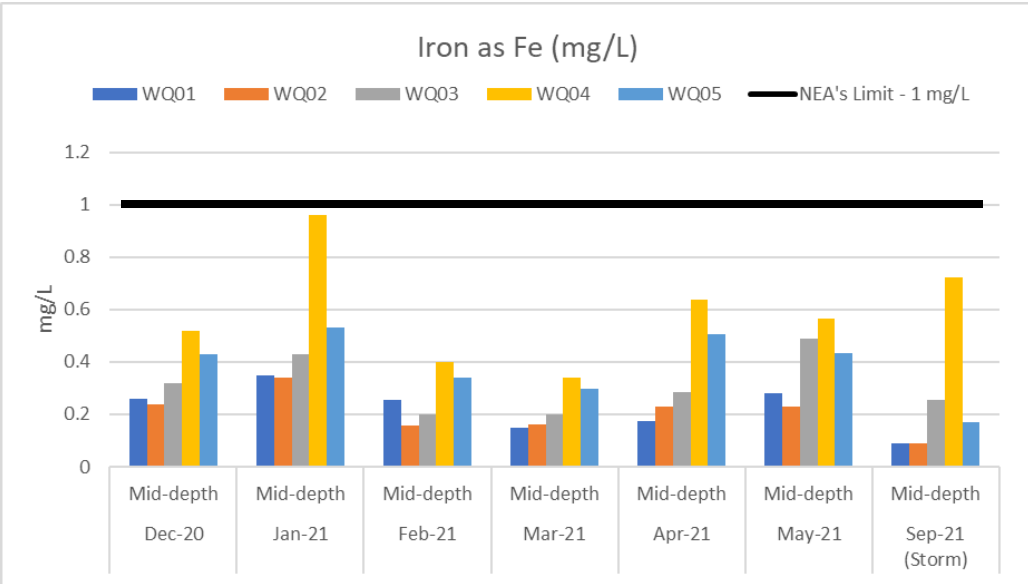

Total Nitrogen (TN) (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

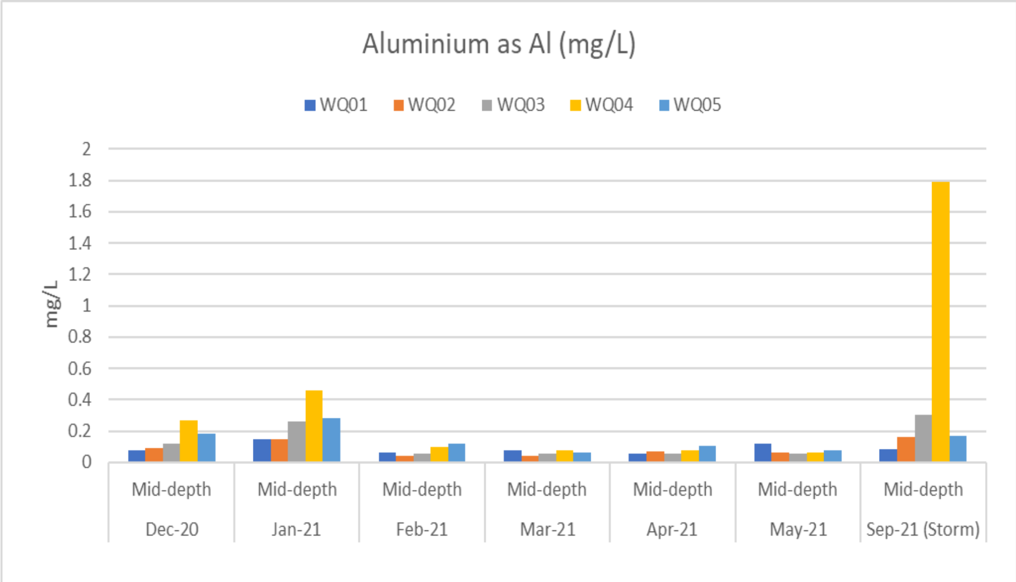

Total Phosphorous (TP) (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.025 mg/L

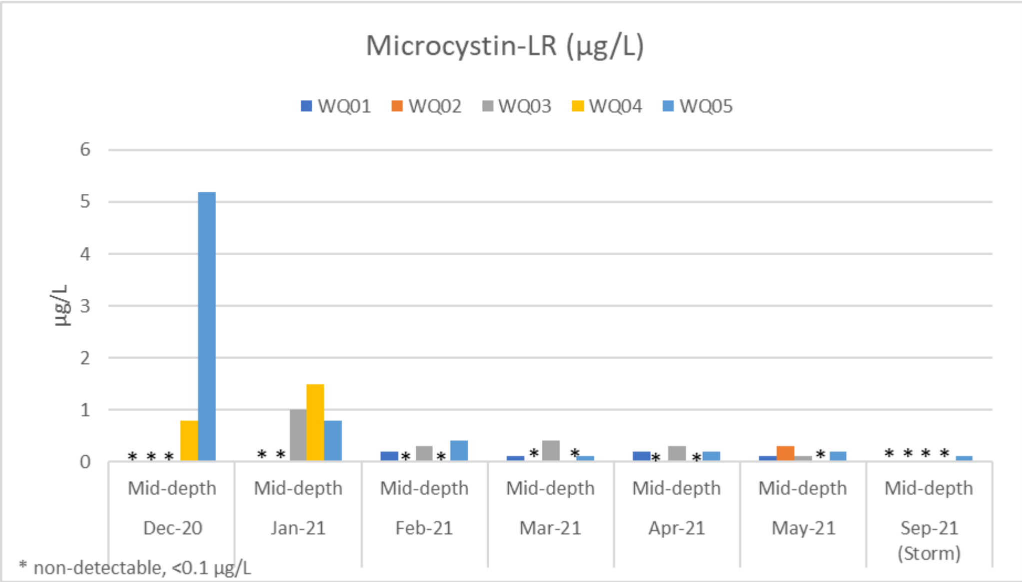

Dissolved Phosphorous (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
0.12
0.1
0.08
0.06
0.04
0.02
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.025 mg/L

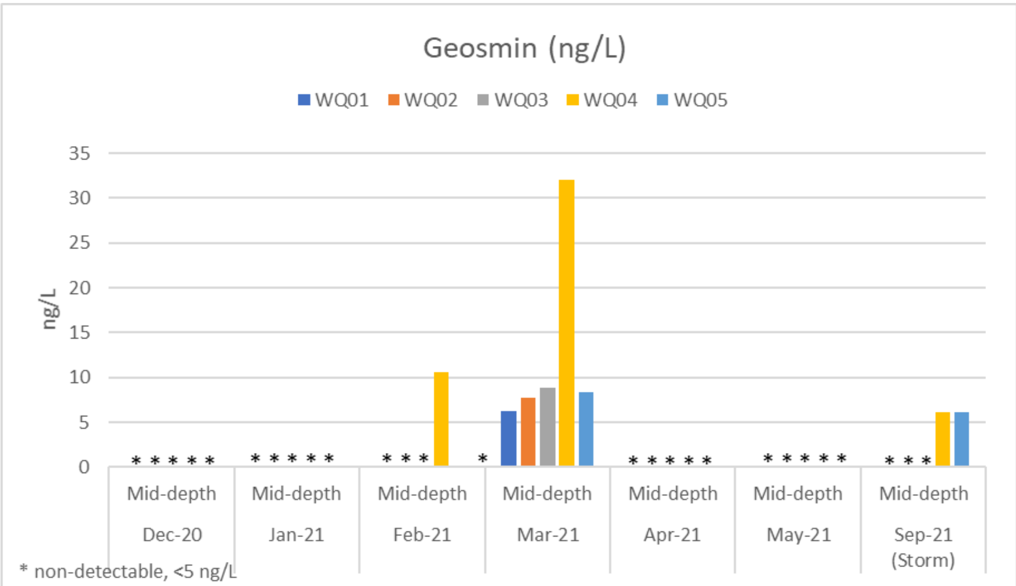

Phosphate as PO4 (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 2 mg/L
mg/L
0.5
0.4
0.3
0.2
0.1
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

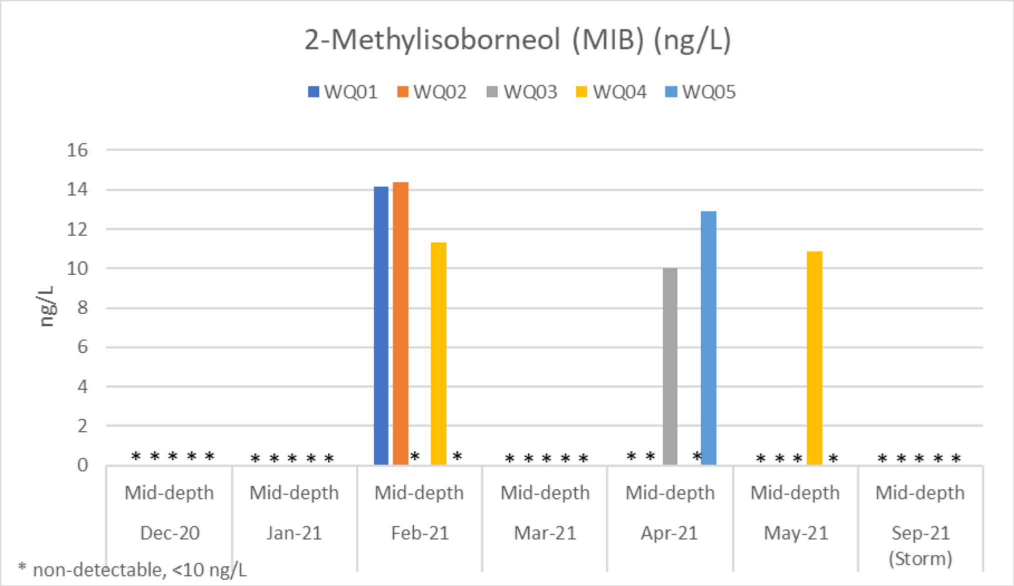

Sulphide (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit -0.2 mg/L
mg/L
0.25
0.2
0.15
0.1
0.05
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.1 mg/L

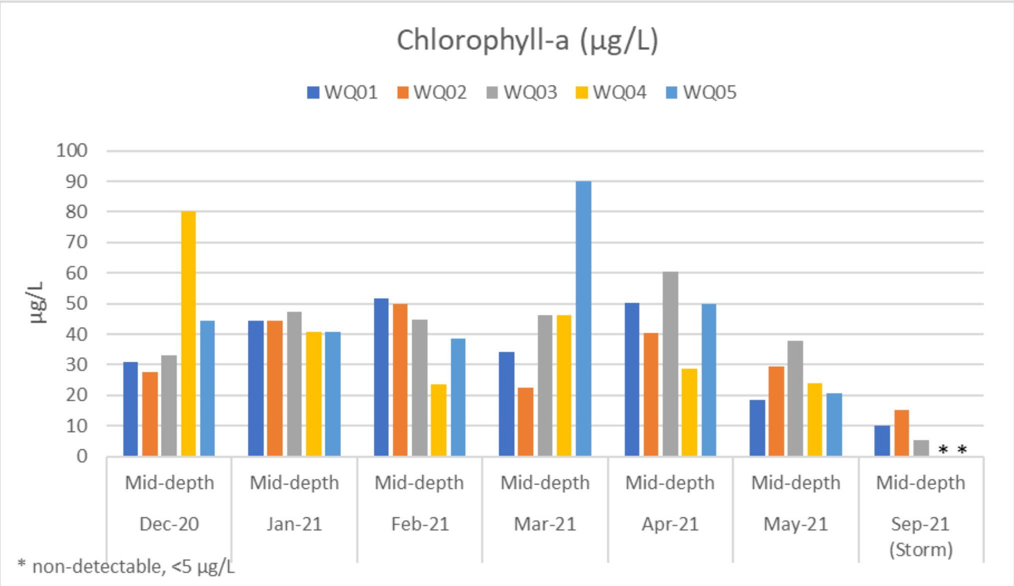

Iron as Fe (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 1 mg/L
mg/L
1.2
1
0.8
0.6
0.4
0.2
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

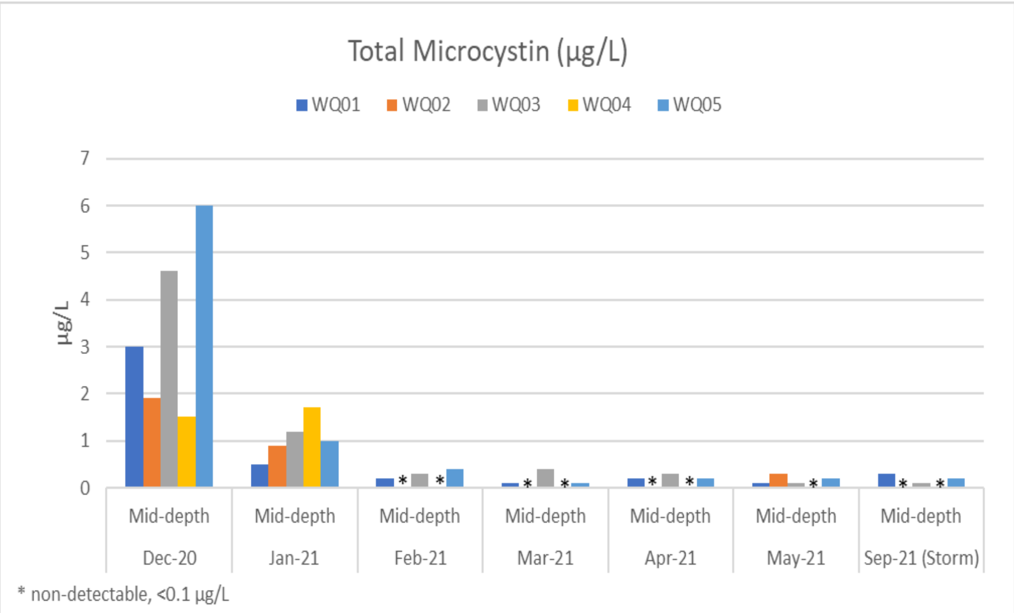

Aluminium as Al (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

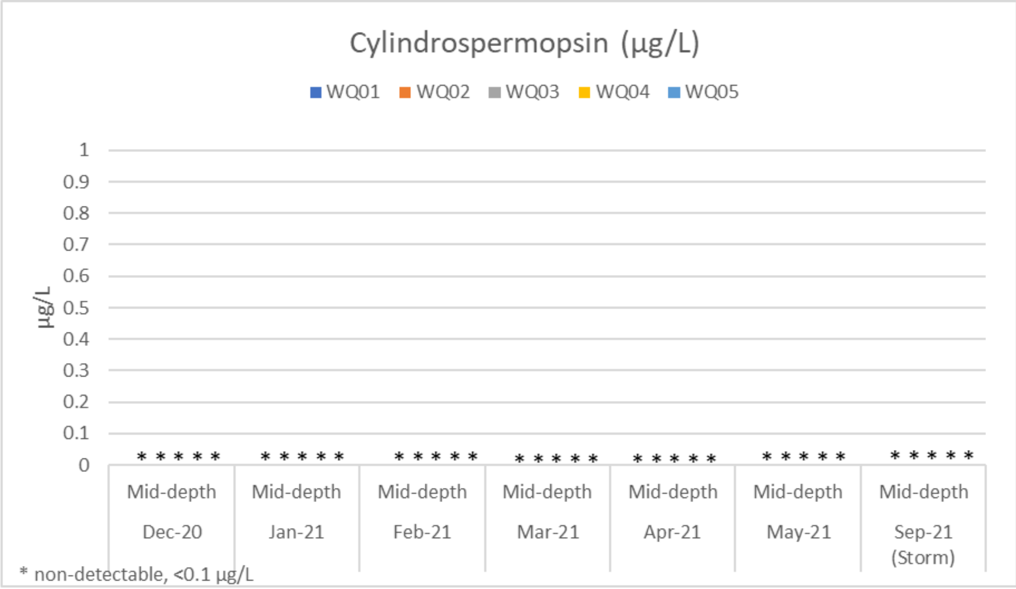

Microcystin-LR (µg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
µg/L
6
5
4
3
2
1
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.1 µg/L

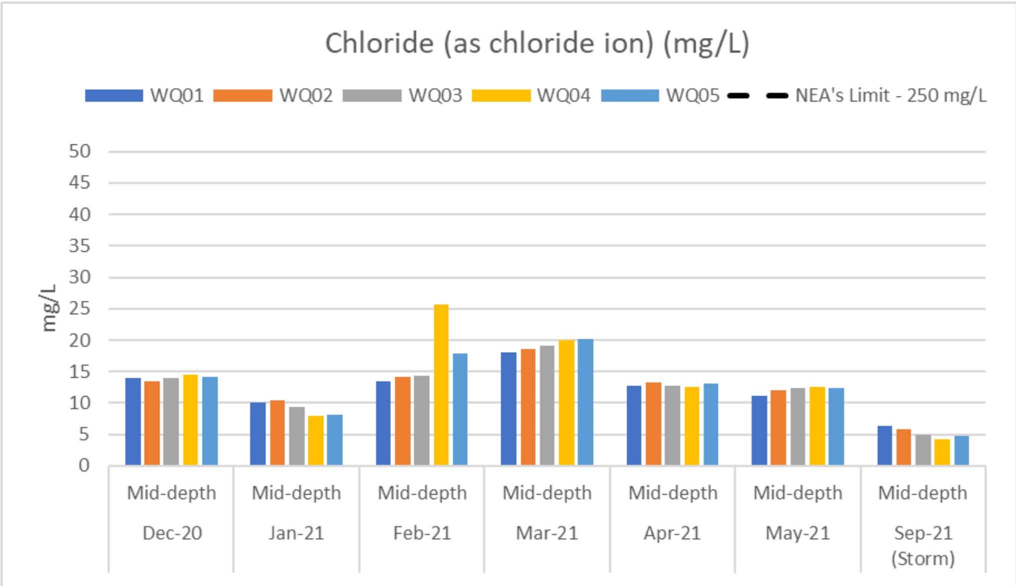

Geosmin (ng/L)
WQ01 WQ02 WQ03 WQ04 WQ05
ng/L
35
30
25
20
15
10
5
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <5 ng/L

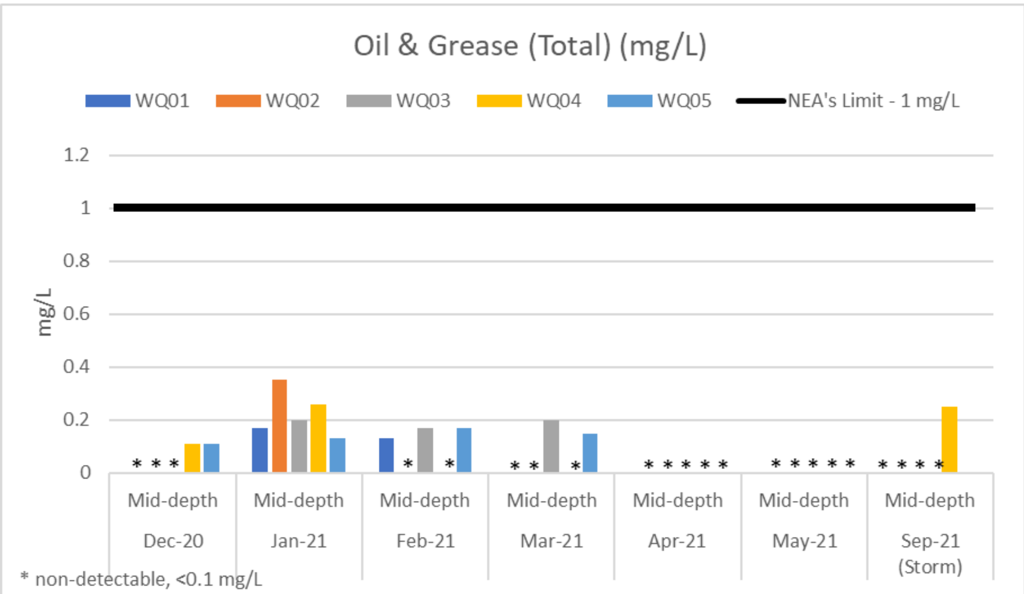

2-Methylisoborneol (MIB) (ng/L)
WQ01 WQ02 WQ03 WQ04 WQ05
ng/L
16
14
12
10
8
6
4
2
0
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)
* non-detectable, <10 ng/L

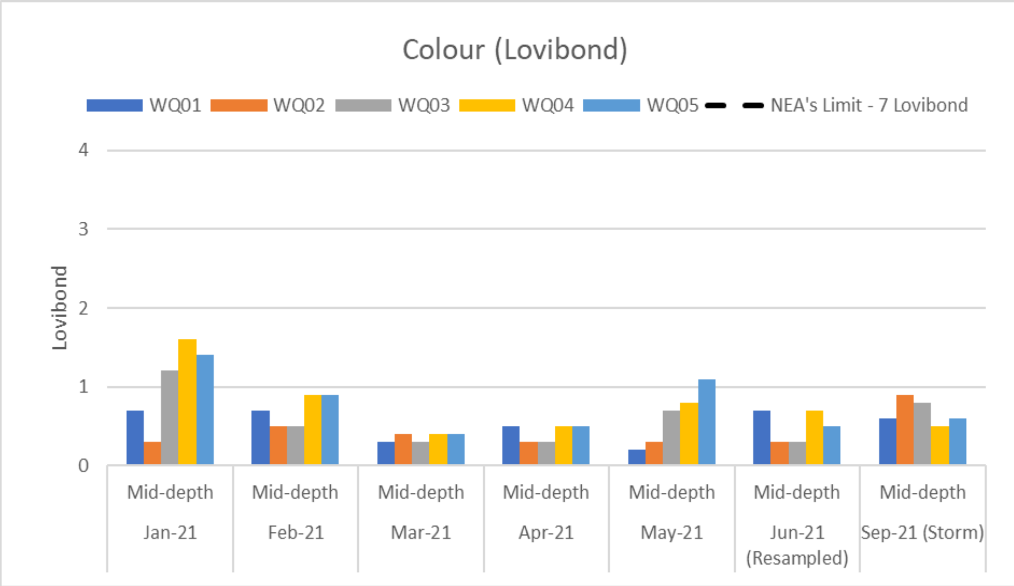

Chlorophyll-a (µg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
µg/L
100
90
80
70
60
50
40
30
20
10
0
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)
* non-detectable, <5 µg/L

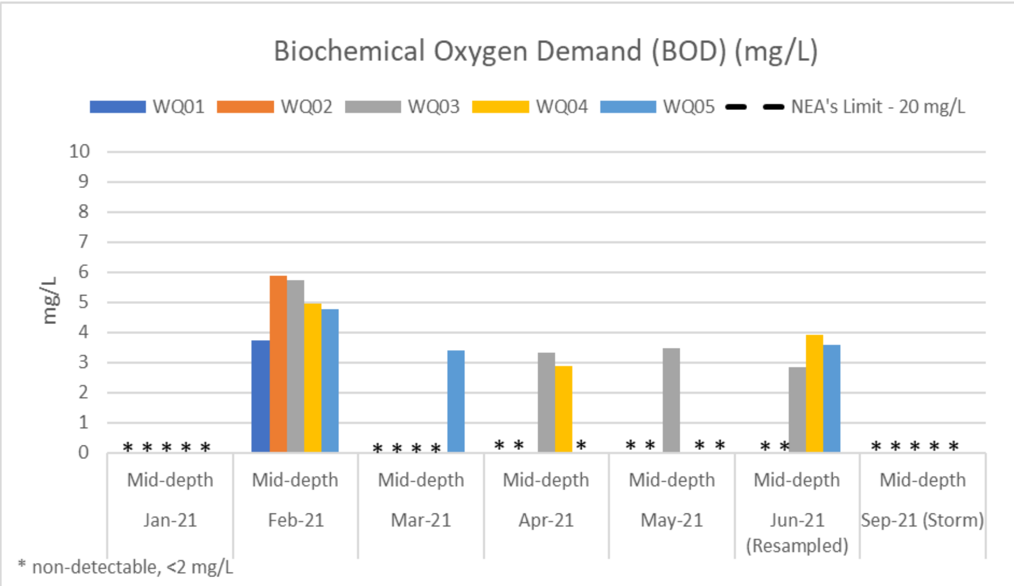

Total Microcystin (µg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
µg/L
7
6
5
4
3
2
1
0
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)
* non-detectable, <0.1 µg/L

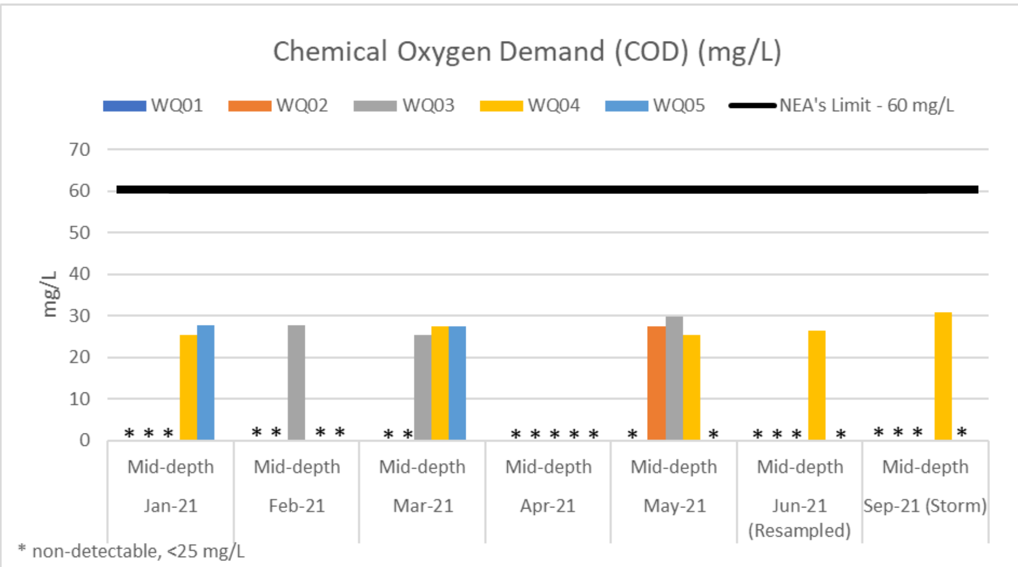

Cylindrospermopsin (µg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
µg/L
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.1 µg/L

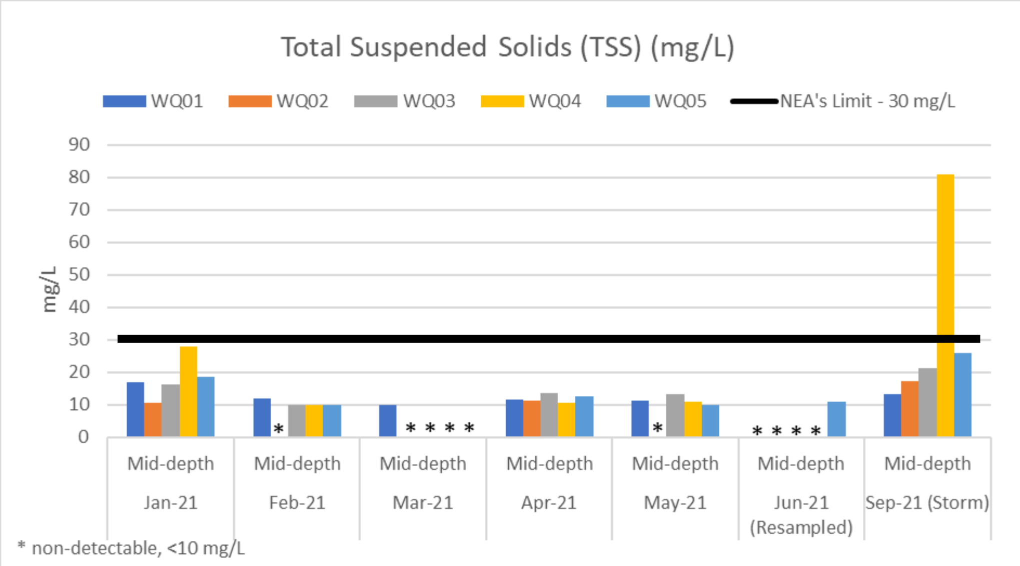

Chloride (as chloride ion) (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 250 mg/L
mg/L
50
45
40
35
30
25
20
15
10
5
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

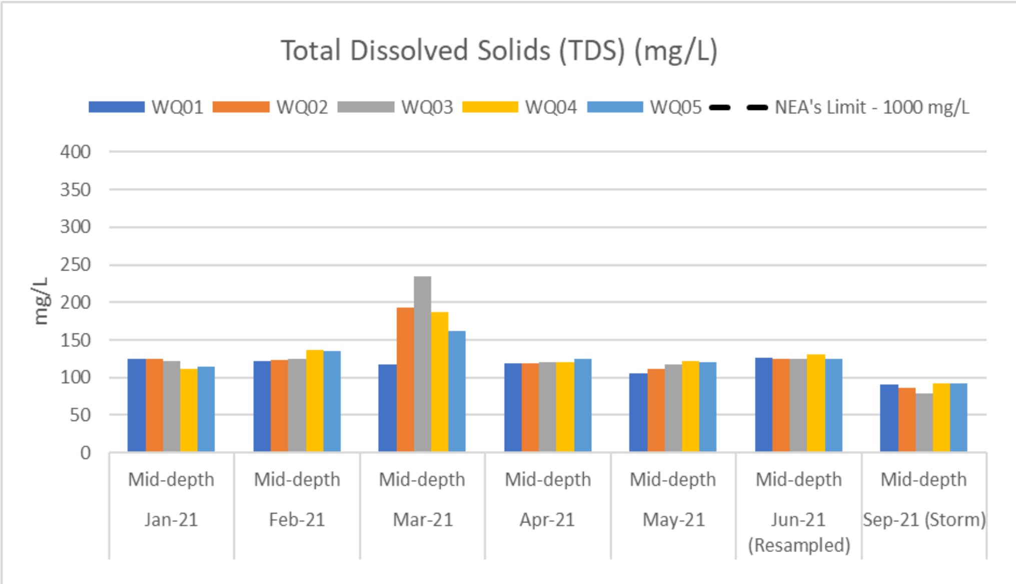

Oil & Grease (Total) (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 1 mg/L
mg/L
1.2
1
0.8
0.6
0.4
0.2
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.1 mg/L

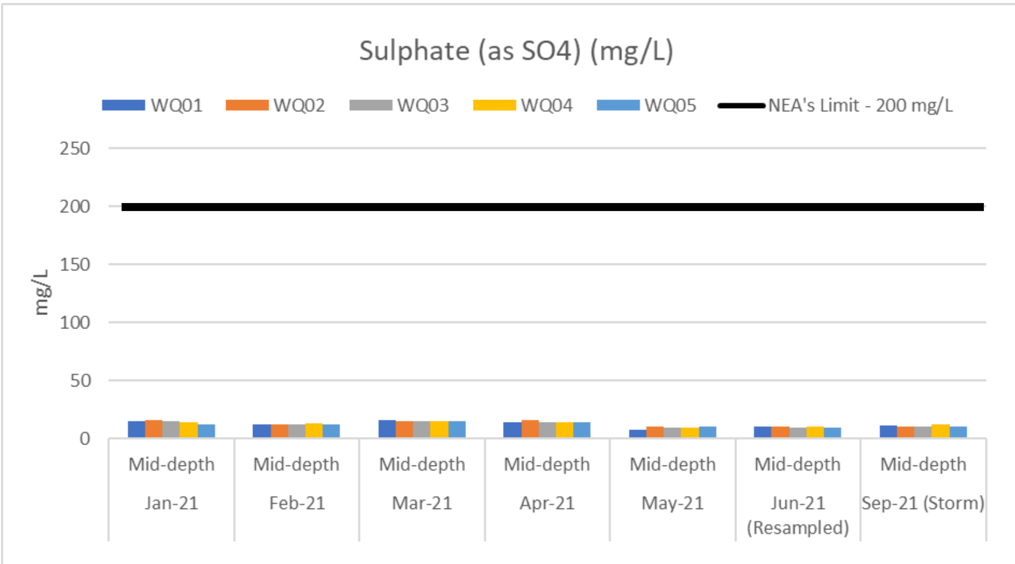

Colour (Lovibond)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 7 Lovibond
Lovibond
4
3
2
1
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)

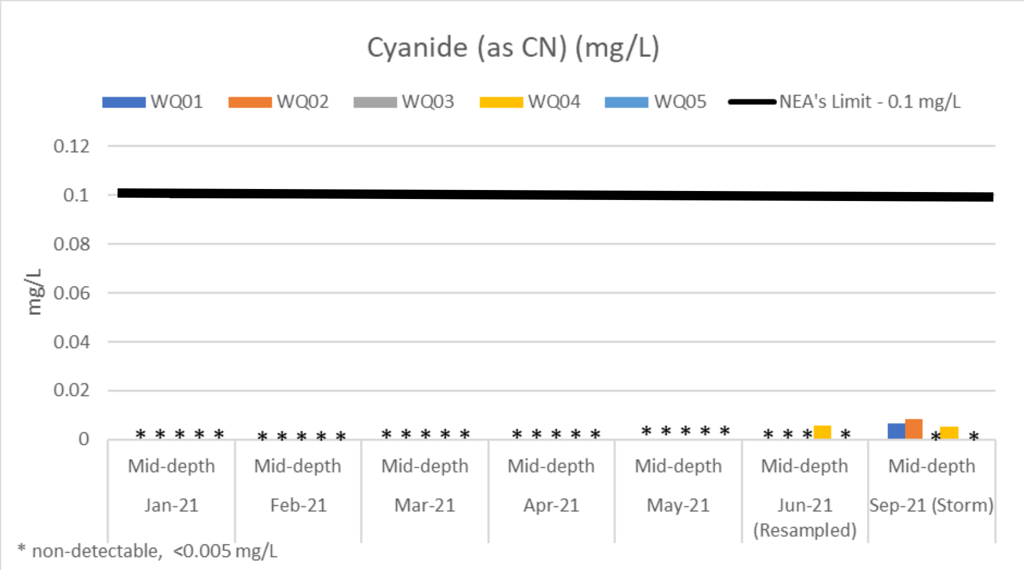

Biochemical Oxygen Demand (BOD) (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 20 mg/L
mg/L
10
9
8
7
6
5
4
3
2
1
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)
* non-detectable, <2 mg/L

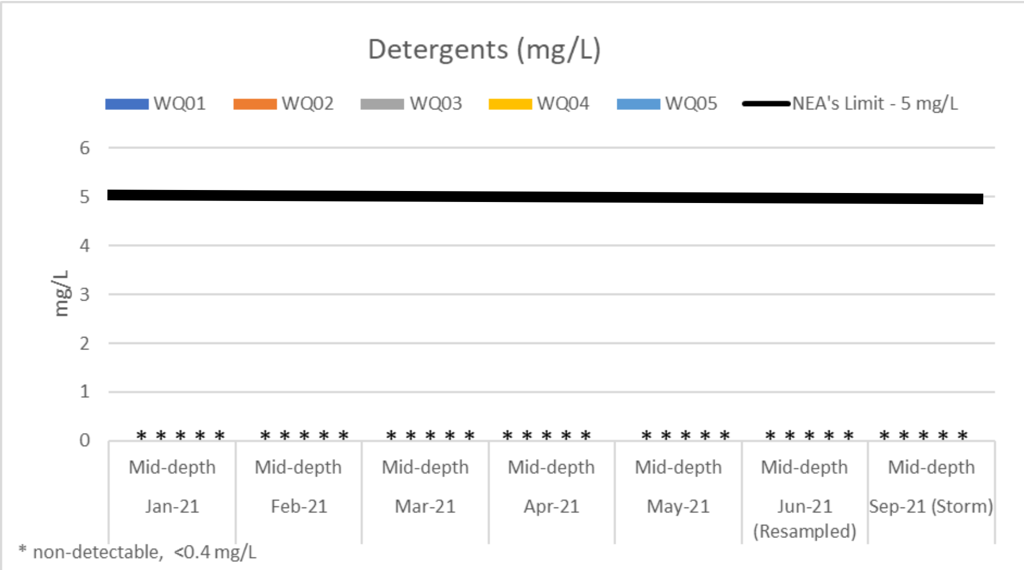

Chemical Oxygen Demand (COD) (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 60 mg/L
mg/L
70
60
50
40
30
20
10
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)
* non-detectable, <25 mg/L

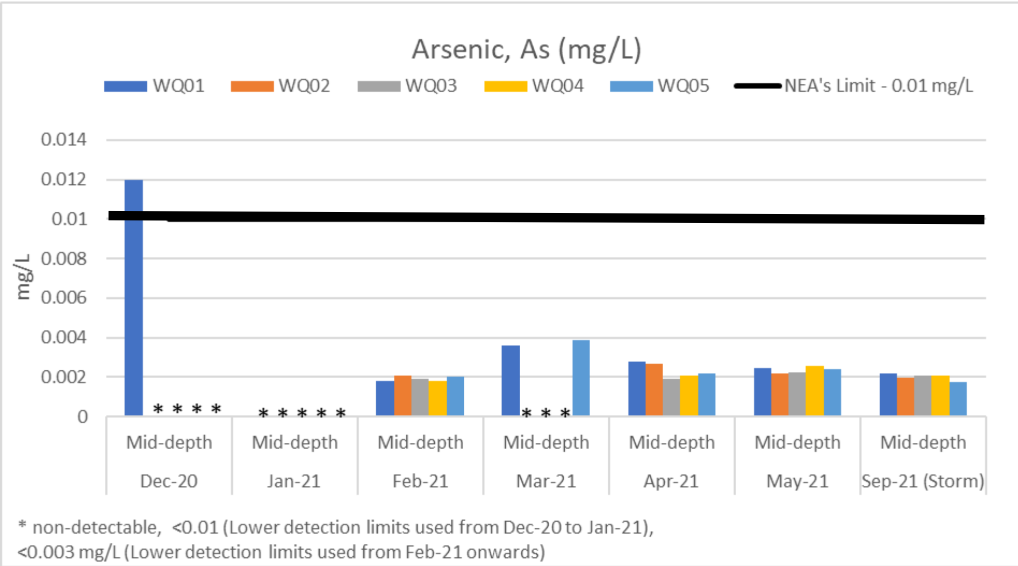

Total Suspended Solids (TSS) (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 30 mg/L
mg/L
90
80
70
60
50
40
30
20
10
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)
* non-detectable, <10 mg/L

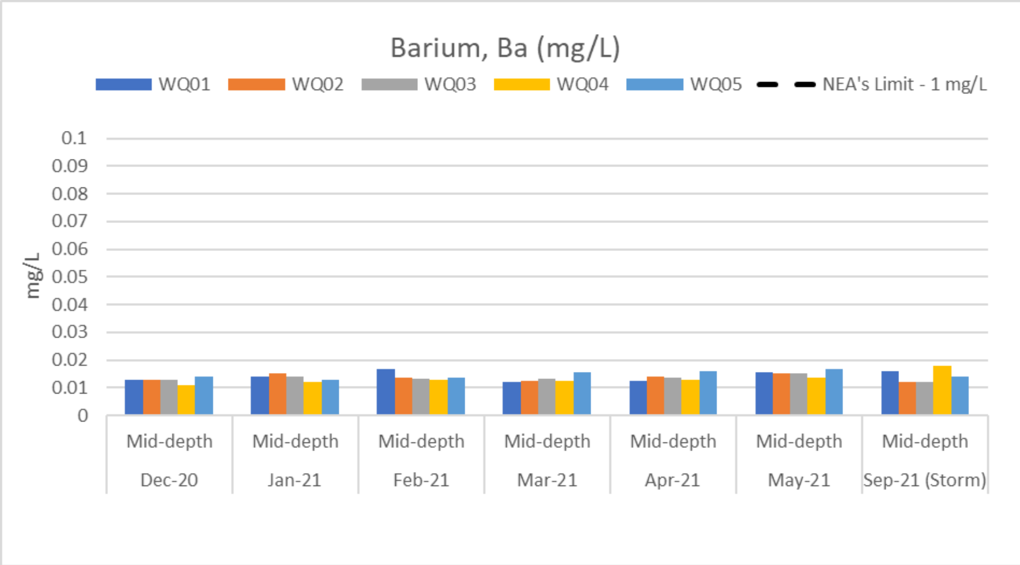

Total Dissolved Solids (TDS) (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 1000 mg/L
mg/L
400
350
300
250
200
150
100
50
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)

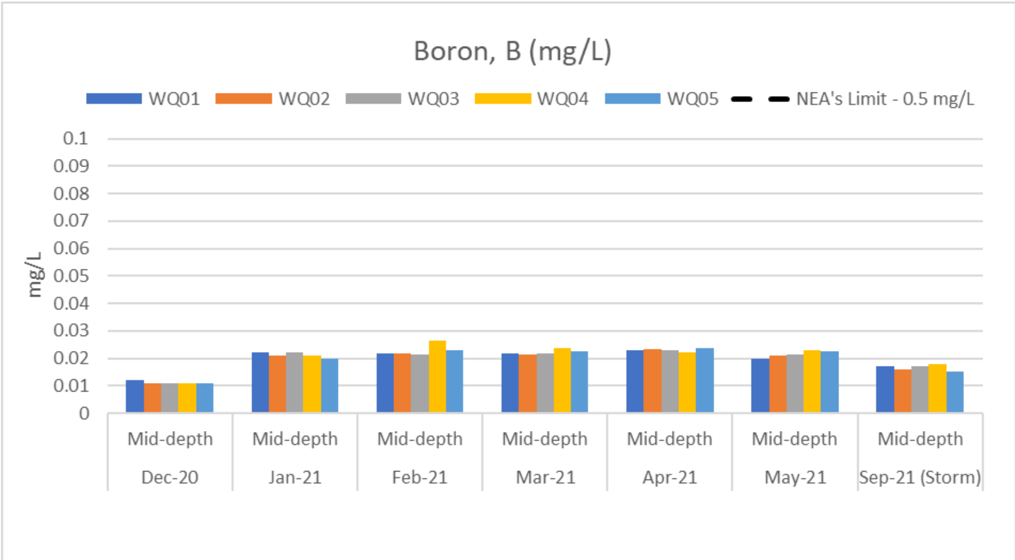

Sulphate (as SO4) (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 200 mg/L
mg/L
250
200
150
100
50
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)

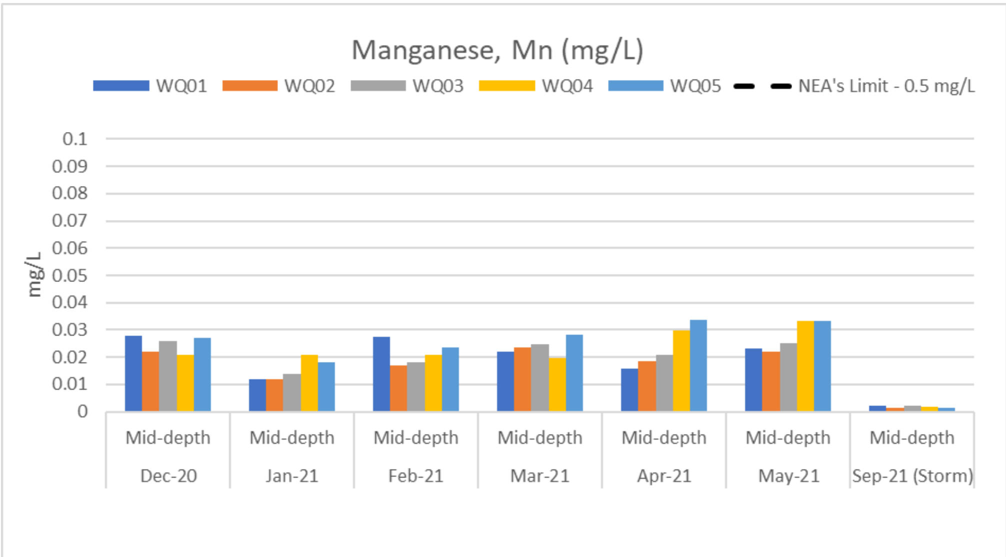

Cyanide (as CN) (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.1 mg/L
mg/L
0.12
0.1
0.08
0.06
0.04
0.02
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)
* non-detectable, <0.005 mg/L

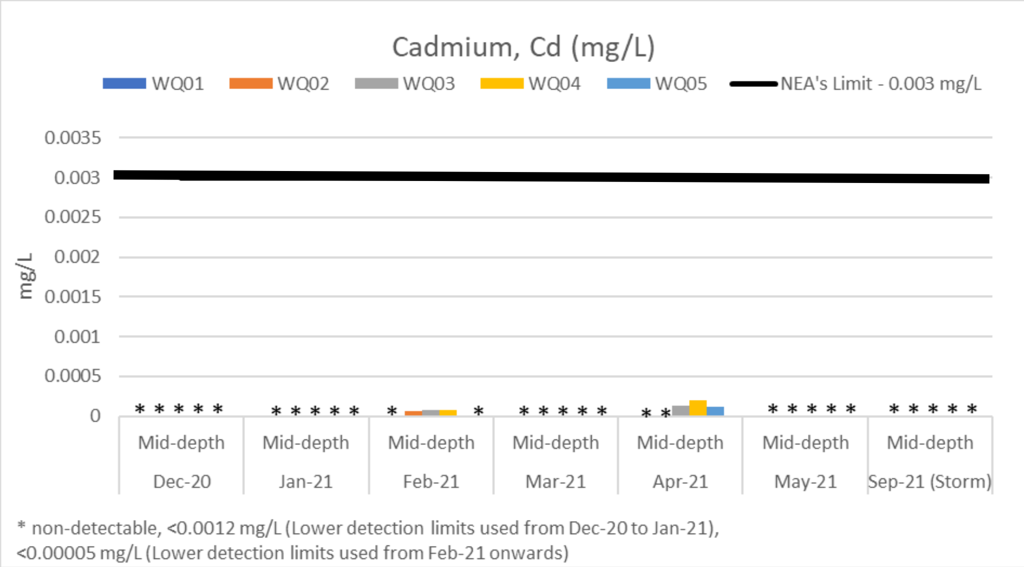

Detergents (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 5 mg/L
mg/L
6
5
4
3
2
1
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)
* non-detectable, <0.4 mg/L

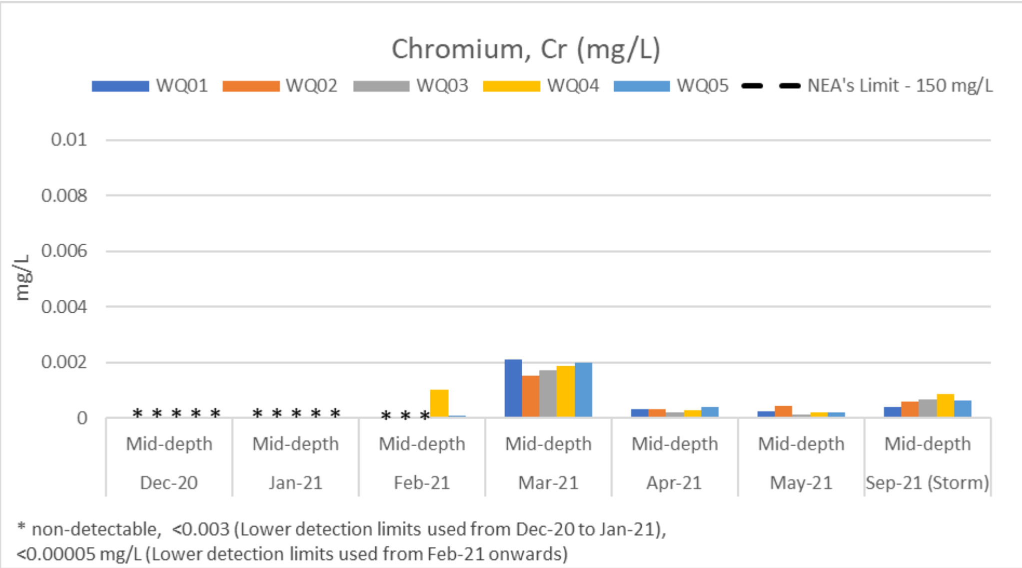

Arsenic, As (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.01 mg/L
mg/L
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.01 (Lower detection limits used from Dec-20 to Jan-21),
<0.003 mg/L (Lower detection limits used from Feb-21 onwards)

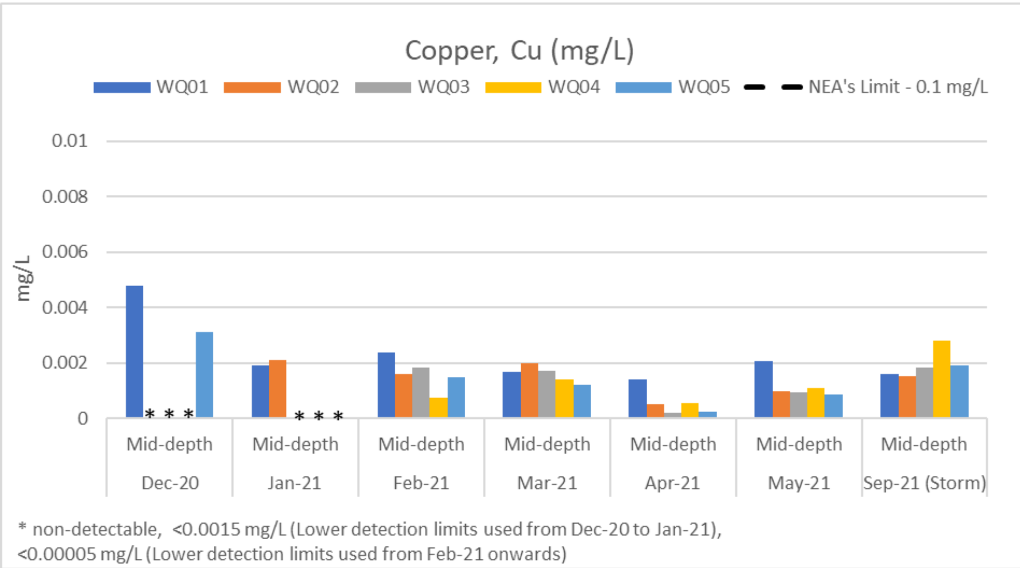

Barium, Ba (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 1 mg/L
mg/L
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

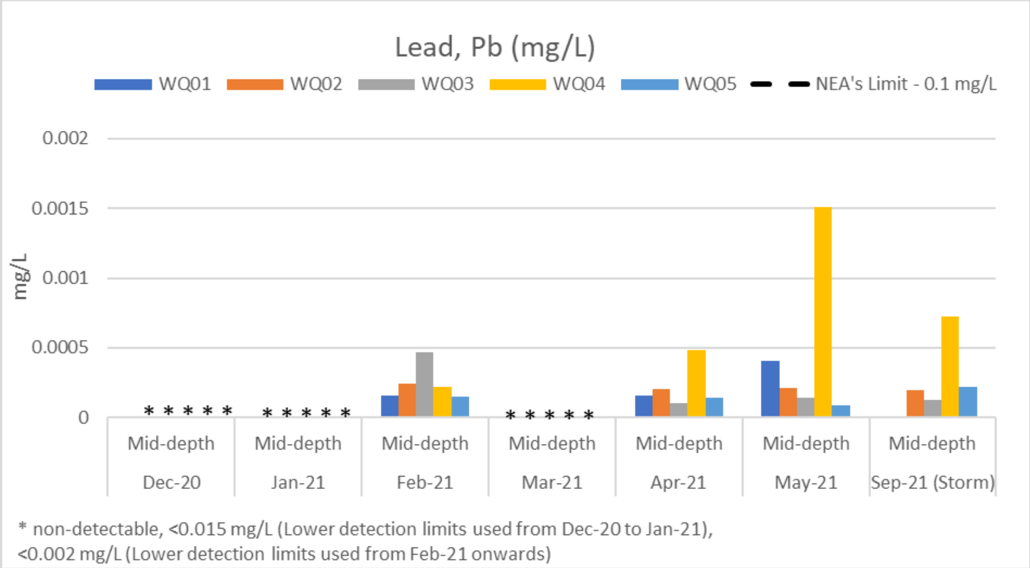

Boron, B (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.5 mg/L
mg/L
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

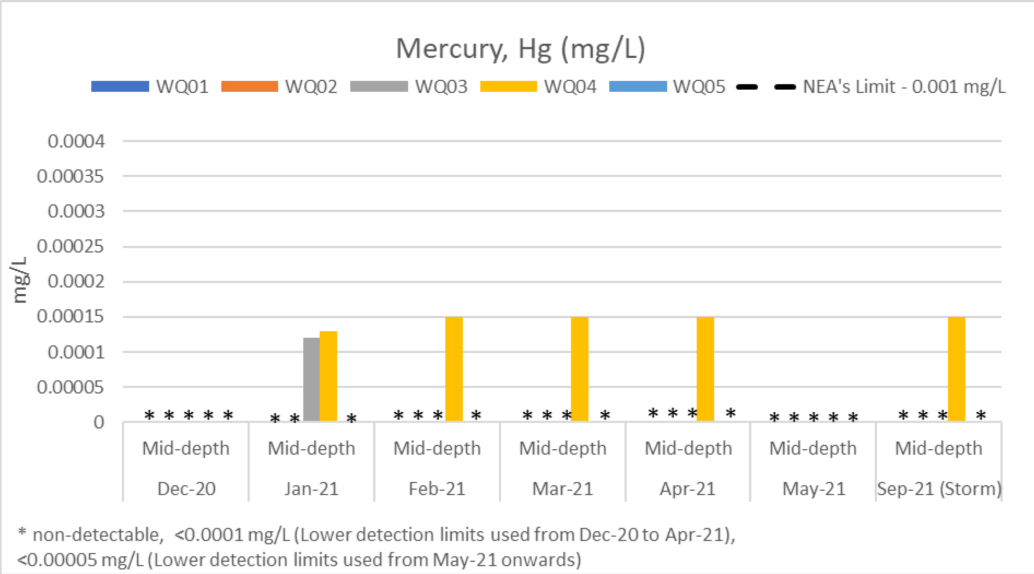

Manganese, Mn (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.5 mg/L
mg/L
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

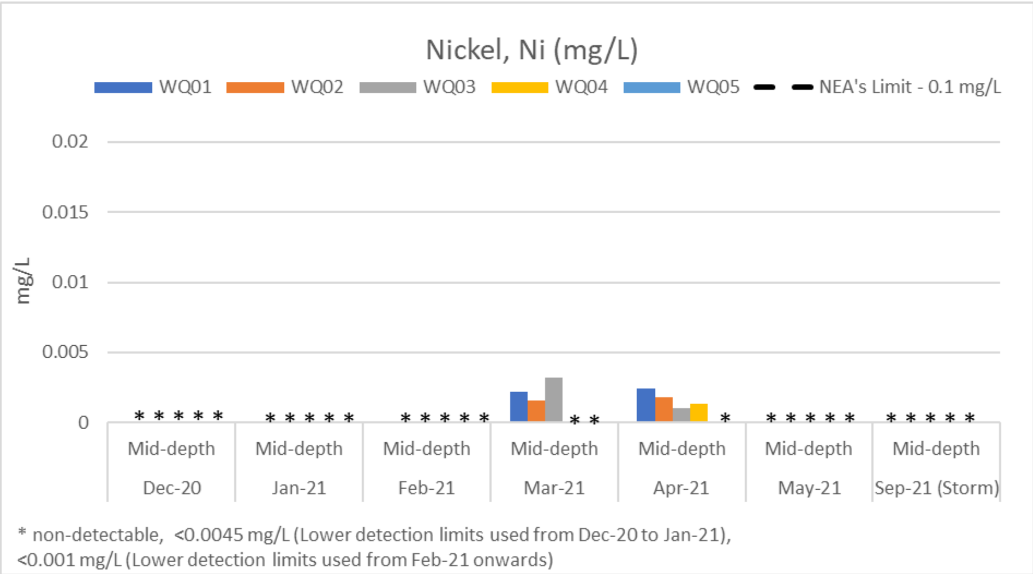

Cadmium, Cd (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.003 mg/L
mg/L
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.0012 mg/L (Lower detection limits used from Dec-20 to Jan-21),
<0.00005 mg/L (Lower detection limits used from Feb-21 onwards)

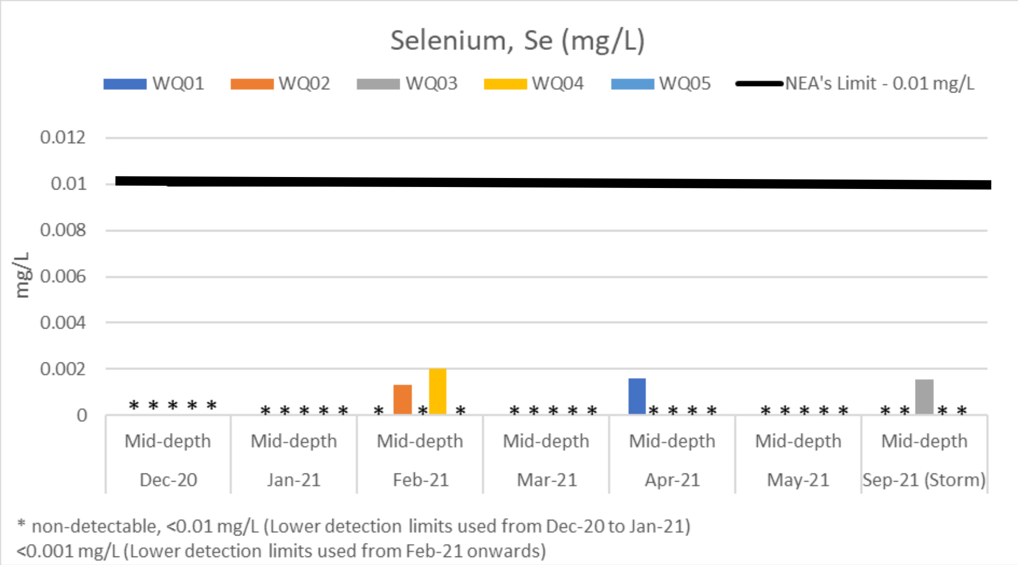

Chromium, Cr (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 150 mg/L
mg/L
0.01
0.008
0.006
0.004
0.002
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.003 (Lower detection limits used from Dec-20 to Jan-21),
<0.00005 mg/L (Lower detection limits used from Feb-21 onwards)

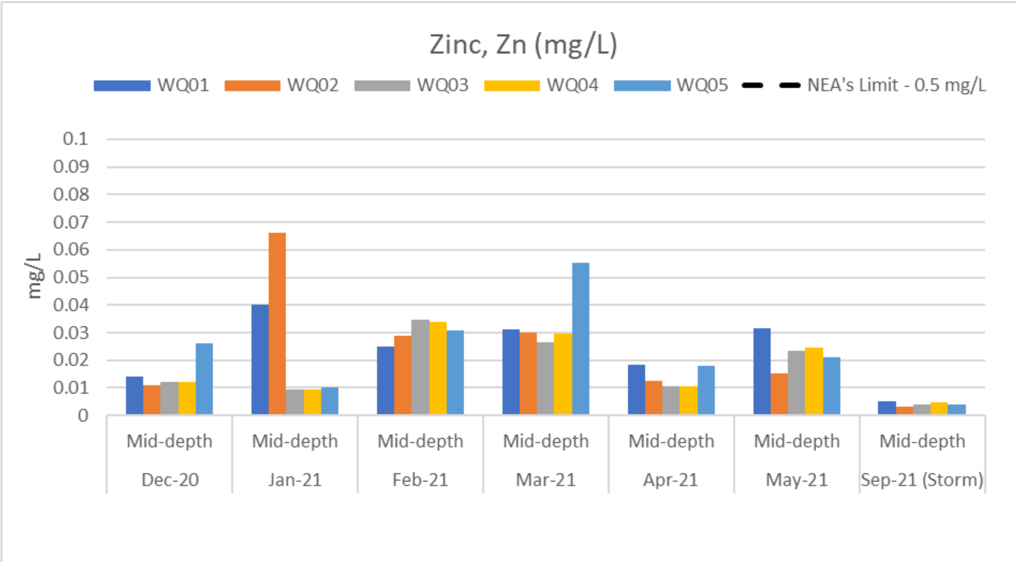

Copper, Cu (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.1 mg/L
mg/L
0.01
0.008
0.006
0.004
0.002
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.0015 mg/L (Lower detection limits used from Dec-20 to Jan-21),
<0.00005 mg/L (Lower detection limits used from Feb-21 onwards)

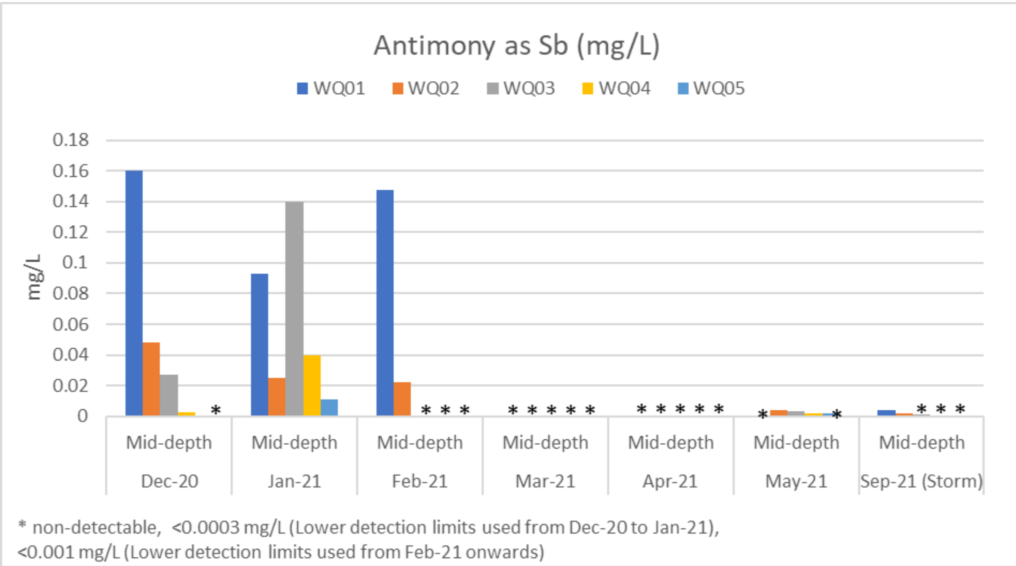

Lead, Pb (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 0.1 mg/L
mg/L
0.002
0.0015
0.001
0.0005
0
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)
* non-detectable, <0.015 mg/L (Lower detection limits used from Dec-20 to Jan-21),
<0.002 mg/L (Lower detection limits used from Feb-21 onwards)

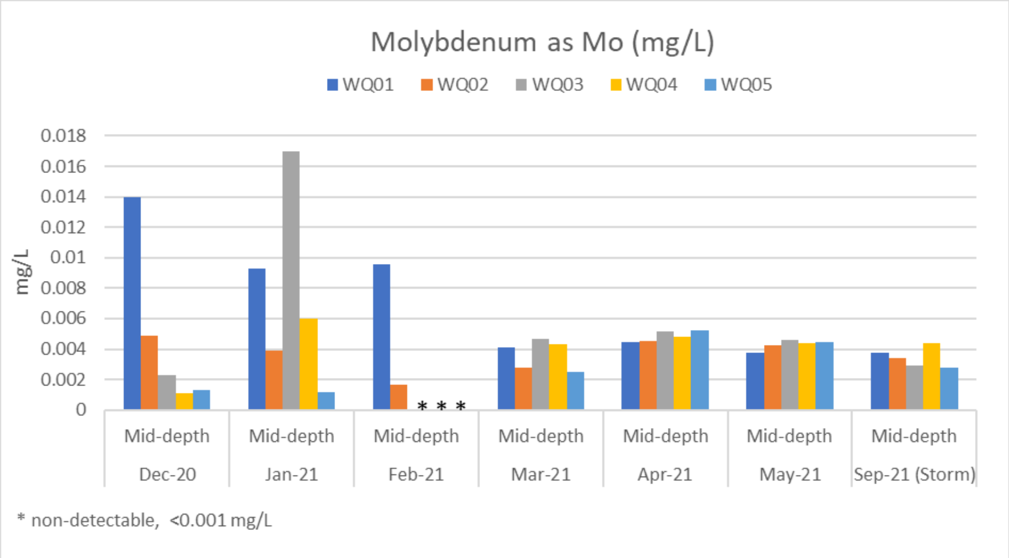

Mercury, Hg (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 0.001 mg/L
mg/L
0.0004
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)
* non-detectable, <0.0001 mg/L (Lower detection limits used from Dec-20 to Apr-21),
<0.00005 mg/L (Lower detection limits used from May-21 onwards)

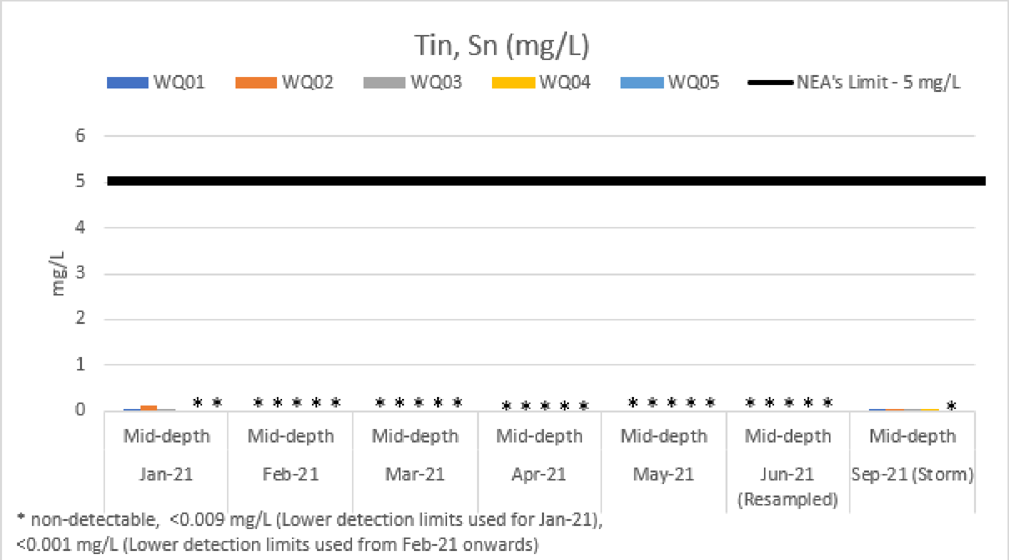

Nickel, Ni (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 0.1 mg/L
mg/L
0.02
0.015
0.01
0.005
0
Mid-depth Dec-20
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Sep-21 (Storm)
* non-detectable, <0.0045 mg/L (Lower detection limits used from Dec-20 to Jan-21),
<0.001 mg/L (Lower detection limits used from Feb-21 onwards)

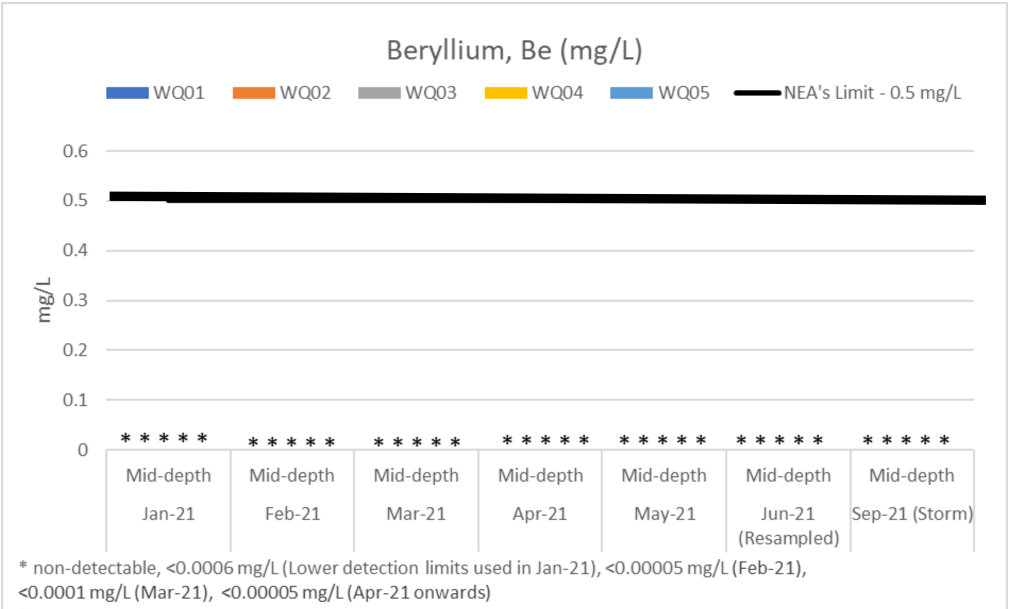

Selenium, Se (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.01 mg/L
mg/L
0.012
0.01
0.008
0.006
0.004
0.002
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.01 mg/L (Lower detection limits used from Dec-20 to Jan-21)
<0.001 mg/L (Lower detection limits used from Feb-21 onwards)

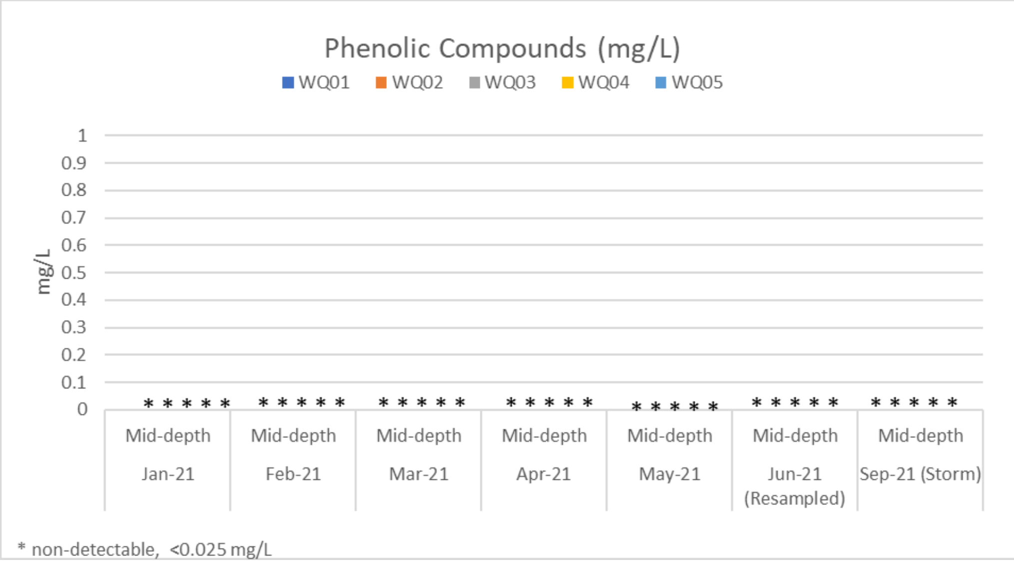

Zinc, Zn (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.5 mg/L
mg/L
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)

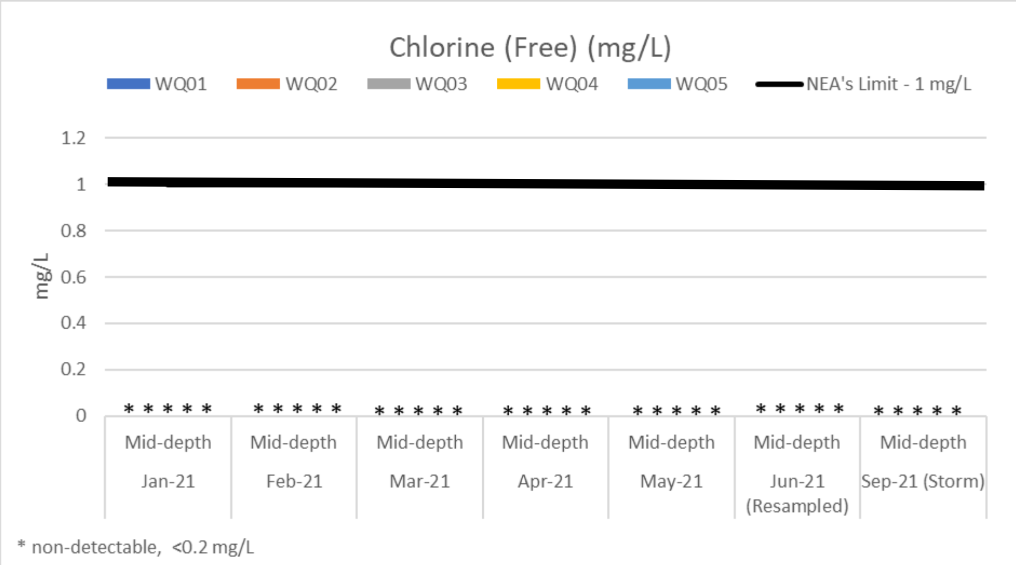

Antimony as Sb (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
mg/L
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.0003 mg/L (Lower detection limits used from Dec-20 to Jan-21),
<0.001 mg/L (Lower detection limits used from Feb-21 onwards)

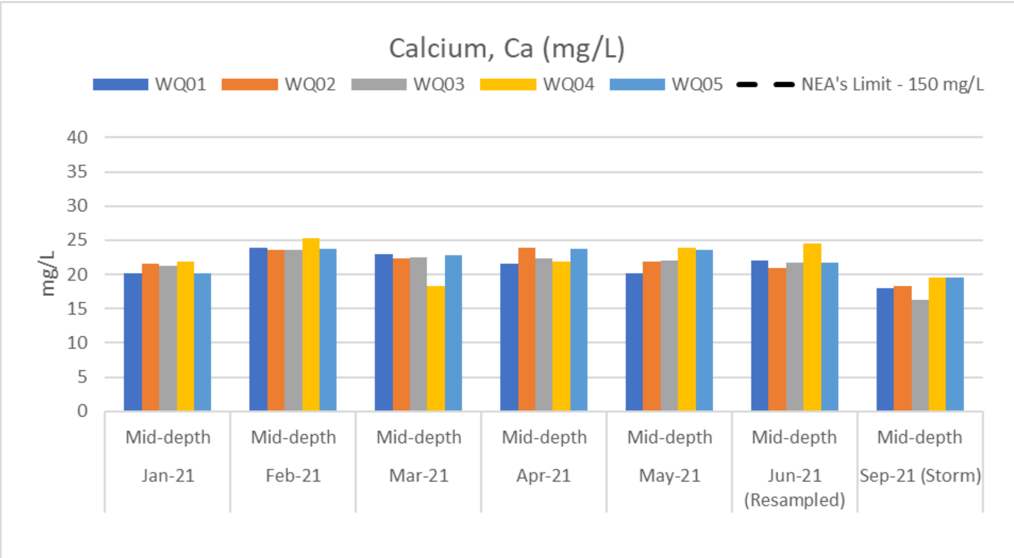

Molybdenum as Mo (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
mg/L
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Mid-depth
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.001 mg/L

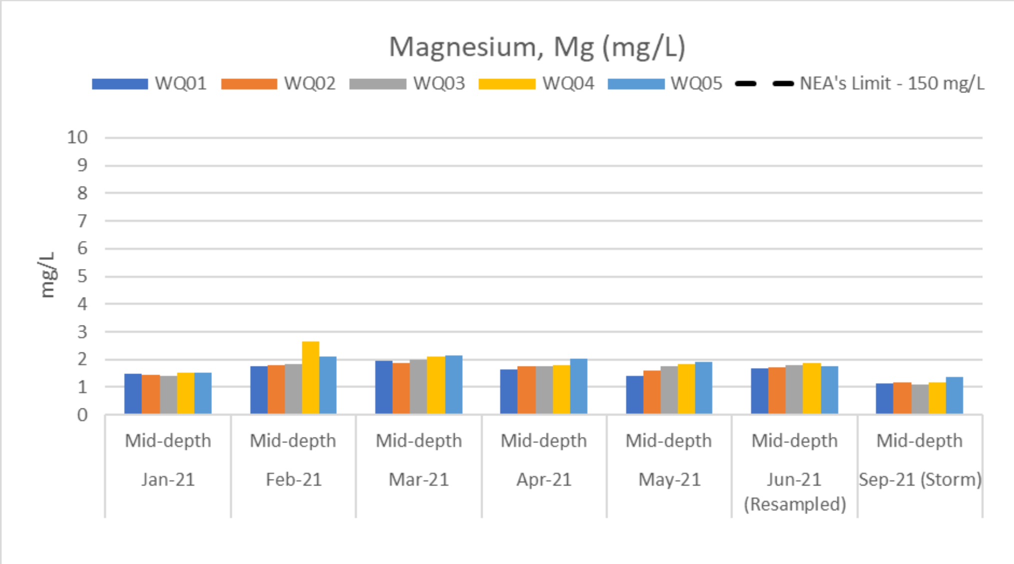

Tin, Sn (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 5 mg/L
mg/L
6
5
4
3
2
1
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)
* non-detectable, <0.009 mg/L (Lower detection limits used for Jan-21),
<0.001 mg/L (Lower detection limits used from Feb-21 onwards)

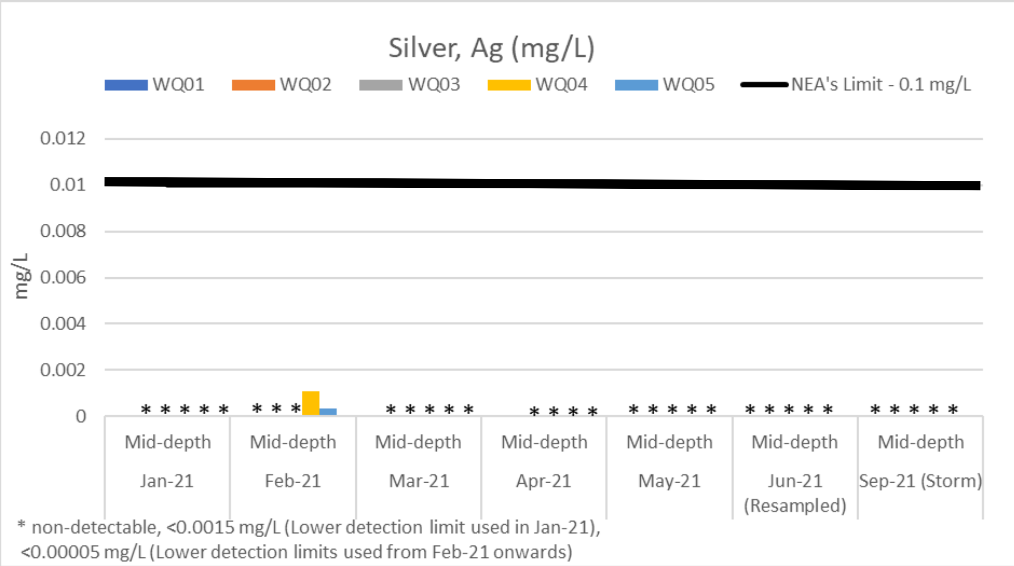

Beryllium, Be (mg/L)
WQ01
WQ02
WQ03
WQ04
WQ05
NEA's Limit - 0.5 mg/L
mg/L
0.6
0.5
0.4
0.3
0.2
0.1
0
Mid-depth
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21 (Resampled)
Sep-21 (Storm)
* non-detectable, <0.0006 mg/L (Lower detection limits used in Jan-21), <0.00005 mg/L (Feb-21),
<0.0001 mg/L (Mar-21), <0.00005 mg/L (Apr-21 onwards)


Phenolic Compounds (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Jun-21 (Resampled)
Mid-depth Sep-21 (Storm)
* non-detectable, <0.025 mg/L


Chlorine (Free) (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 1 mg/L
mg/L
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Jun-21 (Resampled)
Mid-depth Sep-21 (Storm)
* non-detectable, <0.2 mg/L


Calcium, Ca (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 150 mg/L
mg/L
Mid-depth Jan-21
Mid-depth Feb-21
Mid-depth Mar-21
Mid-depth Apr-21
Mid-depth May-21
Mid-depth Jun-21 (Resampled)
Mid-depth Sep-21 (Storm)





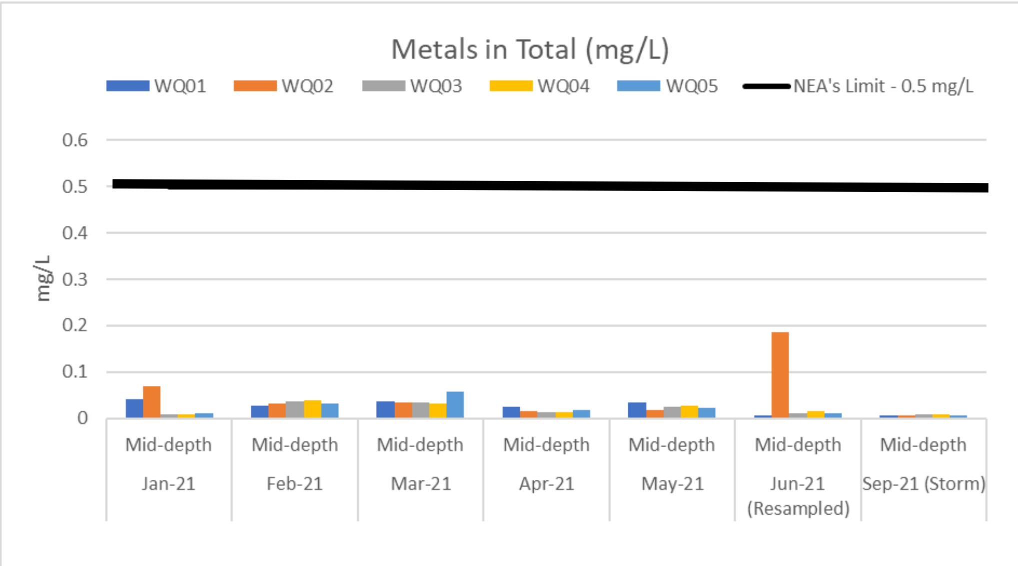
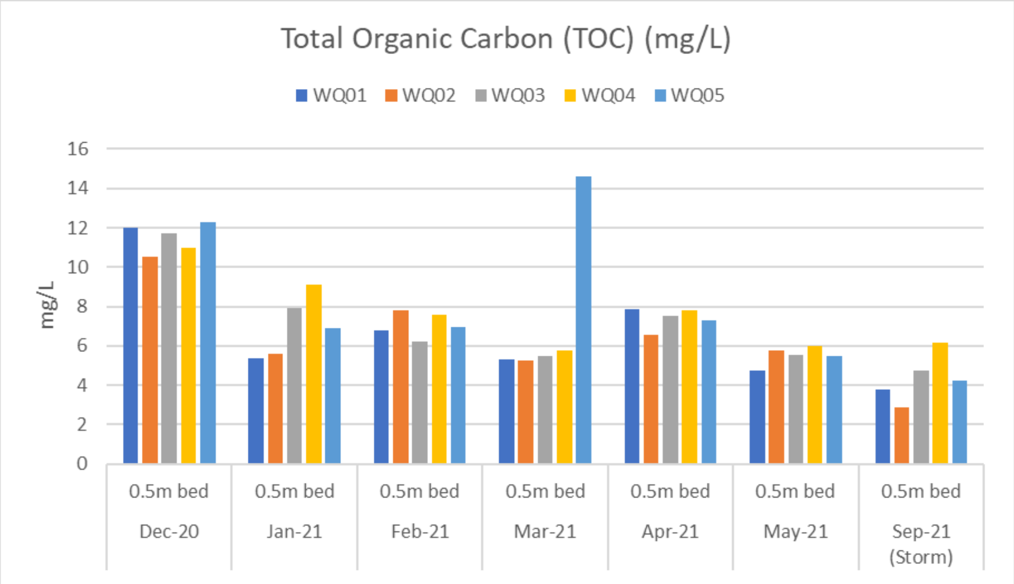
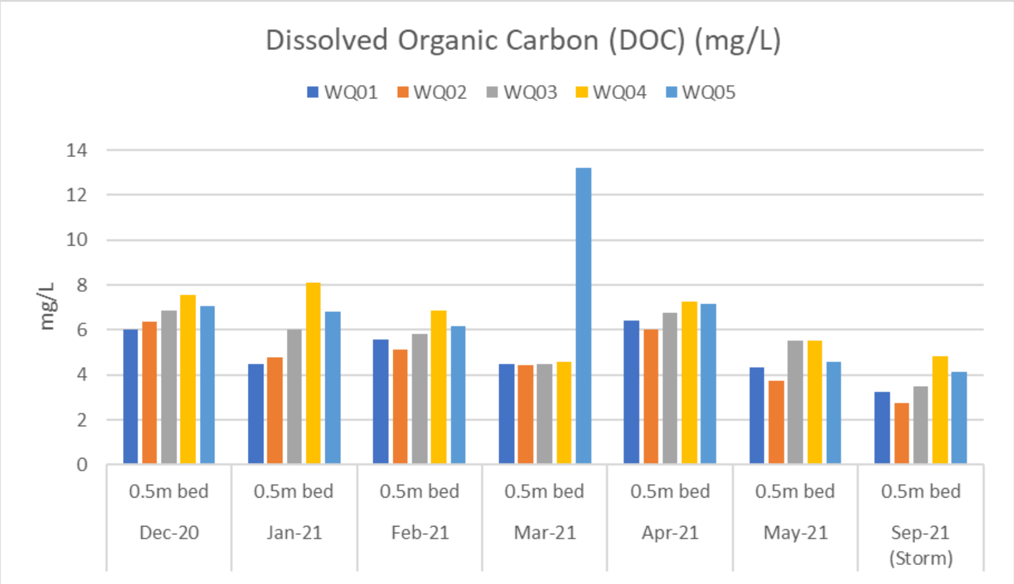
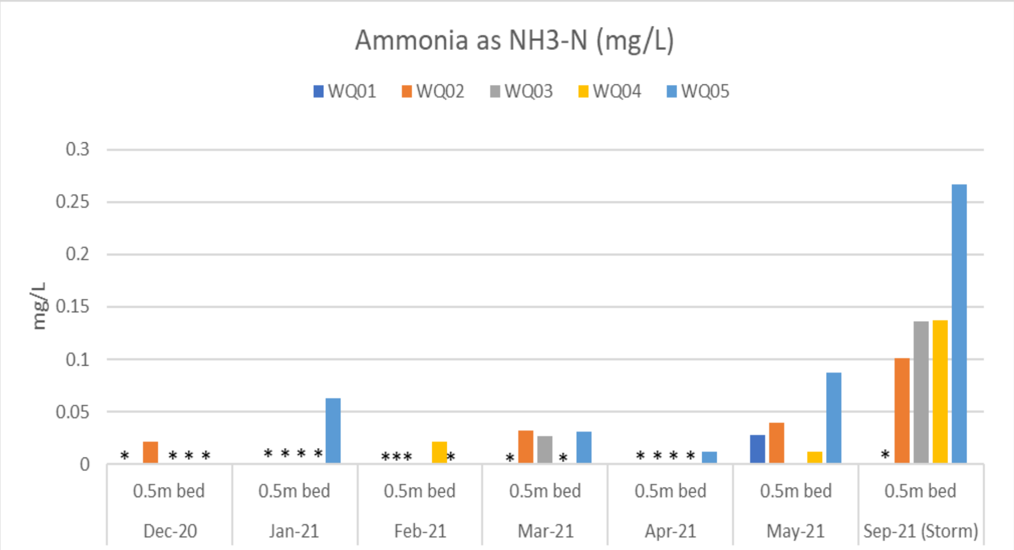


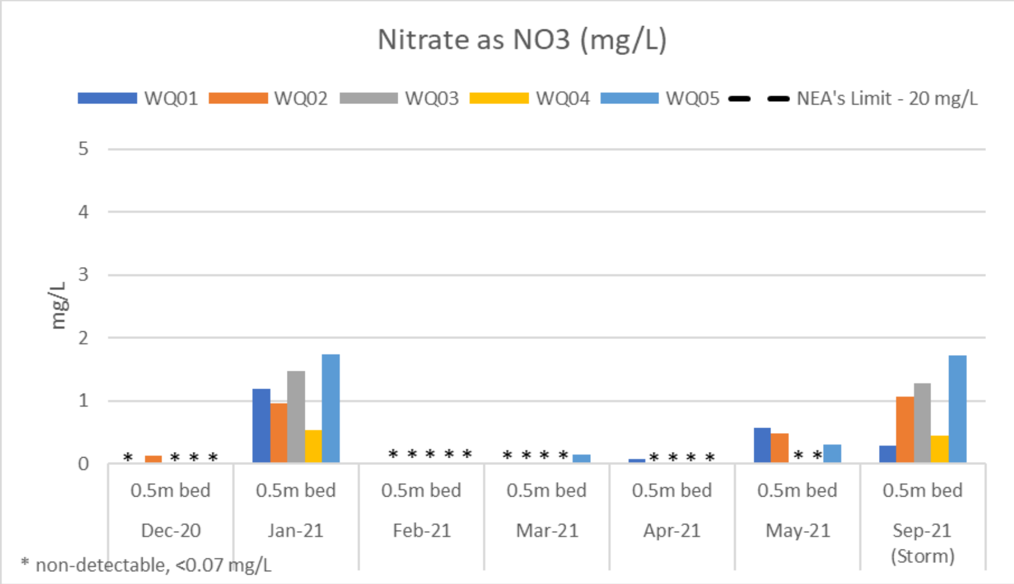
Figure 3-6: Water Quality – Ex-Situ Parameters Analysed at Mid-Depth

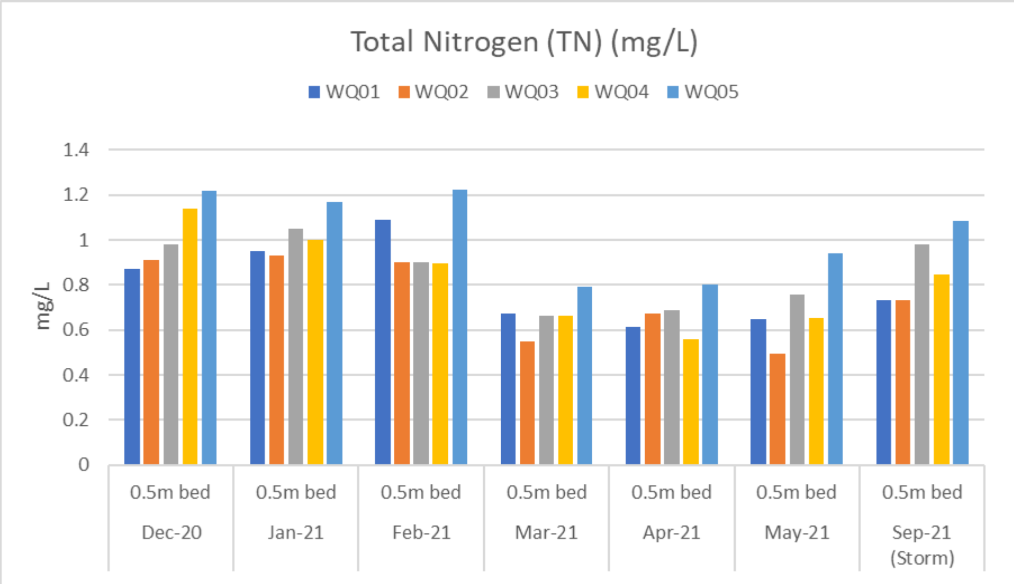


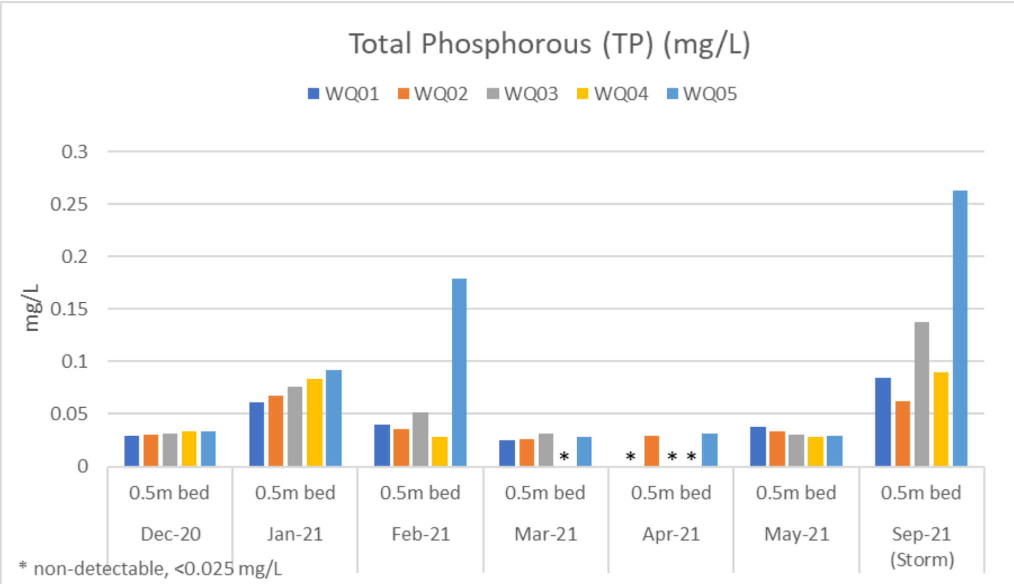


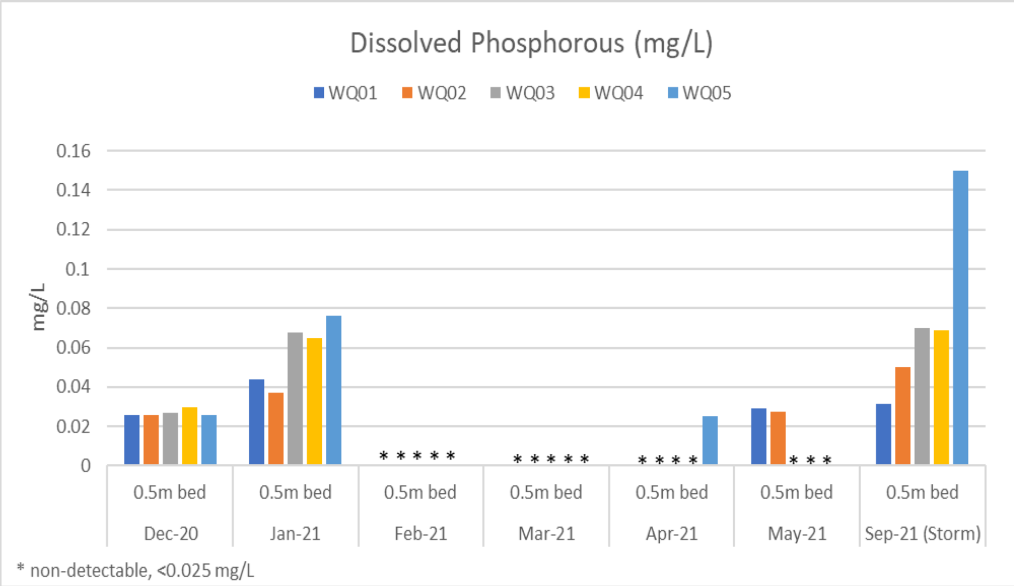


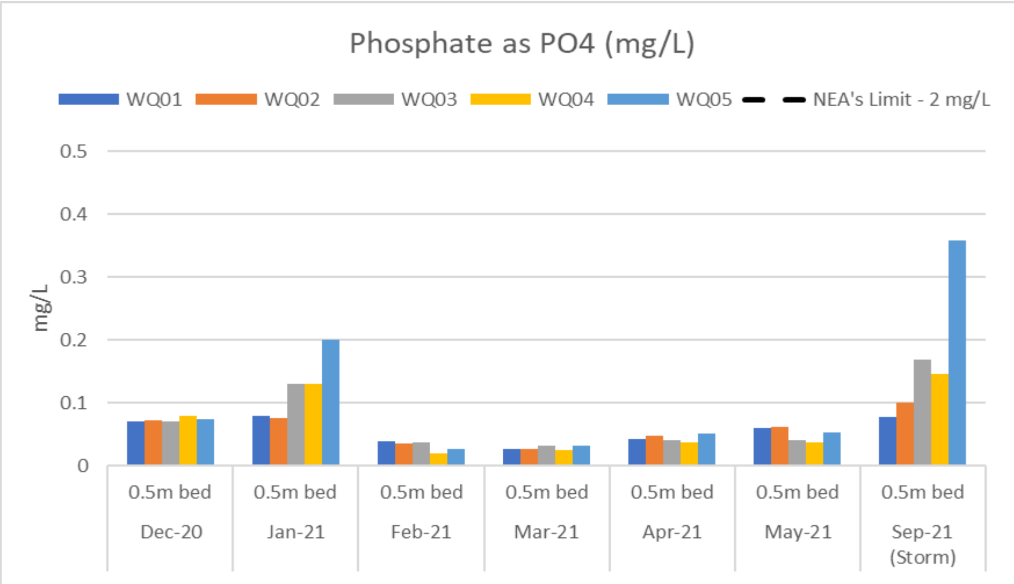
* non-detectable, <0.01 mg/L

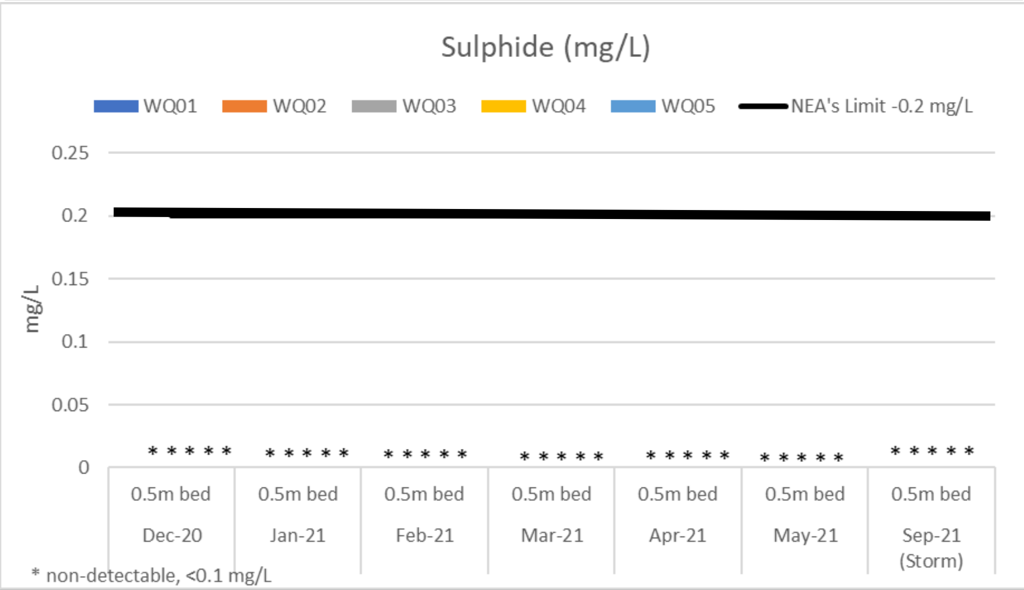

Nitrate as NO3 (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 20 mg/L
mg/L
0.5m bed Dec-20
0.5m bed Jan-21
0.5m bed Feb-21
0.5m bed Mar-21
0.5m bed Apr-21
0.5m bed May-21
0.5m bed Sep-21 (Storm)
* non-detectable, <0.07 mg/L


Total Nitrogen (TN) (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
0.5m bed Dec-20
0.5m bed Jan-21
0.5m bed Feb-21
0.5m bed Mar-21
0.5m bed Apr-21
0.5m bed May-21
0.5m bed Sep-21 (Storm)


Total Phosphorous (TP) (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
0.5m bed Dec-20
0.5m bed Jan-21
0.5m bed Feb-21
0.5m bed Mar-21
0.5m bed Apr-21
0.5m bed May-21
0.5m bed Sep-21 (Storm)
* non-detectable, <0.025 mg/L


Dissolved Phosphorous (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05
mg/L
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.5m bed
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.025 mg/L


Phosphate as PO4 (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit - 2 mg/L
mg/L
0.5
0.4
0.3
0.2
0.1
0
0.5m bed
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)


Sulphide (mg/L)
WQ01 WQ02 WQ03 WQ04 WQ05 NEA's Limit -0.2 mg/L
mg/L
0.25
0.2
0.15
0.1
0.05
0
0.5m bed
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Sep-21 (Storm)
* non-detectable, <0.1 mg/L

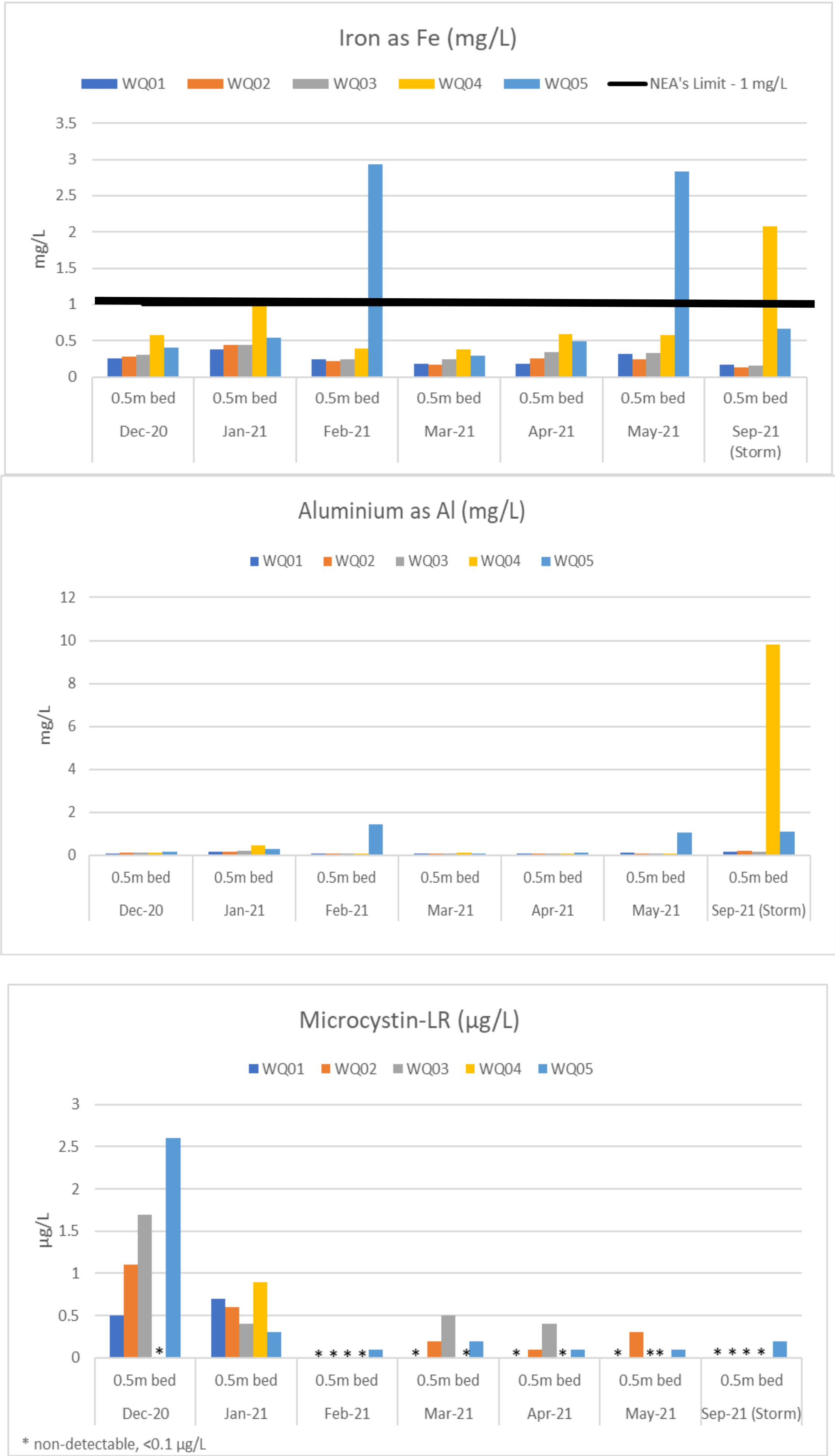


Figure 3-7: Water Quality – Ex-Situ Parameters Analysed at 0.5 m Above Reservoir Bed

3.2.3 QA/ QC Program

The first QA/ QC approach (to test for contamination in lab bottles) results are summarised in *Table 3-4.* The adopted RPD threshold was exceeded for Boron (B), Zinc (Zn) and Aluminium (Al) on two occasions (December and February, no exceedance in January). Given these were analysed for *total* metals, some greater variation in metal concentration is possible due to chance particulates in each sub-sample processed in the laboratory. The results are considered acceptable and demonstrated that there was negligible risk of contamination introduced by laboratory-supplied bottles.

The second QA/ QC approach (to test inter-laboratory variation) results are summarised in *Table 3-5*. Exceedance of the adopted RPD occurred for several analytes, but upon investigation it was determined that the laboratories were using different detection limits. Field blank samples (*Table 3-6*) sent to the third-party laboratory were generally non-detectable, except for a slight detection in Aluminium (Al), Boron (B), Mercury (Hg), Calcium (Ca) and Magnesium (Mg) in some samples. The results are considered overall acceptable.

Table 3-4: Water Quality Sampling QA/ AC (for contamination in lab bottles) – Field Duplicates (Dec 2020, Jan and Feb 2021)

Parameter	Dec 2020			Jan 2021			Feb 2021		
	Sample 1	Sample 2	RPD %	Sample 1	Sample 2	RPD %	Sample 1	Sample 2	RPD %
Ammonia, NH_3	<0.012	<0.012	0.00	<0.012	<0.012	0.00	<0.012	<0.012	0.00
Nitrate, NO_3^-	<0.066	<0.066	0.00	1.06	1.07	0.94	<0.066	<0.066	0.00
Phosphate, PO_4	<0.077	<0.077	0.00	<0.077	<0.077	0.00	<0.077	<0.077	0.00
Sulphide, S^{2-}	<1	<1	0.00	<0.1	<0.1	0.00	<0.1	<0.1	0.00
Iron, Fe	0.66	0.67	1.50	0.44	0.44	0.00	0.25	0.30	18.18
Aluminium, Al	0.67	0.70	4.38	0.35	0.35	0.00	0.23	0.29	23.08
Chloride, Cl^-	14.0	15.00	6.90	9.98	10.1	1.20	14.7	14.6	0.68
Sulphate, SO_4^{2-}	11.3	11.20	0.89	14.4	14.5	0.69	13.9	13.2	5.17
Cyanide, CN^-	<0.005	<0.005	0.00	<0.005	<0.005	0.00	<0.005	<0.005	0.00
Arsenic, As	<0.023	<0.023	0.00	<0.01	<0.01	0.00	<0.01	<0.01	0.00
Barium, Ba	0.016	0.016	0.00	0.015	0.016	6.45	0.015	0.015	0.00
Tin, Sn	<0.009	<0.009	0.00	<0.009	<0.009	0.00	<0.009	<0.009	0.00
Beryllium, Be	<0.0006	<0.0006	0.00	<0.0006	<0.0006	0.00	<0.0006	<0.0006	0.00
Boron, B	0.0064	0.0046	32.73	0.012	0.012	0.00	0.019	0.019	0.00
Manganese, Mn	0.033	0.032	3.08	0.014	0.014	0.00	0.023	0.027	16.00
Cadmium, Cd	<0.0012	<0.0012	0.00	<0.0012	<0.0012	0.00	<0.0012	<0.0012	0.00
Chromium, Cr	<0.003	<0.003	0.00	<0.003	<0.003	0.00	<0.003	<0.003	0.00
Copper, Cu	0.0022	<0.0015	0.00	0.0032	0.0032	0.00	<0.0015	<0.0015	0.00
Lead, Pb	<0.015	<0.015	0.00	<0.01	<0.01	0.00	<0.01	<0.01	0.00
Mercury, Hg	<0.0001	<0.0001	0.00	<0.0001	<0.0001	0.00	<0.0001	<0.0001	0.00
Nickel, Ni	<0.0045	<0.0045	0.00	<0.0045	<0.0045	0.00	<0.0045	<0.0045	0.00
Selenium, Se	<0.045	<0.045	0.00	<0.01	<0.01	0.00	<0.01	<0.01	0.00
Silver, Ag	<0.0015	<0.0015	0.00	<0.0015	<0.0015	0.00	<0.0015	<0.0015	0.00
Zinc, Zn	0.0098	0.0058	51.28	0.0077	0.0075	2.63	0.005	0.0041	19.78
Free Chlorine, Cl_2	<0.2	<0.2	0.00	<0.2	<0.2	0.00	<0.2	<0.2	0.00
Calcium, Ca	20.6	20.6	0.00	19.8	20	1.01	22.1	22.2	0.45

Parameter	Dec 2020			Jan 2021			Feb 2021		
	Sample 1	Sample 2	RPD %	Sample 1	Sample 2	RPD %	Sample 1	Sample 2	RPD %
Magnesium, Mg	2.03	2.03	0.00	1.62	1.62	0.00	1.96	1.96	0.00
Note: Columns highlighted in orange are RPD numbers; cells highlighted in blue contain RPD numbers of more than 20%.									

Table 3-5: Water Quality Sampling QA/ AC (for inter-laboratory variation) – Field Duplicates (Mar, Apr and May 2021)

Parameter	March 2021			April 2021			May 2021		
	Sample 1	Sample 2	RPD %	Sample 1	Sample 2	RPD %	Sample 1	Sample 2	RPD %
Ammonia, NH_3	<0.07	<0.012	0.00	<0.01	<0.012	0.00	<0.01	<0.012	0.00
Nitrate, NO_3^-	0.64	<0.066	0.00	<0.07	<0.066	0.00	<0.07	<0.066	0.00
Phosphate, PO_4	0.027	<0.077	0.00	0.034	<0.077	0.00	0.033	<0.077	0.00
Sulphide, S^{2-}	<0.1	<0.1	0.00	<0.1	<0.1	0.00	<0.1	<0.1	0.00
Iron, Fe	0.16	0.23	36.31	0.64	0.39	48.39	0.57	0.59	4.17
Aluminium, Al	0.040	0.19	130.43	0.073	0.24	106.91	0.059	0.33	139.22
Chloride, Cl^-	18.7	19.6	4.89	12.5	14.0	11.51	12.50	12.1	3.24
Sulphate, SO_4^{2-}	15.2	15.9	4.66	13.7	16.3	17.66	9.81	13.2	29.44
Cyanide, CN^-	<0.005	<0.005	0.00	<0.005	<0.005	0.00	<0.005	<0.005	0.00
Arsenic, As	<0.003	<0.01	0.00	0.0021	<0.01	0.00	0.0026	<0.01	0.00
Barium, Ba	0.012	0.013	4.93	0.013	0.015	15.42	0.0138	0.014	1.55
Tin, Sn	<0.002	<0.009	0.00	<0.001	<0.009	0.00	<0.001	<0.009	0.00
Beryllium, Be	<0.0001	<0.0006	0.00	<0.00005	<0.0006	0.00	<0.00005	<0.0006	0.00
Boron, B	0.021	0.023	7.60	0.022	0.020	10.15	0.023	0.0084	92.97
Manganese, Mn	0.024	0.029	20.49	0.030	0.023	25.73	0.03	0.030	10.18
Cadmium, Cd	<0.0005	<0.0012	0.00	0.00020	<0.0012	0.00	<0.00005	<0.0012	0.00
Chromium, Cr	0.0015	<0.003	0.00	0.0003	<0.003	0.00	0.00	<0.003	0.00
Copper, Cu	0.0020	<0.0015	0.00	0.00054	<0.0015	0.00	0.00	<0.0015	0.00
Lead, Pb	<0.002	<0.01	0.00	0.00048	<0.01	0.00	0.00	<0.01	0.00
Mercury, Hg	<0.0001	<0.0001	0.00	0.00015	<0.0001	0.00	<0.00005	<0.0001	0.00
Nickel, Ni	0.0016	<0.0045	0.00	0.0013	<0.0045	0.00	<0.001	<0.0045	0.00

Parameter	March 2021			April 2021			May 2021		
	Sample 1	Sample 2	RPD %	Sample 1	Sample 2	RPD %	Sample 1	Sample 2	RPD %
Selenium, Se	<0.005	<0.01	0.00	<0.001	<0.01	0.00	<0.001	<0.01	0.00
Silver, Ag	<0.001	<0.0015	0.00	<0.00005	<0.0015	0.00	<0.00005	<0.0015	0.00
Zinc, Zn	0.030	0.0050	142.72	0.011	0.0060	55.14	0.02	0.0015	177.10
Free Chlorine, Cl_2	<0.2	<0.2	0.00	<0.2	<0.2	0.00	<0.2	<0.2	0.00
Calcium, Ca	22.3	21.8	2.13	21.9	19.2	13.08	23.82	21.0	12.59
Magnesium, Mg	1.87	2.10	11.66	1.79	1.74	3.01	1.855	1.86	0.29

Note: Columns highlighted in orange are RPD numbers; cells highlighted in blue contain RPD numbers of more than 20%.

Table 3-6: Water Quality QA/ AC (for inter-laboratory variation) – Field Blanks (Mar, Apr, and May 2021)

Test Parameter (mg/L)	Mar-21	Apr-21	May-21
	Field Blanks	*Field Blanks*	*Field Blanks*
Ammonia, NH_3	<0.012	<0.012	<0.012
Nitrate, NO_3^-	<0.066	<0.066	<0.066
Phosphate, PO_4	<0.077	<0.077	<0.077
Sulphide, S^{2-}	<0.1	<0.1	<0.1
Iron, Fe	<0.0015	<0.0015	<0.0015
Aluminium, Al	<0.003	<0.003	0.091
Chloride, Cl^-	<1	<1	<1
Sulphate, SO_4^{2-}	<1	<1	<1
Cyanide, CN^-	<0.005	<0.005	<0.005
Arsenic, As	<0.01	<0.01	<0.01
Barium, Ba	0.0150	<0.0003	0.0003
Tin, Sn	<0.009	<0.009	<0.009
Beryllium, Be	<0.0006	<0.0006	<0.0006
Boron, B	0.084	0.040	0.041
Manganese, Mn	<0.0003	<0.0003	<0.0003
Cadmium, Cd	<0.0012	<0.0012	<0.0012
Chromium, Cr	<0.003	<0.003	<0.003
Copper, Cu	<0.0015	<0.0015	<0.0015
Lead, Pb	<0.01	<0.01	<0.01
Mercury, Hg	<0.0001	<0.0001	0.0006
Nickel, Ni	<0.0045	<0.0045	<0.0045
Selenium, Se	<0.01	<0.01	<0.01
Silver, Ag	<0.0015	<0.0015	<0.0015
Zinc, Zn	<0.0012	<0.0012	<0.0012
Free Chlorine, Cl_2	<0.2	<0.2	<0.2
Calcium, Ca	<0.047	0.060	2.03
Magnesium, Mg	<0.0058	0.0070	0.016
Notes: Cells highlighted in blue contain values with slight detection, < denominates below limit of detection.			

3.3 Sediment

Sediment samples were taken at up to 20 cm into the reservoir bed at each of the 5 locations. This *Section 3.3* presents the lab results for these sediment samples. As there are no local sediment quality regulations to classify the results, the 2009 Dutch Soil Quality Standard (Dutch Standards) was adopted for comparison. Parameter concentrations were compared to both target and intervention limits of the Dutch Standards. Organic Matter as Loss On Ignition (LOI) and Total Organic Carbon (TOC) were only required to be analysed once throughout the sediment sampling program, while pore water (*Figure 3-9)* and elutriate (*Figure 3-10*) were also only analysed once for various parameters solely for the purpose of water quality assessment inputs.

Where detectable and without target or intervention limits, these results serve as a benchmark for future monitoring purposes. These include sediment parameters: Total Nitrogen (TN), Total Phosphorous

(TP), Loosely-bound P, Fe/ Al bound P, Ca bound P, Organic bound P, Organic Matter as LOI, TOC, Aluminium (Al), Boron (B), Iron (Fe) and Manganese (Mn).

Overall, relatively high TP contents were measured in sediment samples of five locations of Kranji at the highest of 6,868 mg/kg at SS05 in May 2021 and lowest at SS01 in March 2021 (1,704 mg/kg). The concentrations of different forms of P varied slightly among different locations and likely illustrates the effects of human activities, catchment characteristics and sources of phosphorus inputs into the reservoirs:

- **Loosely-bound phosphorous** is an easily released form of P (or available P form), extracted from water in the sediment samples. Readings ranged from 2.83 to 92 mg/kg, with the highest concentration detected at SS03 (Jan 2021). Concentrations in Jan 2021 were at least 10 mg/kg, while those in March and May 2021 were all recorded below 10 mg/kg. The most likely explanation for high loosely-bound phosphorous observed in January 2021 is sediment resuspension and external loadings of P from surface runoff, caused by the heavy rainfall period at this time. This is consistent with the elevated values of different forms of P measured in water samples that were collected during this same period.
- **Base releasable P** (P bound to Fe and Al) was the predominant form of P in all sediment samples (38 – 1,250 mg/kg dry sediment). These forms of P are readily dissolved under alkaline conditions and in changing redox conditions. Dissolved P forms may enter overlying water and reduce water quality if certain environmental conditions are met, such as during pH level increases.
- **Acid releasable P (Ca bound P)** ranged from 94 to 673 mg/kg dry sediment. This P form is of the least concern as they are least likely to be released into the water column.

A relatively high ratio of base releasable P to acid releasable P (FeP:CaP) was observed at Kranji Reservoir (up to 12), indicating anthropogenic inputs of P over time, likely released under alkaline conditions.

Total Nitrogen concentration in the sediment samples were rather high, ranging from 82.46 to 654.29 mg/kg. The highest total nitrogen was detected at SS02 in May 2021.

Overall, sediment in Kranji Reservoir have very high levels of aluminium, iron and manganese than that of a natural freshwater body. The highest of Manganese was recorded at 418.44 mg/kg while the highest of Iron as recorded at 58,282 mg/kg, both at SS03 in March 2021. The highest Al concentration (35,287 mg/kg) was measured at SS05 in May 2021.

In comparison to target and intervention limits of the Dutch Standards, most metals (Ba, Cd, Cr, Cu, Pb, Mo, Ni, Se and Zn) were below both Dutch Standards limits (Chen, 2002) except Copper (Cu), Zinc (Zn) and Antimony (Sb). Sediment samples from different sampling locations and sampling events exceeded the Dutch Standards target value for Cu, Zn and Sb. In addition, As in sediment collected from most locations exceeded both target and intervention limits of Dutch Standards. The individual exceedances are noted in *Section 3.3.1*.

The presence of heavy metal in sediment could impact both the genetic structure and the functional potential of chronically exposed microbial communities. This poses an ecological risk as it may impact ecosystem and benthic communities' functions. Within sediments, benthic heterotrophic microbial communities support various ecosystem functions from organic matter recycling to pollutant degradation and biomass production.

3.3.1 Exceedances in Thresholds

The main observations and summary for sediment parameters analysed are as follows:

3.3.1.1 Antimony, Sb

Were non-detectable in location SS01 and SS02 in January 2021 and across all sites in March 2021, the Sb levels in sediments collected in May 2021 were detected and above the target levels at SS02 and SS03.

3.3.1.2 Arsenic, As

Arsenic levels were observed to exceed both target and intervention levels at SS01, SS02 and SS03 throughout the sampling months. Nine (9) out of a total 15 of samples (at SS01, SS02 and SS03) taken at 5 locations and 3 sampling dates have arsenic levels exceeding the target limit. Two (2) of the samples (at SS01 and SS03) also exceeded the corresponding intervention limits as well. Arsenic in sediments can enter the water supply from natural deposits in the earth or from industrial and agricultural pollution.

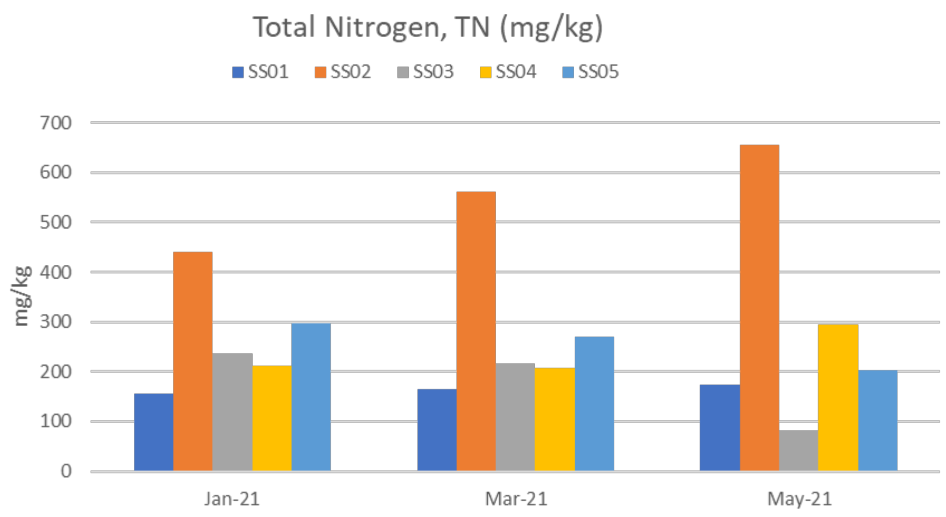
3.3.1.3 Copper, Cu

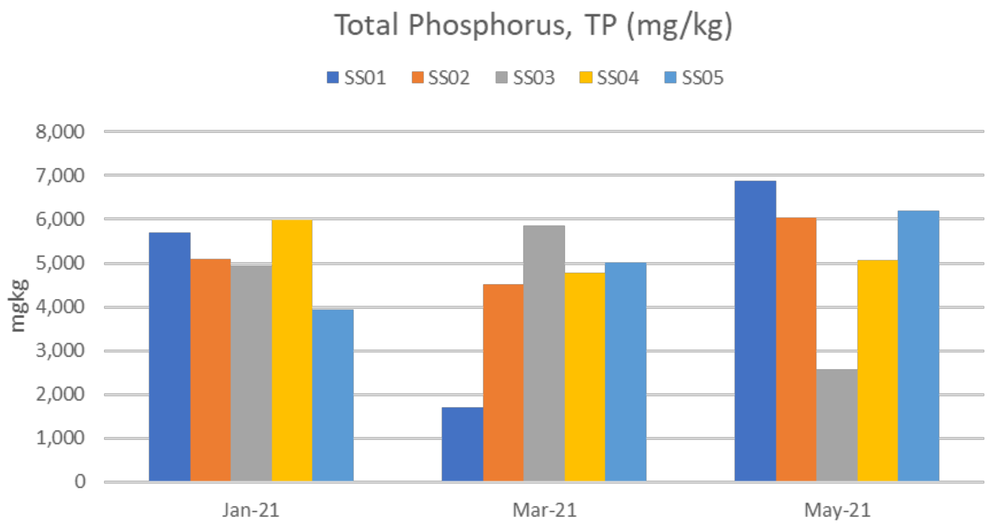
Cu levels were generally above the target levels across all sites (i.e. 11 out of a total of 15 samples) over the sampling months. The Cu levels were observed to dropped significantly at SS03 in May 2021.

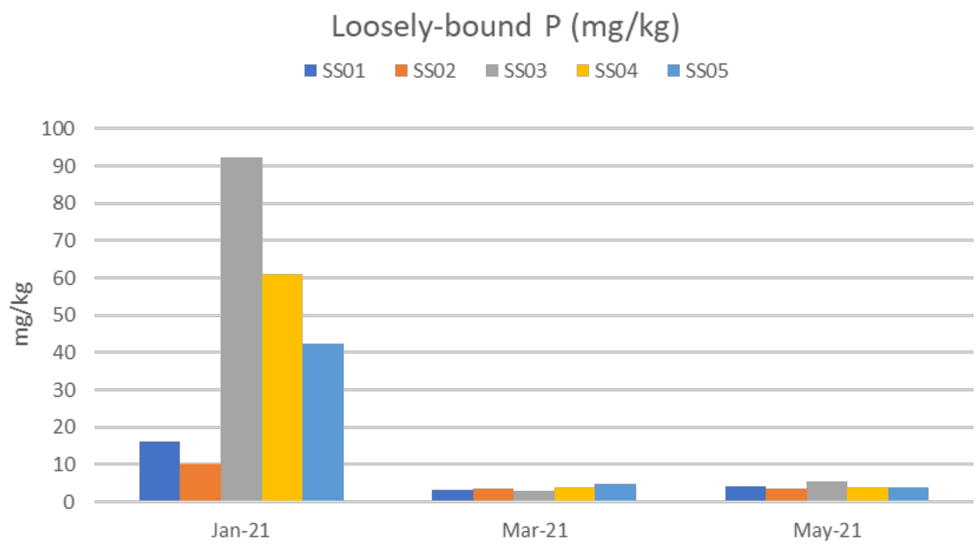
3.3.1.4 Zinc, Zn

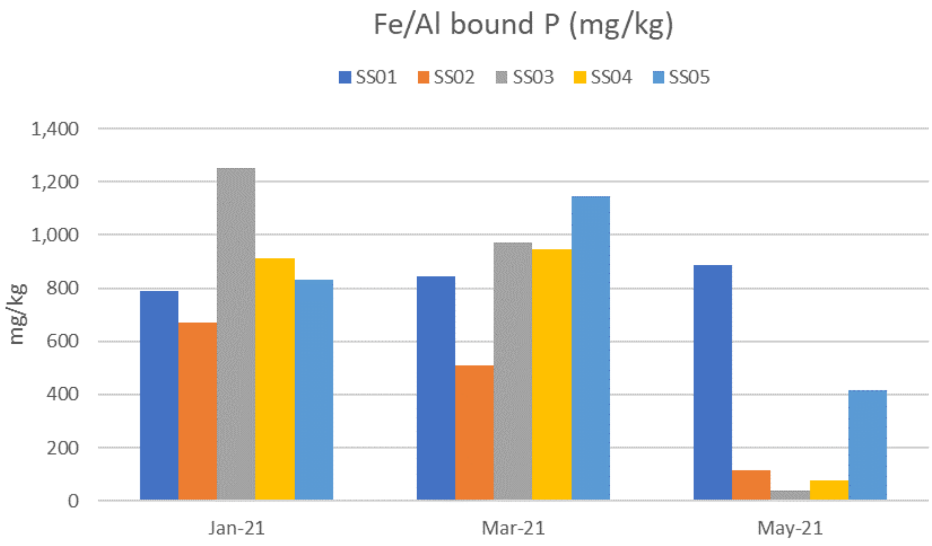
Majority of samples (i.e. 14 out of a total of 15) taken at 5 locations and 3 sampling dates have zinc levels exceeding the target limit. Zn concentrations in sediments at SS02 are substantially high compared to the other sampling locations. This suggests large contributions of Zn may be transported and delivered via surface runoff and atmospheric deposition from its proximity to industrial zones.

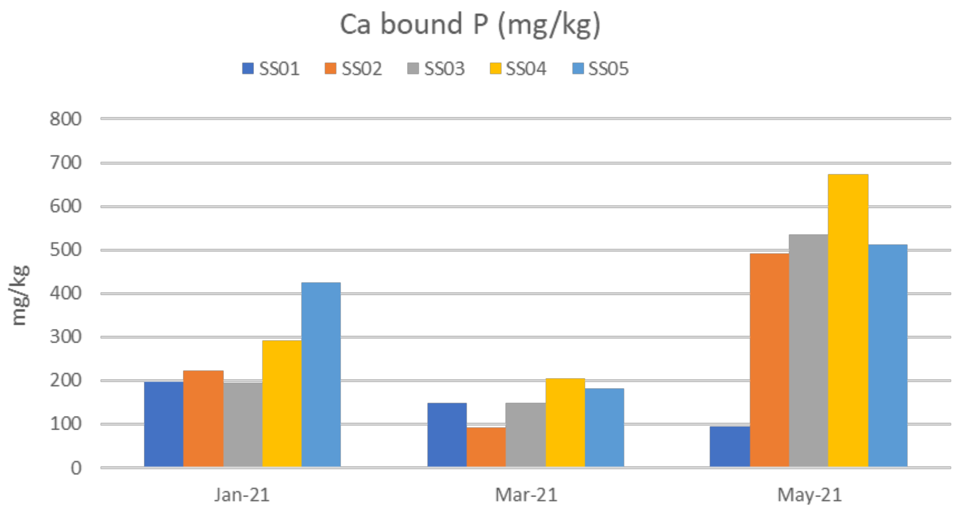
Figure 3-8, Figure 3-9 and *Figure 3-10* presents the lab results for sediment, pore water and elutriate samples respectively.

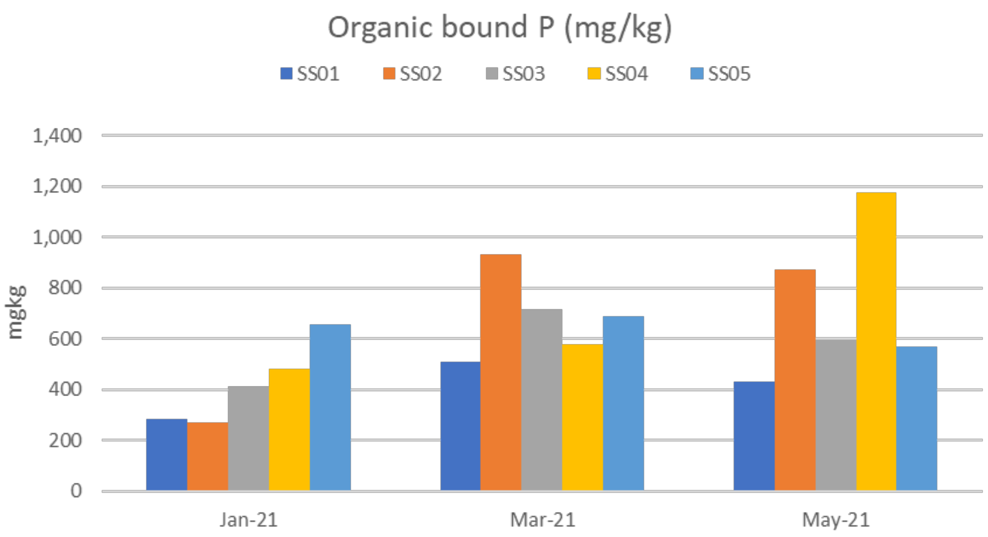

Total Nitrogen, TN (mg/kg)
SS01
SS02
SS03
SS04
SS05
mg/kg
700
600
500
400
300
200
100
0
Jan-21
Mar-21
May-21

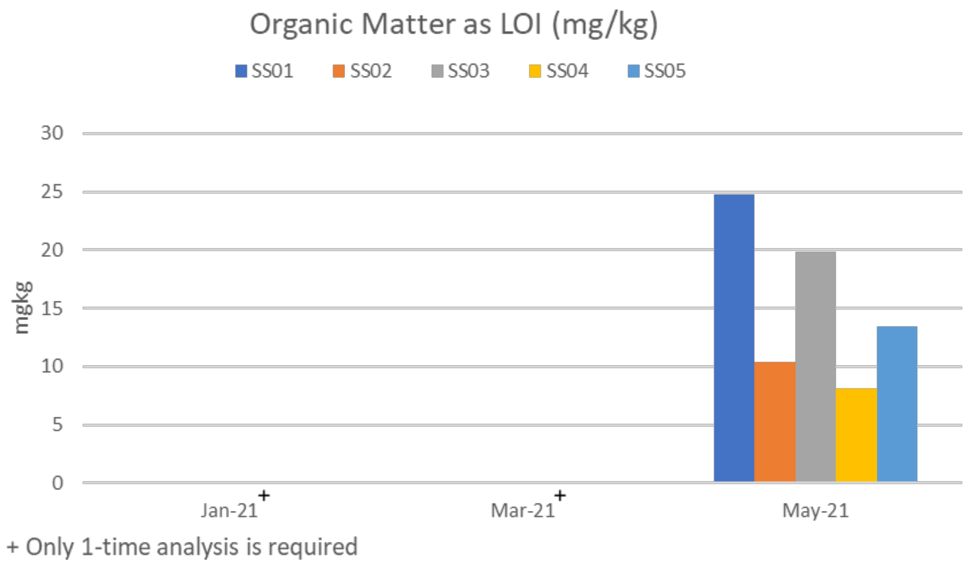

Total Phosphorus, TP (mg/kg)
SS01
SS02
SS03
SS04
SS05
mgkg
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-21
Mar-21
May-21

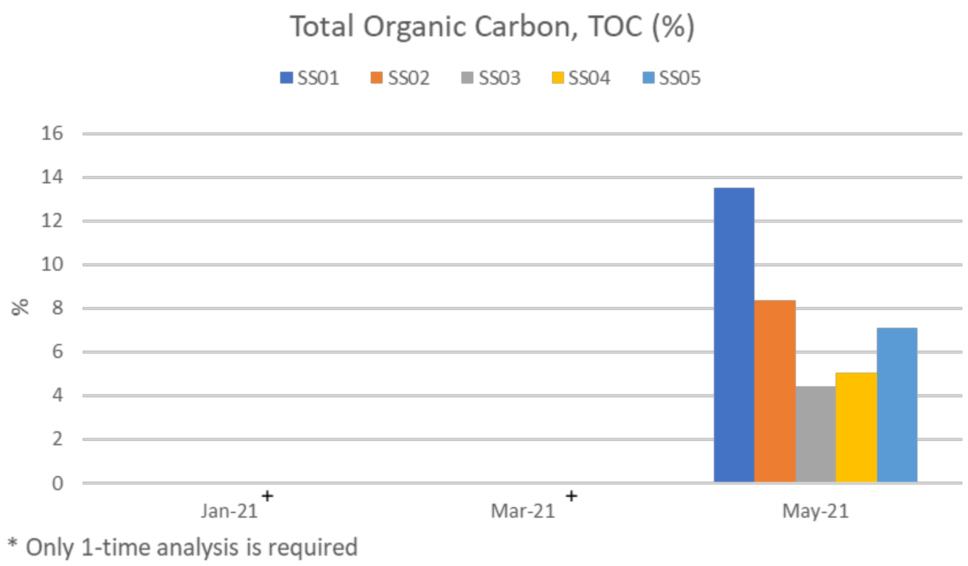

Loosely-bound P (mg/kg)
SS01
SS02
SS03
SS04
SS05
mg/kg
100
90
80
70
60
50
40
30
20
10
0
Jan-21
Mar-21
May-21

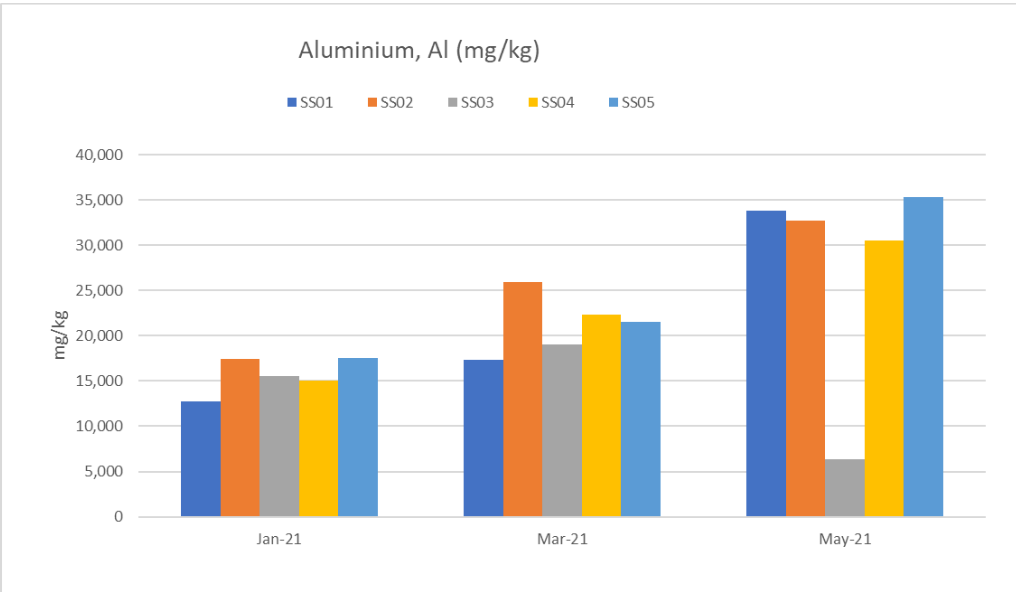

Fe/Al bound P (mg/kg)
SS01
SS02
SS03
SS04
SS05
mg/kg
1,400
1,200
1,000
800
600
400
200
0
Jan-21
Mar-21
May-21

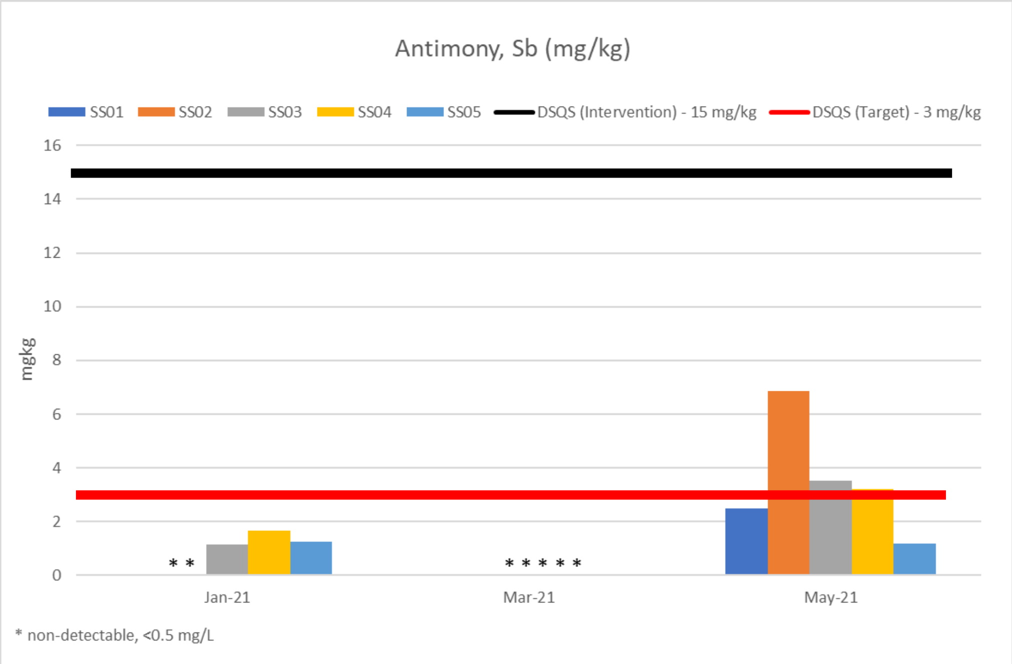

Ca bound P (mg/kg)
SS01
SS02
SS03
SS04
SS05
mg/kg
800
700
600
500
400
300
200
100
0
Jan-21
Mar-21
May-21

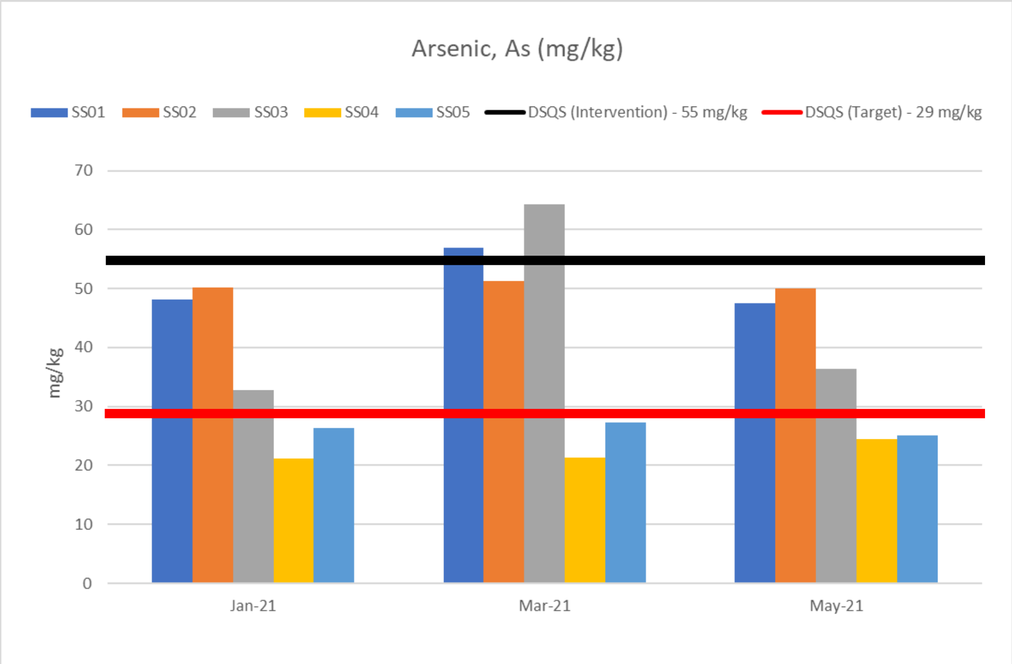

Organic bound P (mg/kg)
SS01
SS02
SS03
SS04
SS05
mgkg
1,400
1,200
1,000
800
600
400
200
0
Jan-21
Mar-21
May-21

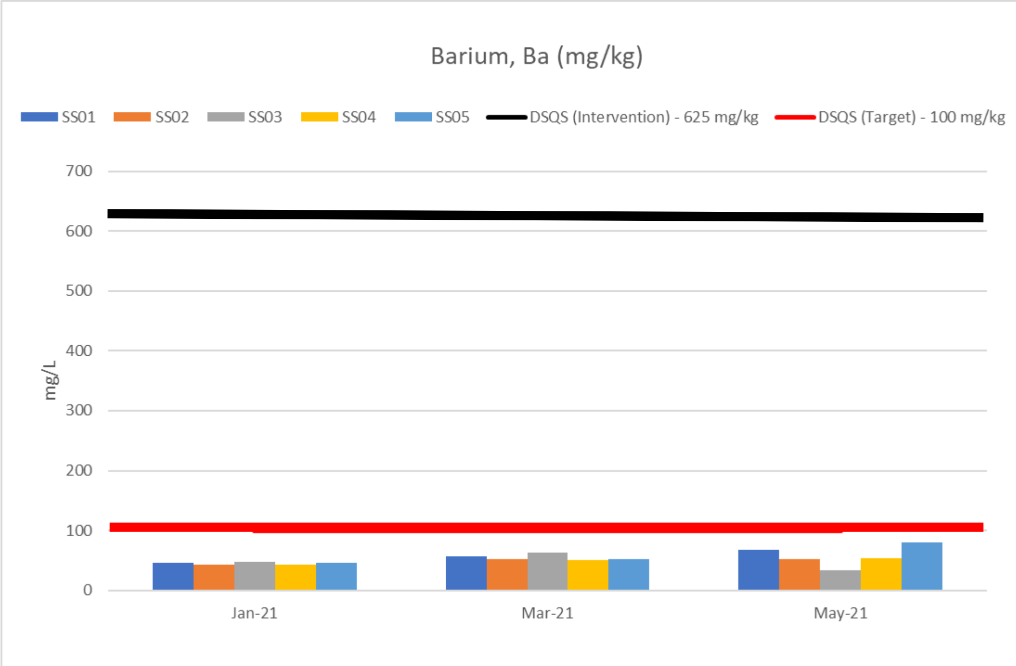

Organic Matter as LOI (mg/kg)
SS01
SS02
SS03
SS04
SS05
mgkg
30
25
20
15
10
5
0
Jan-21+
Mar-21+
May-21
+ Only 1-time analysis is required

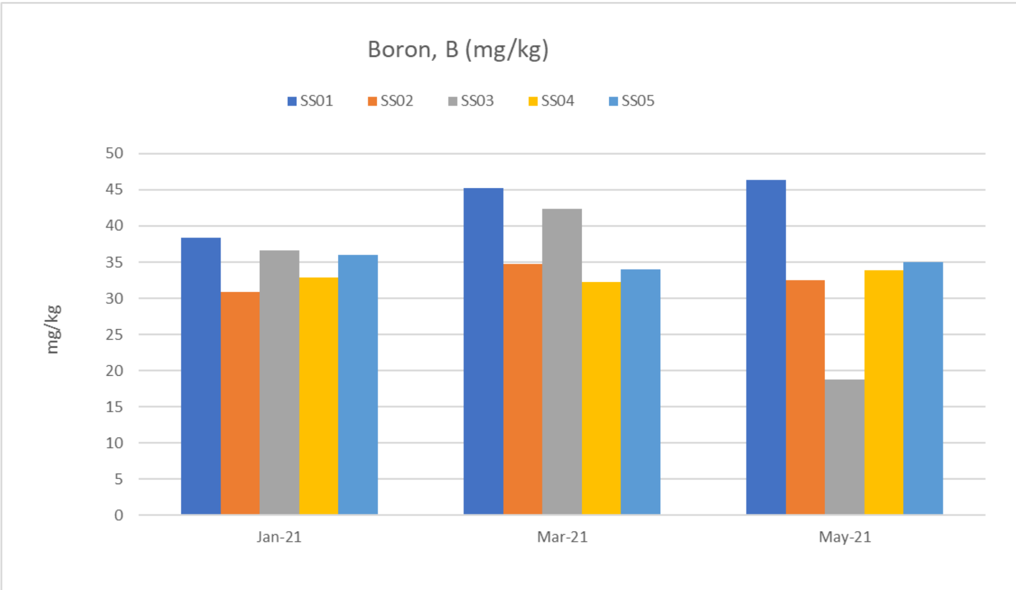

Total Organic Carbon, TOC (%)
SS01
SS02
SS03
SS04
SS05
%
16
14
12
10
8
6
4
2
0
Jan-21+
Mar-21+
May-21
* Only 1-time analysis is required

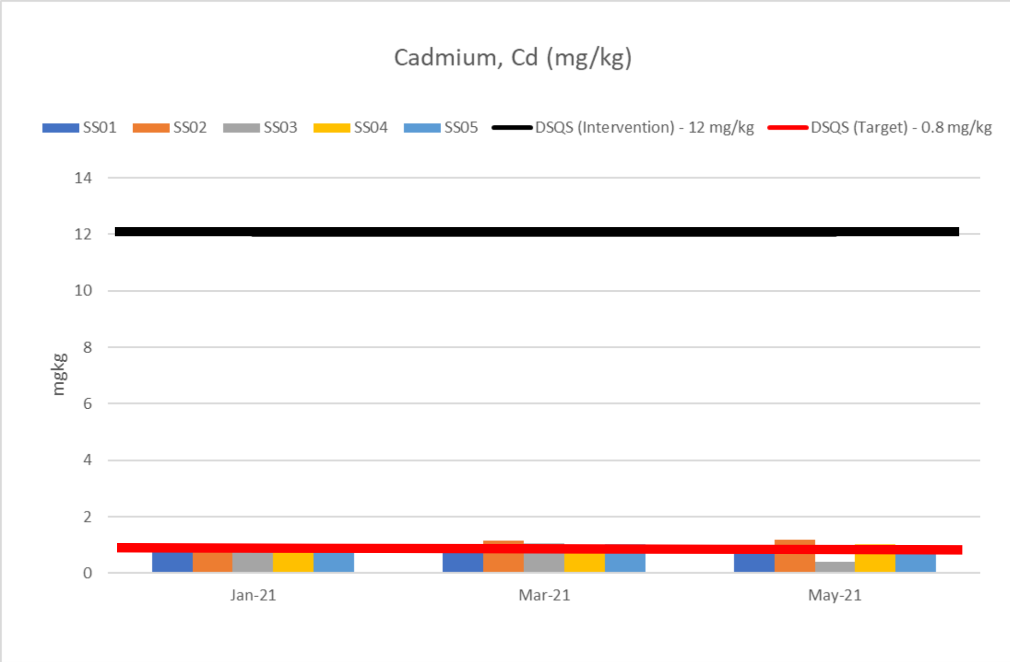

Aluminium, Al (mg/kg)
SS01
SS02
SS03
SS04
SS05
mg/kg
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-21
Mar-21
May-21

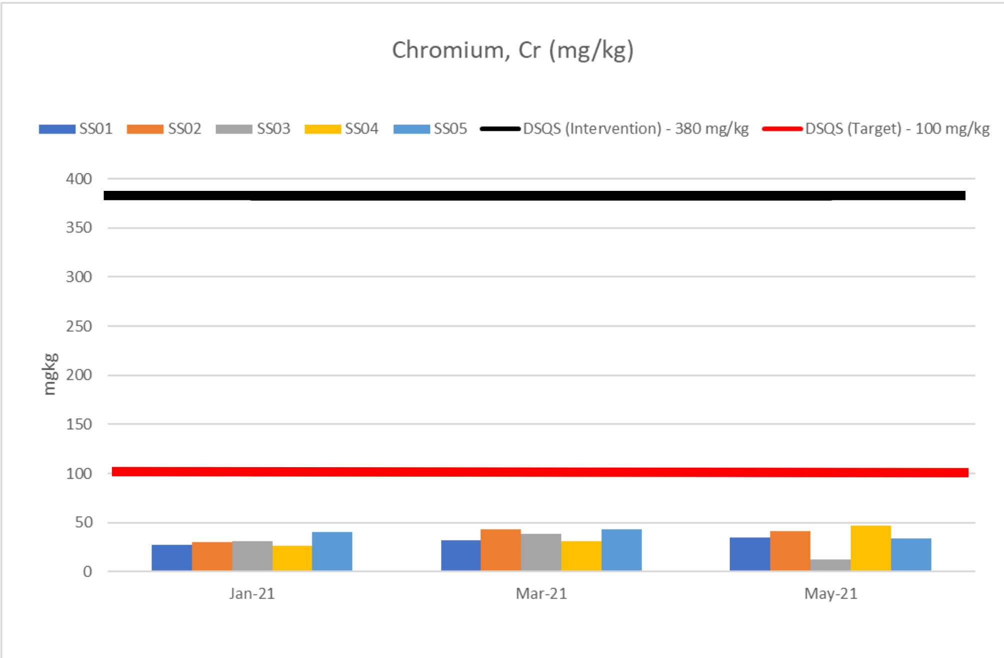

Antimony, Sb (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 15 mg/kg
DSQS (Target) - 3 mg/kg
mgkg
16
14
12
10
8
6
4
2
0
* *
* * * * *
Jan-21
Mar-21
May-21
* non-detectable, <0.5 mg/L

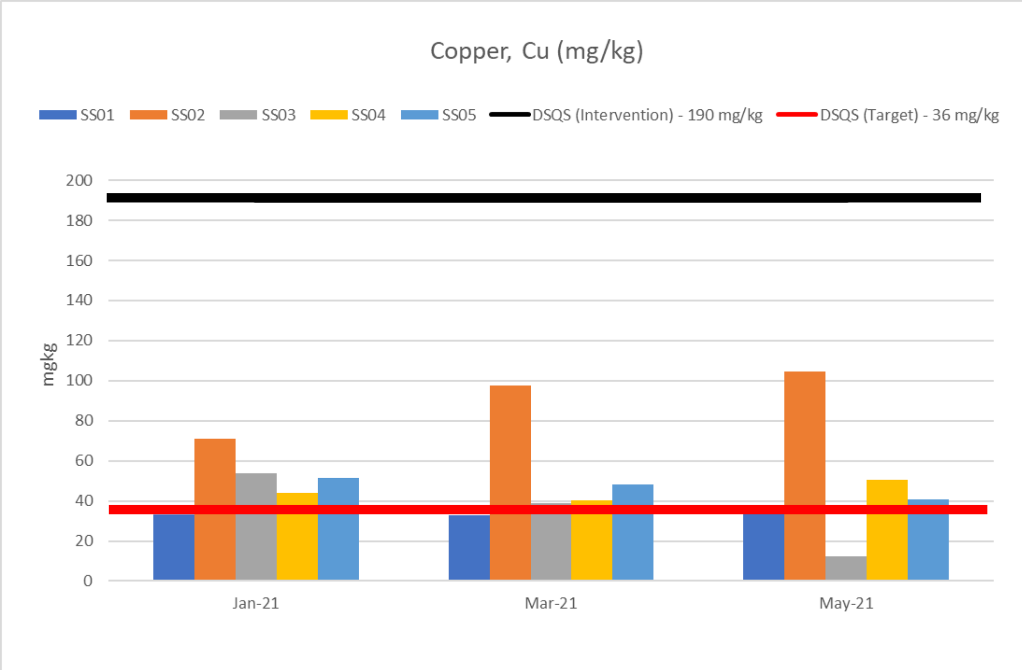

Arsenic, As (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 55 mg/kg
DSQS (Target) - 29 mg/kg
mg/kg
70
60
50
40
30
20
10
0
Jan-21
Mar-21
May-21

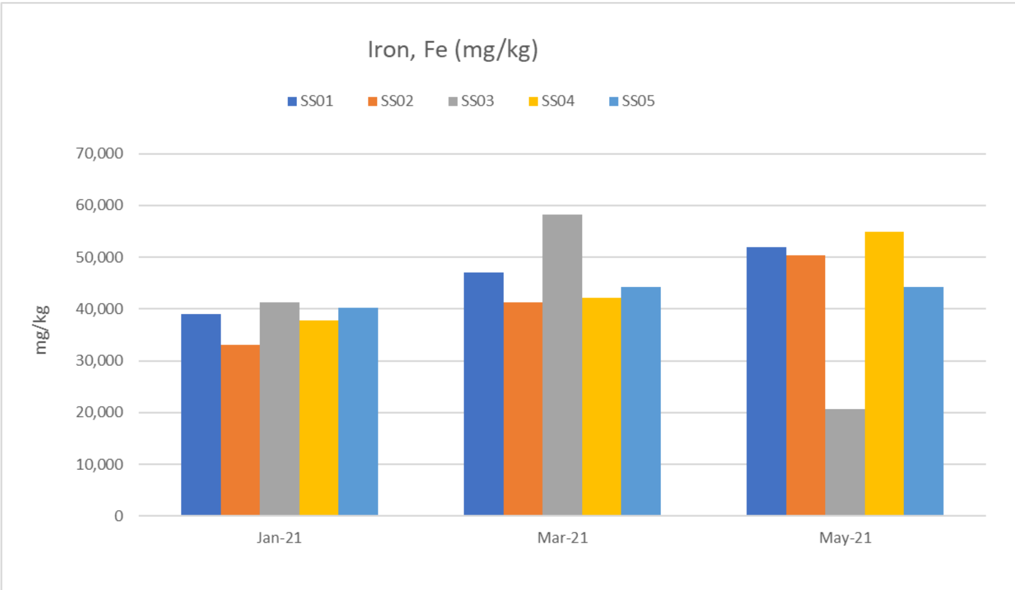

Barium, Ba (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 625 mg/kg
DSQS (Target) - 100 mg/kg
mg/L
700
600
500
400
300
200
100
0
Jan-21
Mar-21
May-21

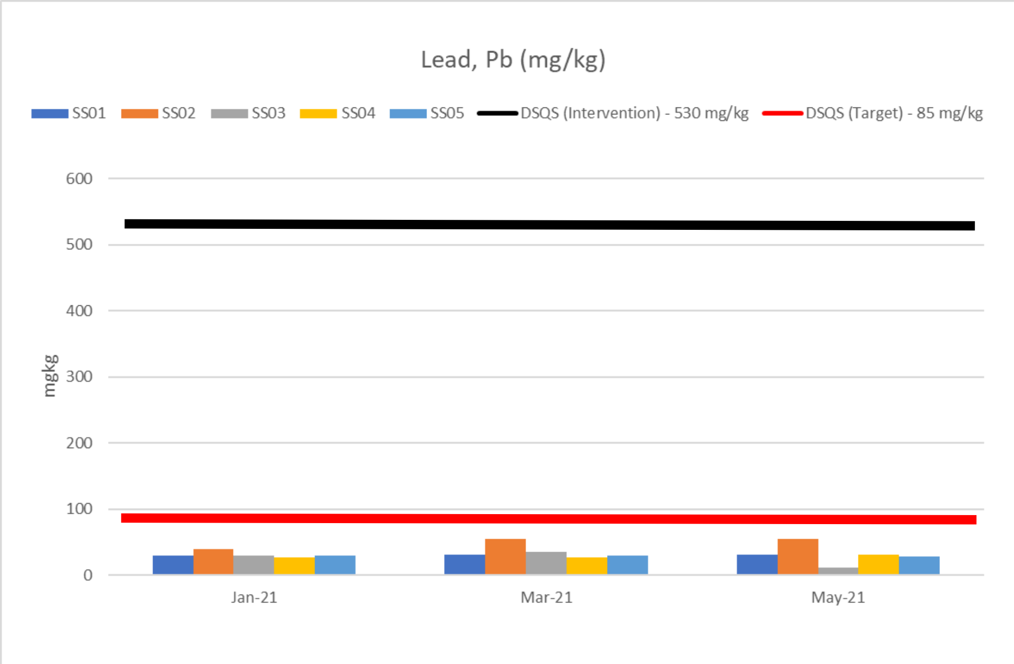

Boron, B (mg/kg)
SS01
SS02
SS03
SS04
SS05
mg/kg
50
45
40
35
30
25
20
15
10
5
0
Jan-21
Mar-21
May-21

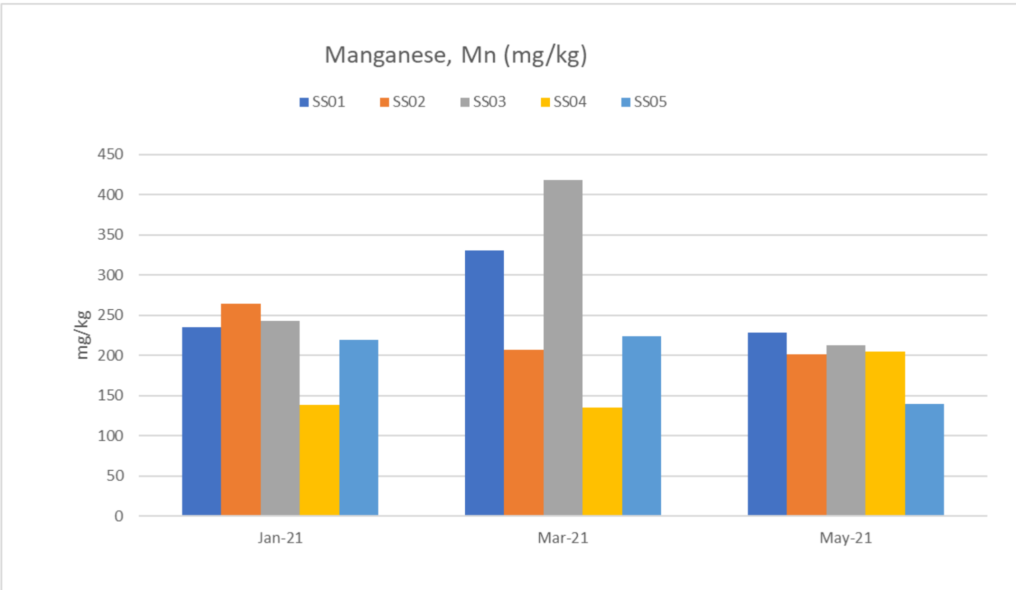

Cadmium, Cd (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 12 mg/kg
DSQS (Target) - 0.8 mg/kg
mgkg
0
2
4
6
8
10
12
14
Jan-21
Mar-21
May-21

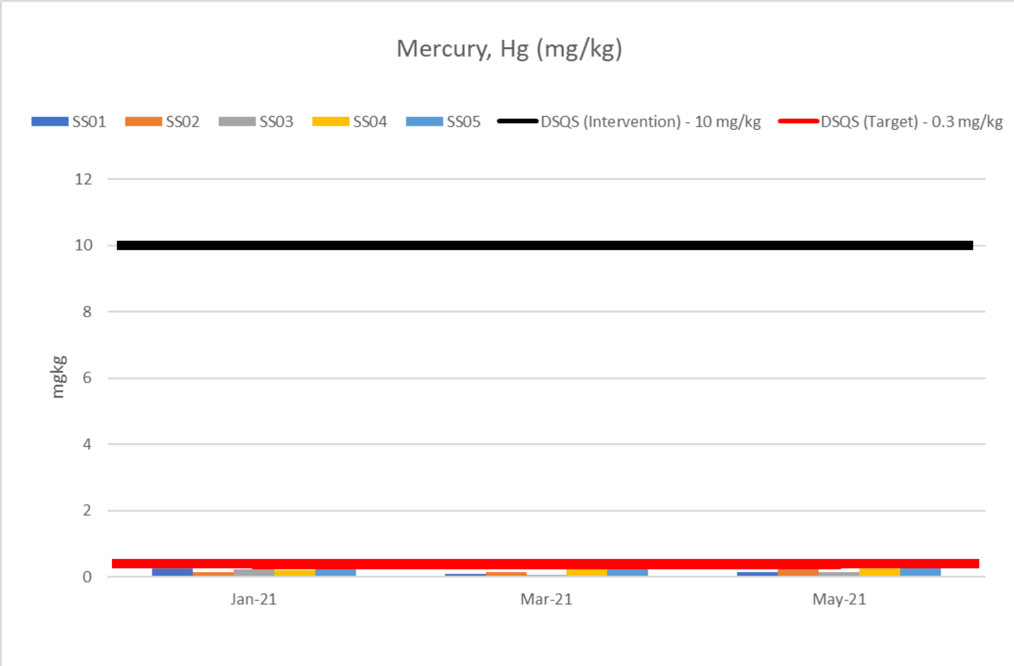

Chromium, Cr (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 380 mg/kg
DSQS (Target) - 100 mg/kg
mgkg
0
50
100
150
200
250
300
350
400
Jan-21
Mar-21
May-21

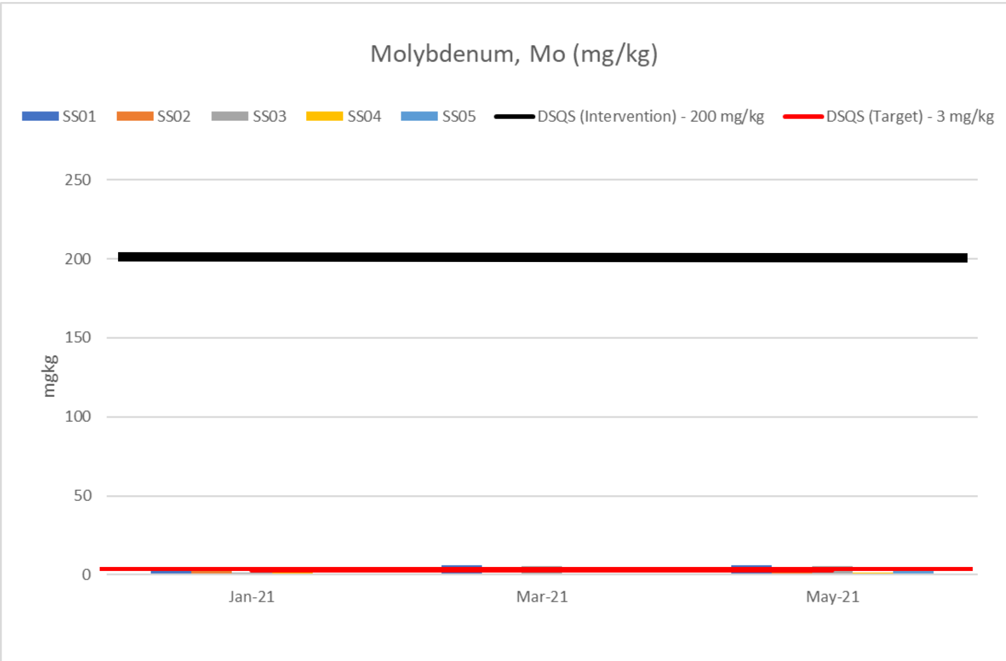

Copper, Cu (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 190 mg/kg
DSQS (Target) - 36 mg/kg
mgkg
200
180
160
140
120
100
80
60
40
20
0
Jan-21
Mar-21
May-21

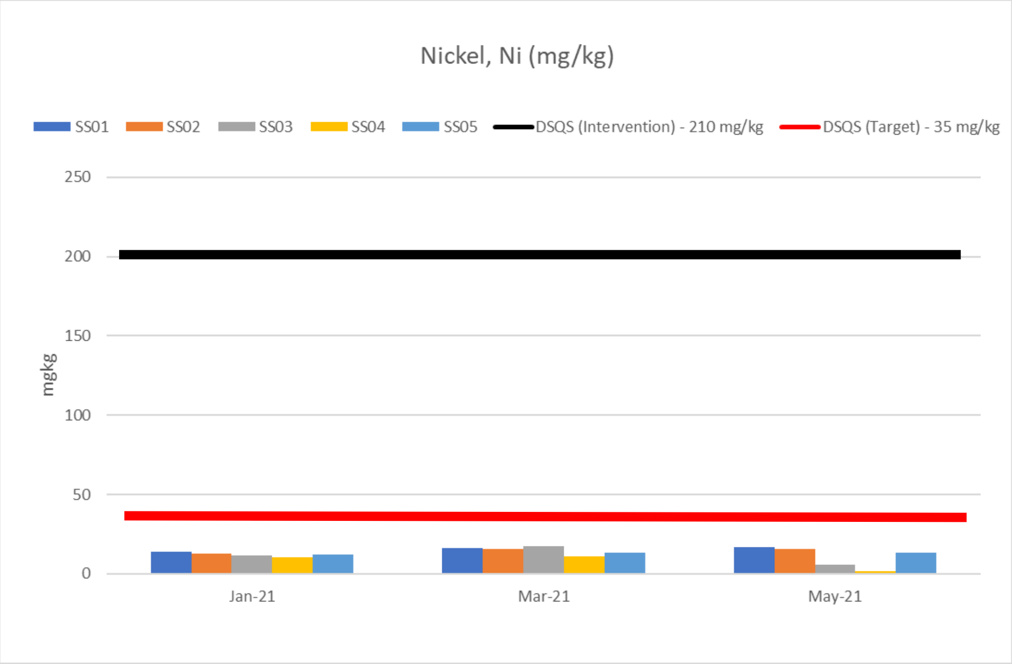

Iron, Fe (mg/kg)
SS01
SS02
SS03
SS04
SS05
mg/kg
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan-21
Mar-21
May-21

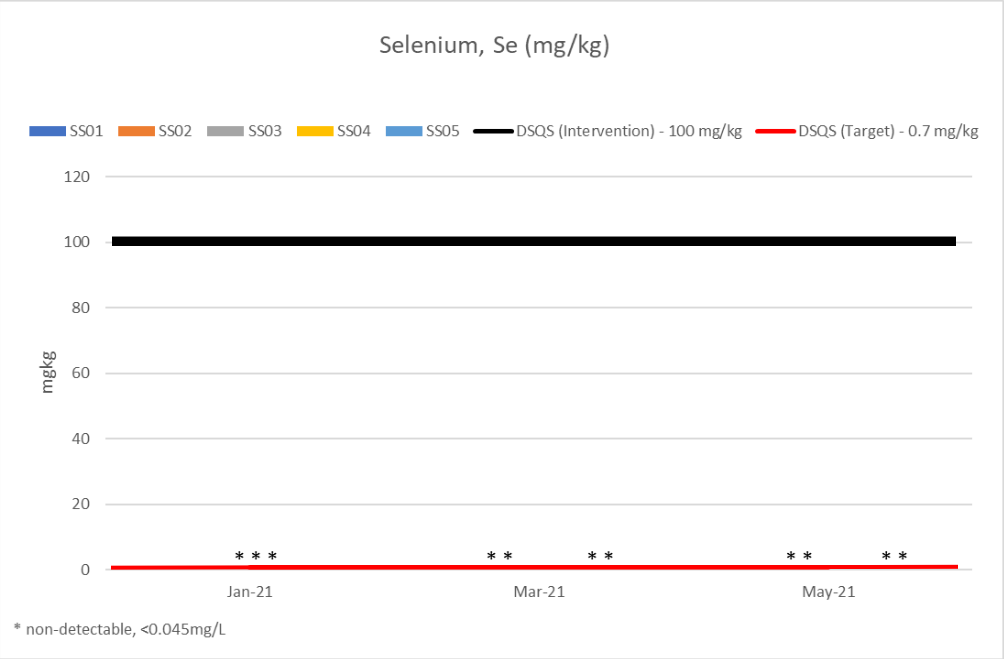

Lead, Pb (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 530 mg/kg
DSQS (Target) - 85 mg/kg
mgkg
600
500
400
300
200
100
0
Jan-21
Mar-21
May-21


Manganese, Mn (mg/kg)
SS01
SS02
SS03
SS04
SS05
mg/kg
450
400
350
300
250
200
150
100
50
0
Jan-21
Mar-21
May-21


Mercury, Hg (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 10 mg/kg
DSQS (Target) - 0.3 mg/kg
mgkg
12
10
8
6
4
2
0
Jan-21
Mar-21
May-21


Molybdenum, Mo (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 200 mg/kg
DSQS (Target) - 3 mg/kg
mgkg
250
200
150
100
50
0
Jan-21
Mar-21
May-21


Nickel, Ni (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 210 mg/kg
DSQS (Target) - 35 mg/kg
mgkg
250
200
150
100
50
0
Jan-21
Mar-21
May-21


Selenium, Se (mg/kg)
SS01
SS02
SS03
SS04
SS05
DSQS (Intervention) - 100 mg/kg
DSQS (Target) - 0.7 mg/kg
mgkg
120
100
80
60
40
20
0
Jan-21
Mar-21
May-21
* non-detectable, <0.045mg/L

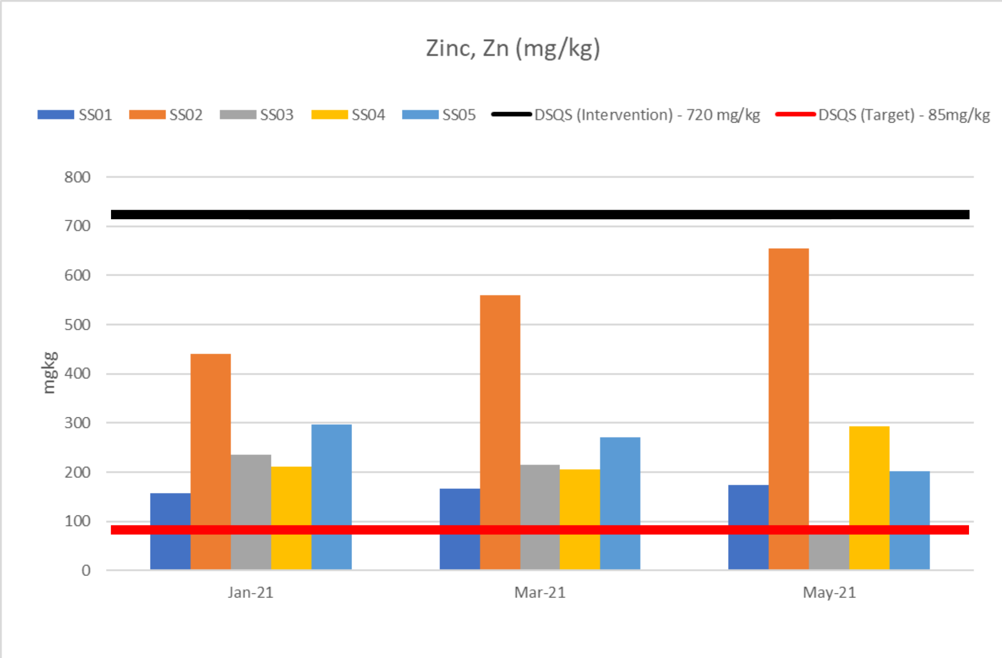
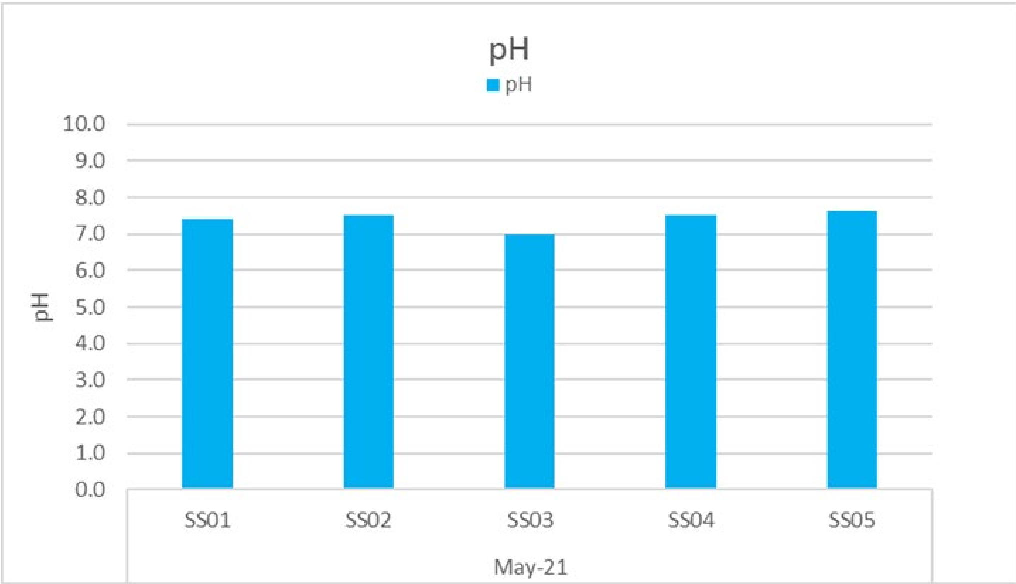
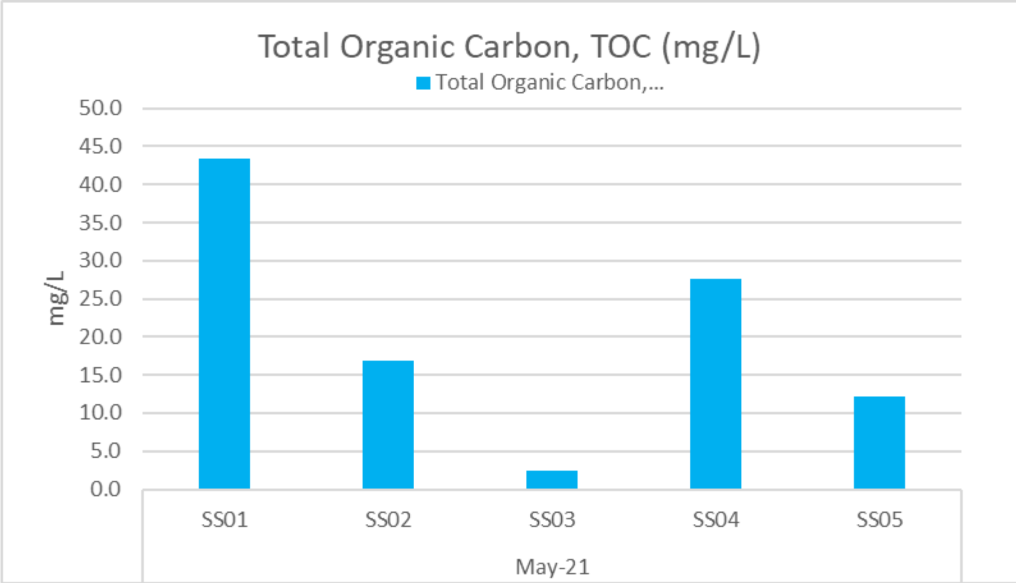
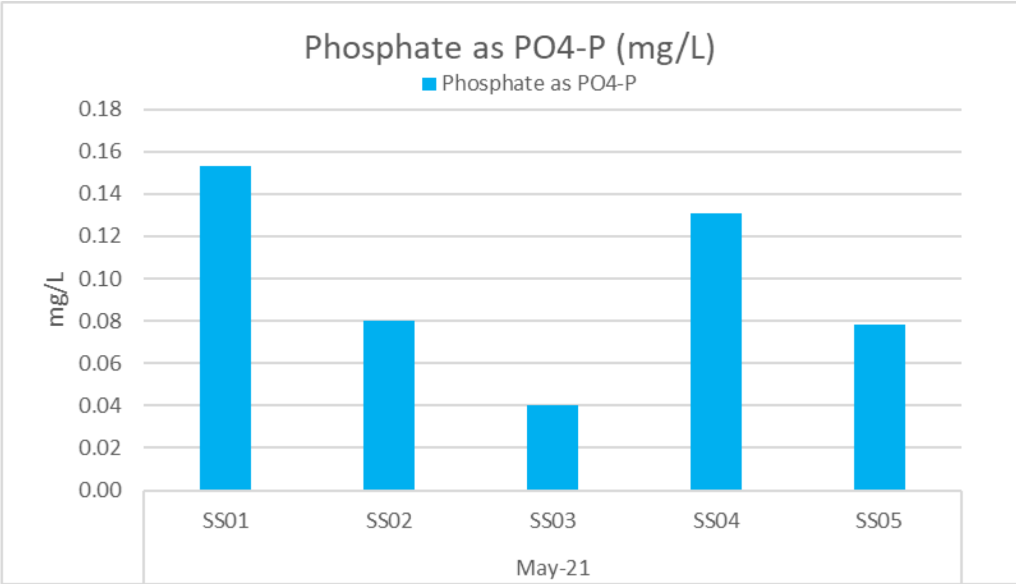
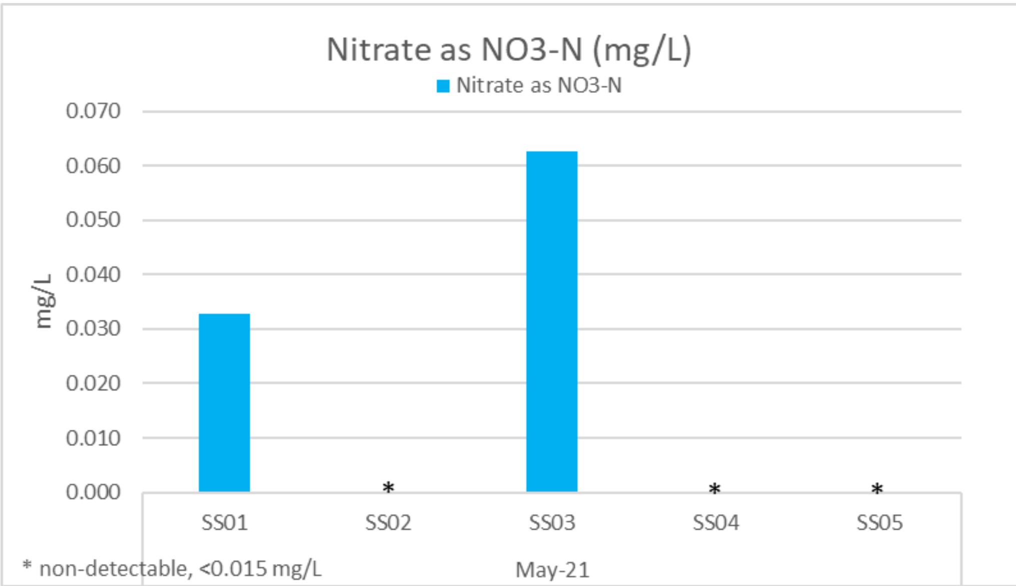


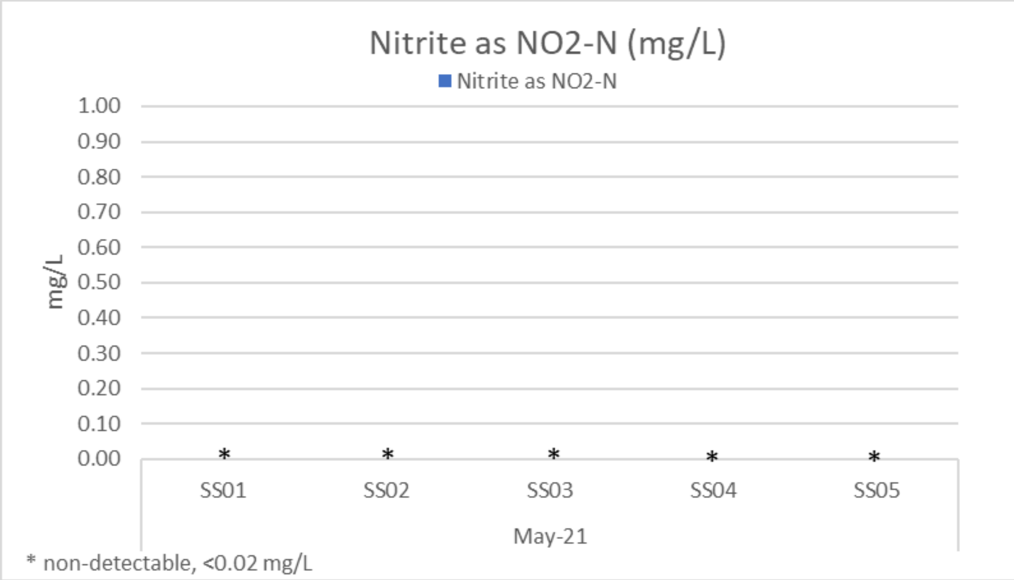
Figure 3-8: Sediment Quality – Analysis of Reservoir Bed Surface

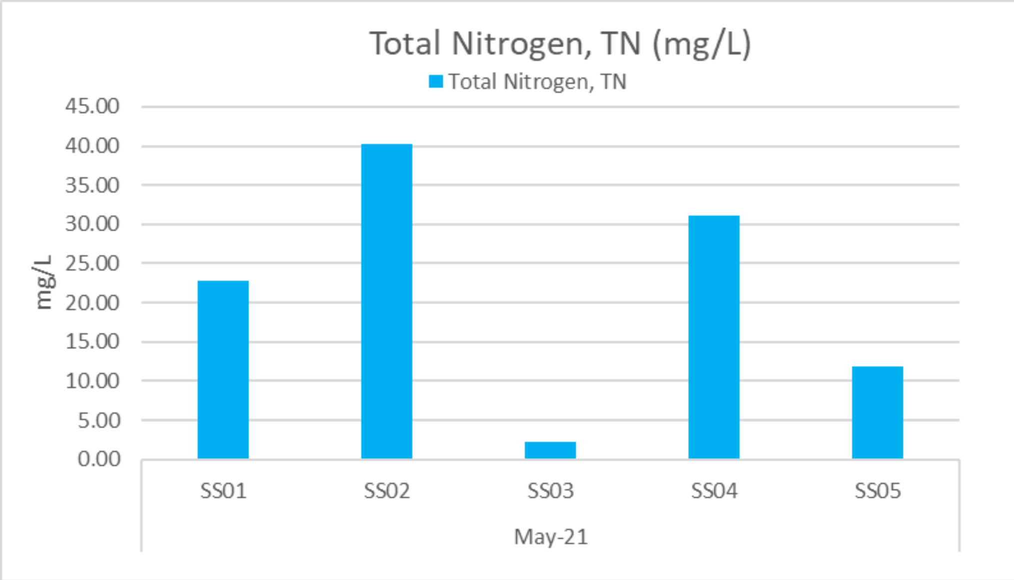


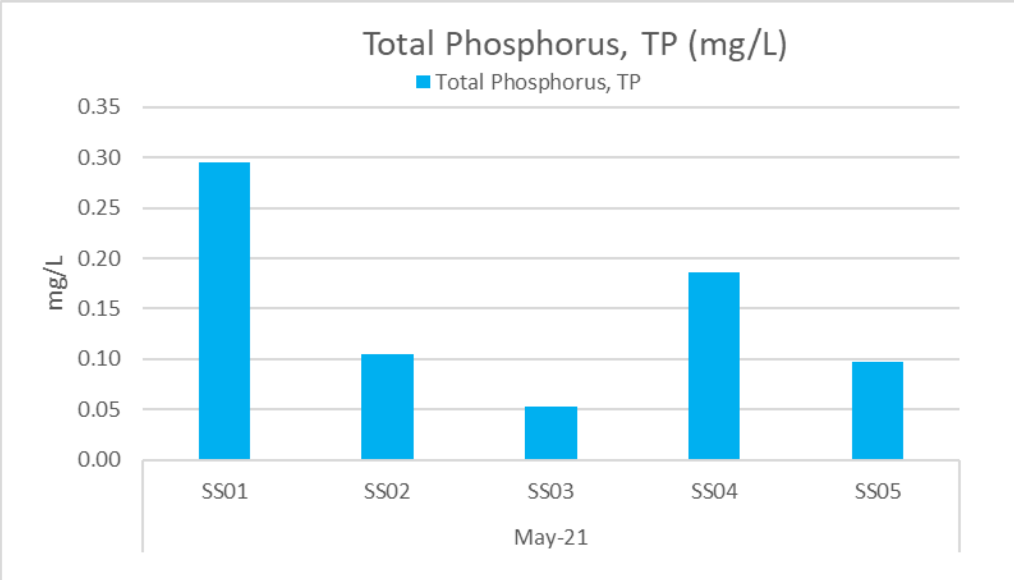

Total Organic Carbon, TOC (mg/L)
Total Organic Carbon,...
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
mg/L
SS01
SS02
SS03
SS04
SS05
May-21

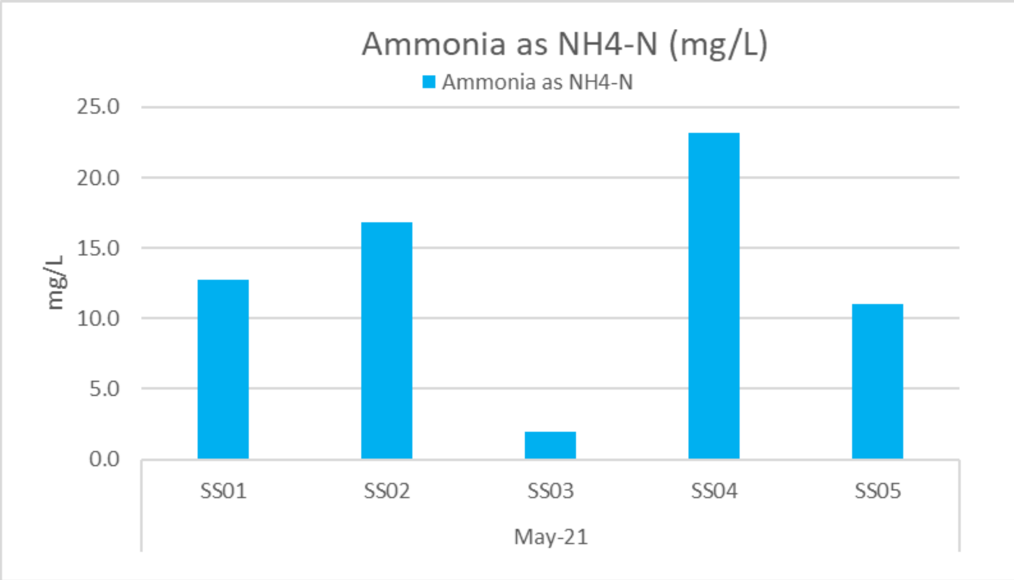

Phosphate as PO4-P (mg/L)
Phosphate as PO4-P
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
mg/L
SS01
SS02
SS03
SS04
SS05
May-21

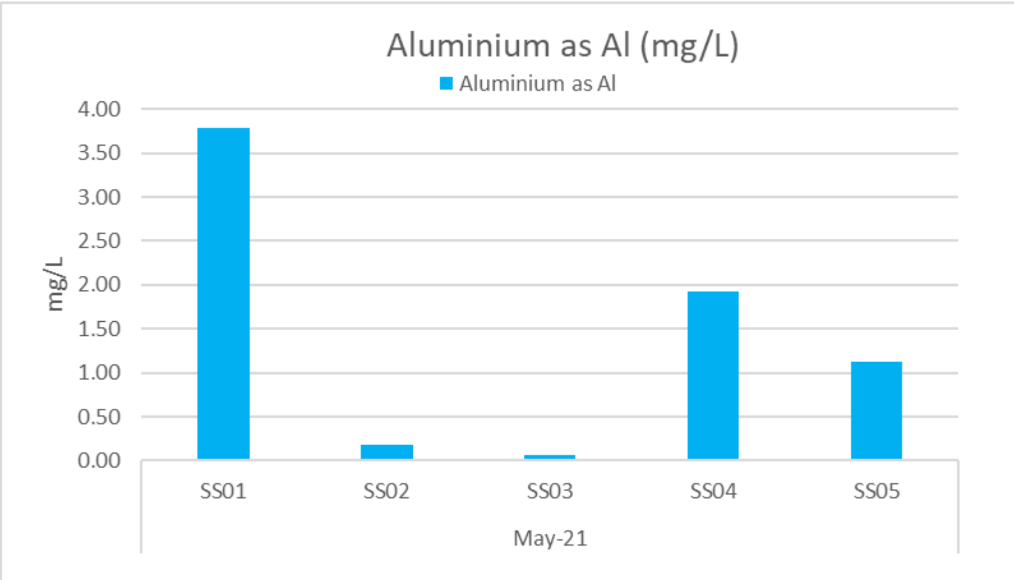

Nitrate as NO3-N (mg/L)
Nitrate as NO3-N
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
mg/L
*
*
*
SS01
SS02
SS03
SS04
SS05
* non-detectable, <0.015 mg/L
May-21

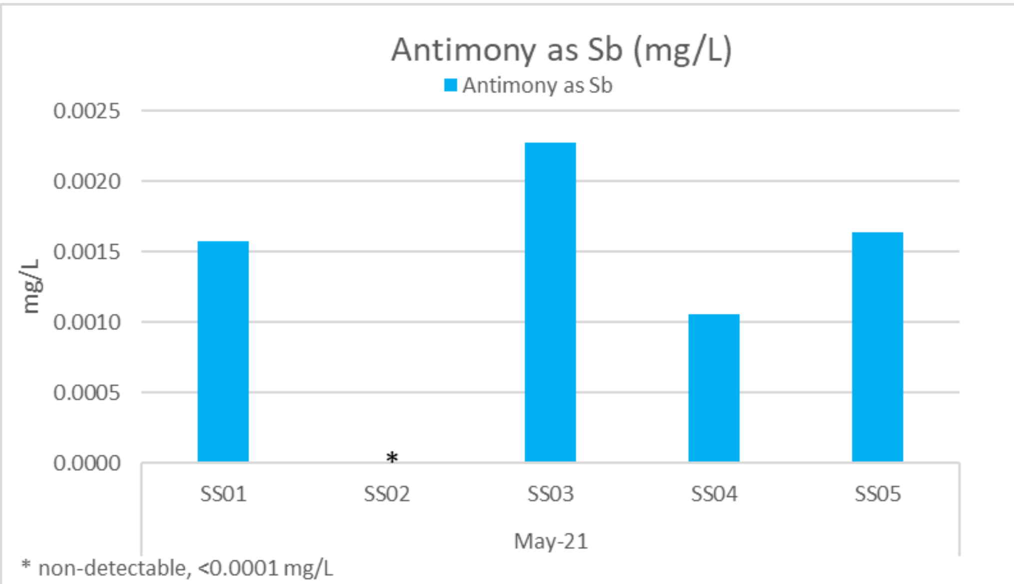

Nitrite as NO2-N (mg/L)
Nitrite as NO2-N
mg/L
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
*
SS01
SS02
SS03
SS04
SS05
May-21
* non-detectable, <0.02 mg/L

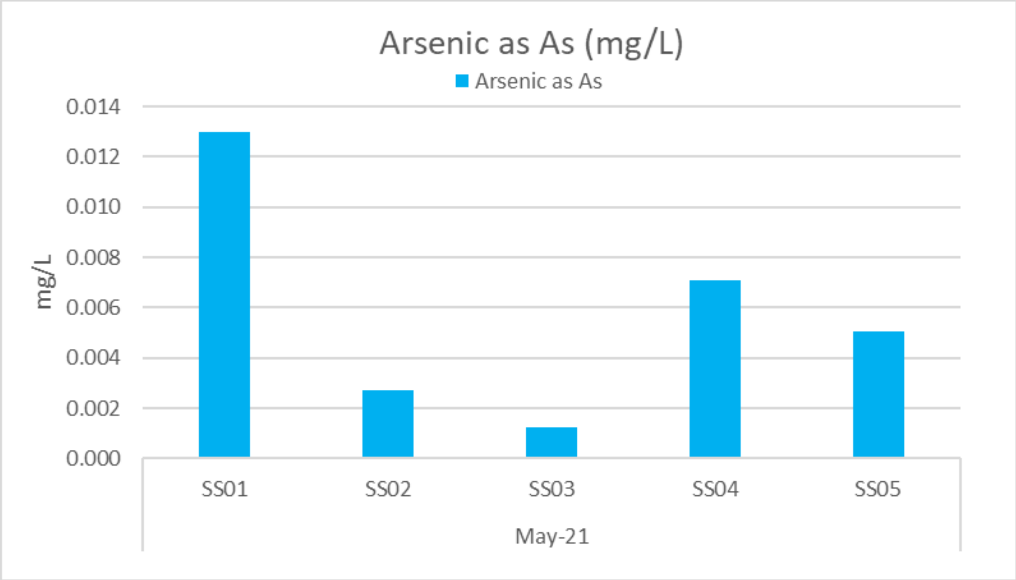

Total Nitrogen, TN (mg/L)
Total Nitrogen, TN
mg/L
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
SS01
SS02
SS03
SS04
SS05
May-21

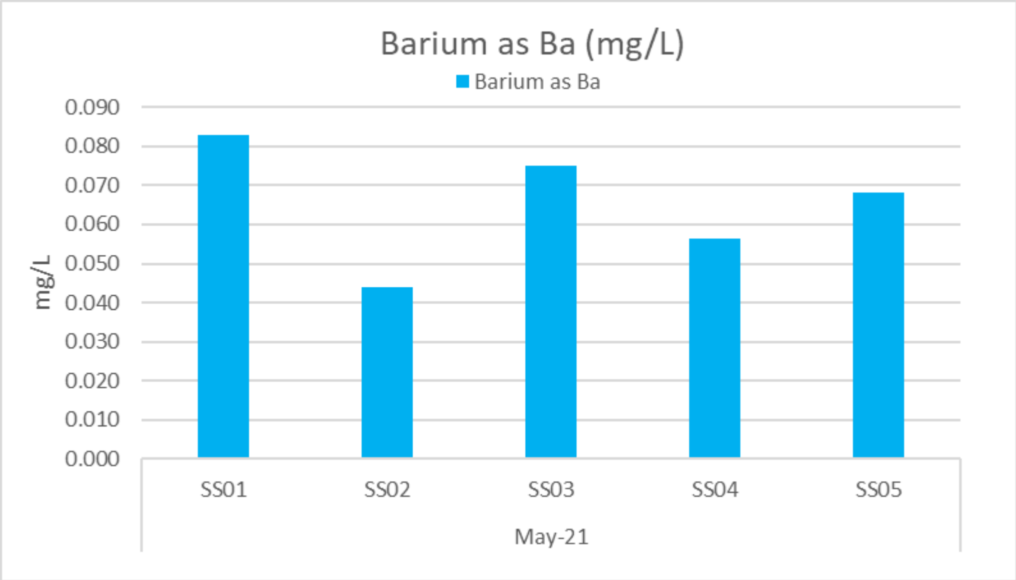

Total Phosphorus, TP (mg/L)
Total Phosphorus, TP
mg/L
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
SS01
SS02
SS03
SS04
SS05
May-21

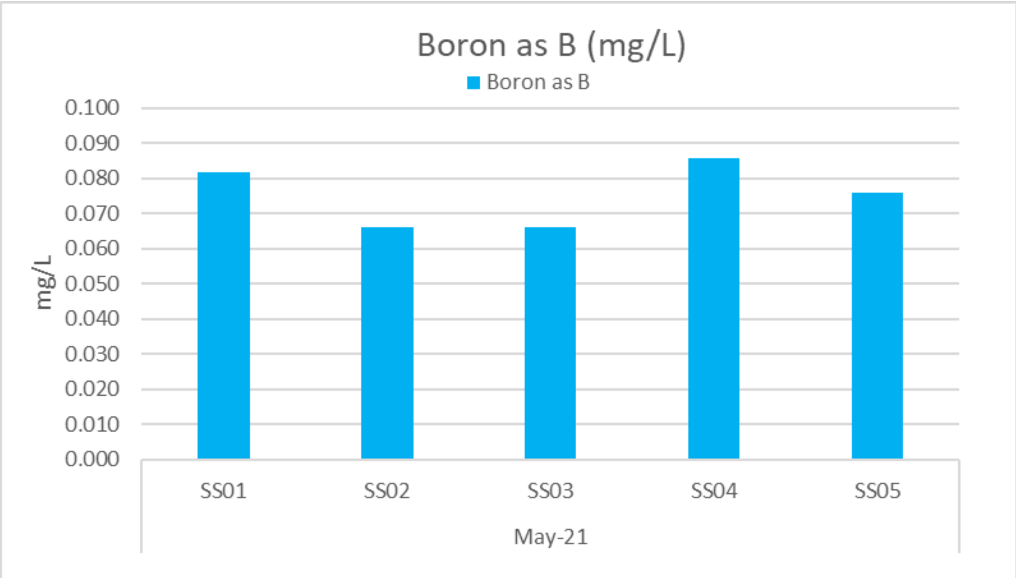

Ammonia as NH4-N (mg/L)
Ammonia as NH4-N
25.0
20.0
15.0
10.0
5.0
0.0
mg/L
SS01
SS02
SS03
SS04
SS05
May-21

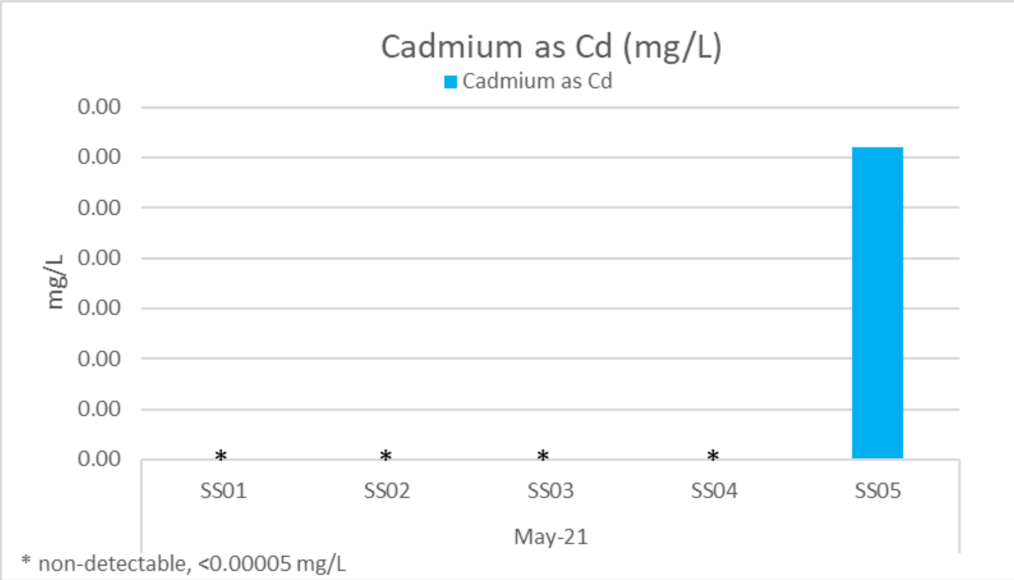

Aluminium as Al (mg/L)
Aluminium as Al
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
mg/L
SS01
SS02
SS03
SS04
SS05
May-21

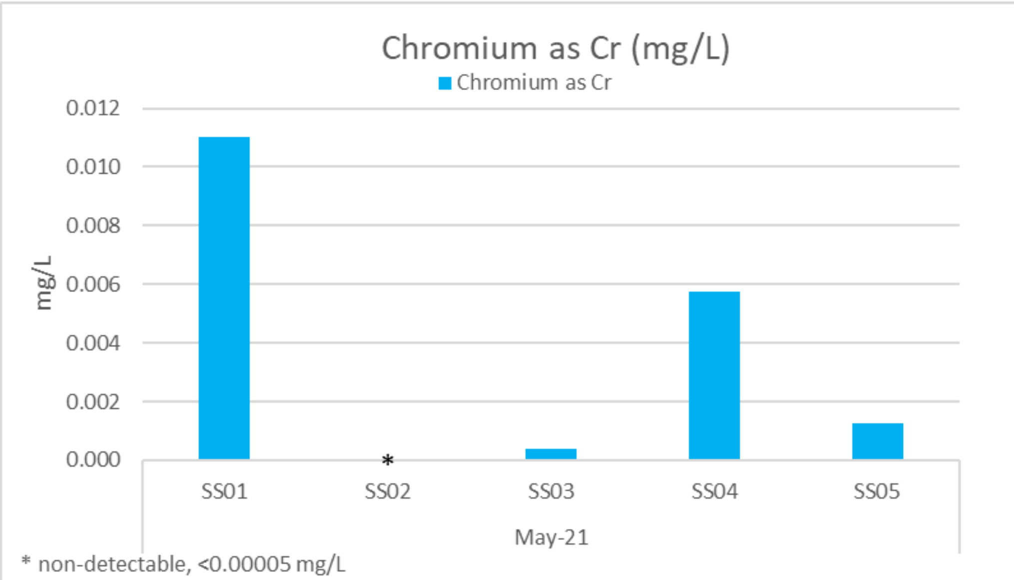

Antimony as Sb (mg/L)
Antimony as Sb
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
mg/L
*
SS01
SS02
SS03
SS04
SS05
May-21
* non-detectable, <0.0001 mg/L


Arsenic as As (mg/L)
Arsenic as As
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
mg/L
SS01
SS02
SS03
SS04
SS05
May-21


Barium as Ba (mg/L)
Barium as Ba
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
mg/L
SS01
SS02
SS03
SS04
SS05
May-21


Boron as B (mg/L)
Boron as B
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
mg/L
SS01
SS02
SS03
SS04
SS05
May-21


Cadmium as Cd (mg/L)
Cadmium as Cd
mg/L
0.00
SS01
SS02
SS03
SS04
SS05
May-21
* non-detectable, <0.00005 mg/L


Chromium as Cr (mg/L)
Chromium as Cr
mg/L
0.012
0.010
0.008
0.006
0.004
0.002
0.000
SS01
SS02
SS03
SS04
SS05
May-21
* non-detectable, <0.00005 mg/L

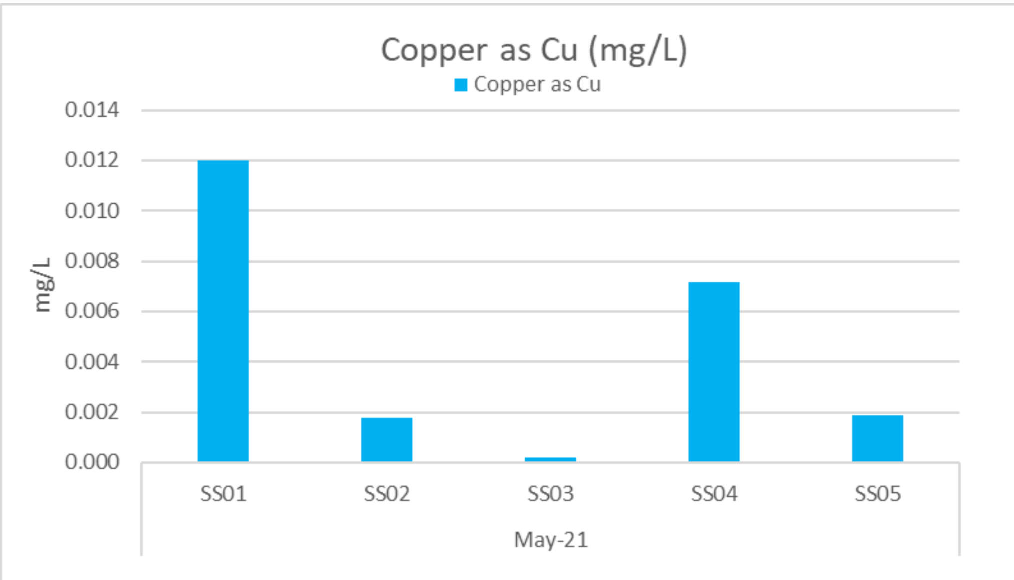
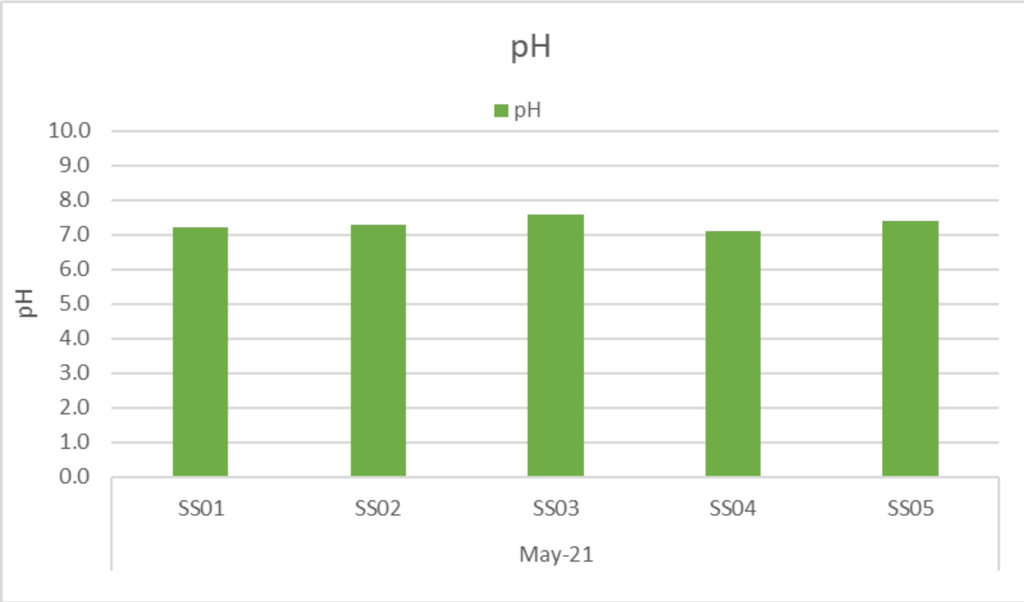
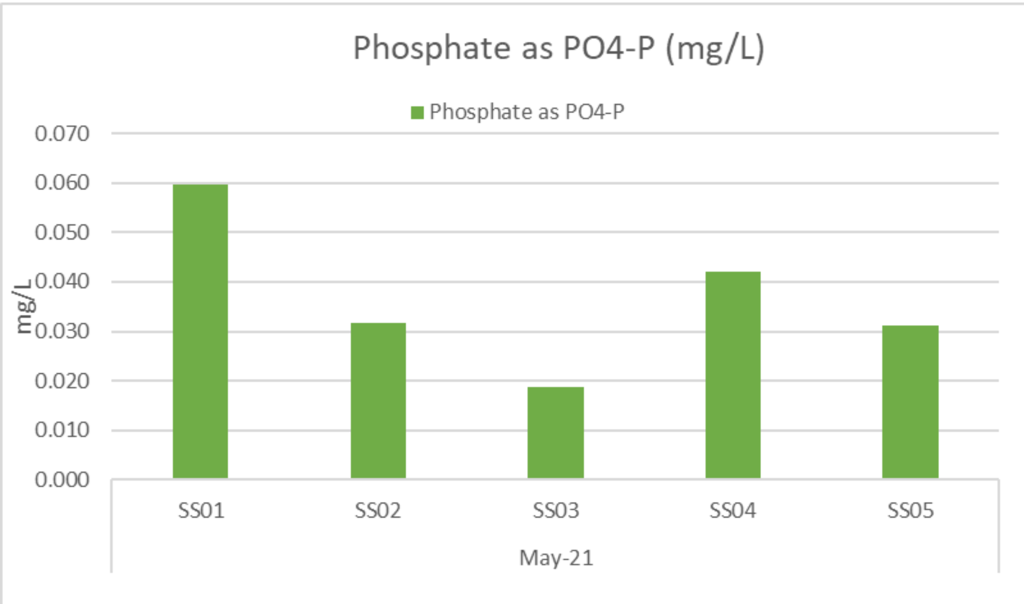
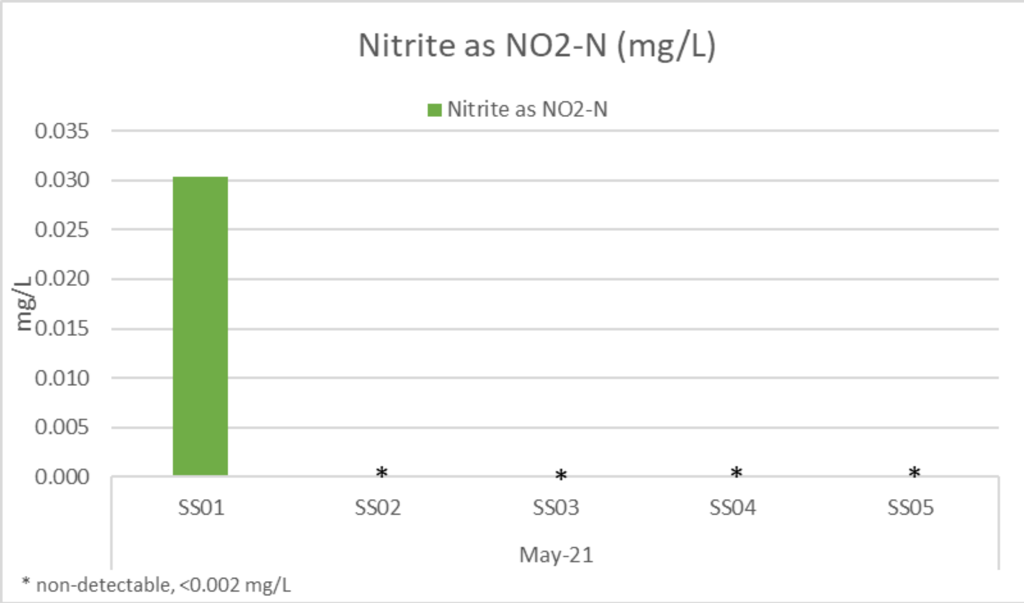
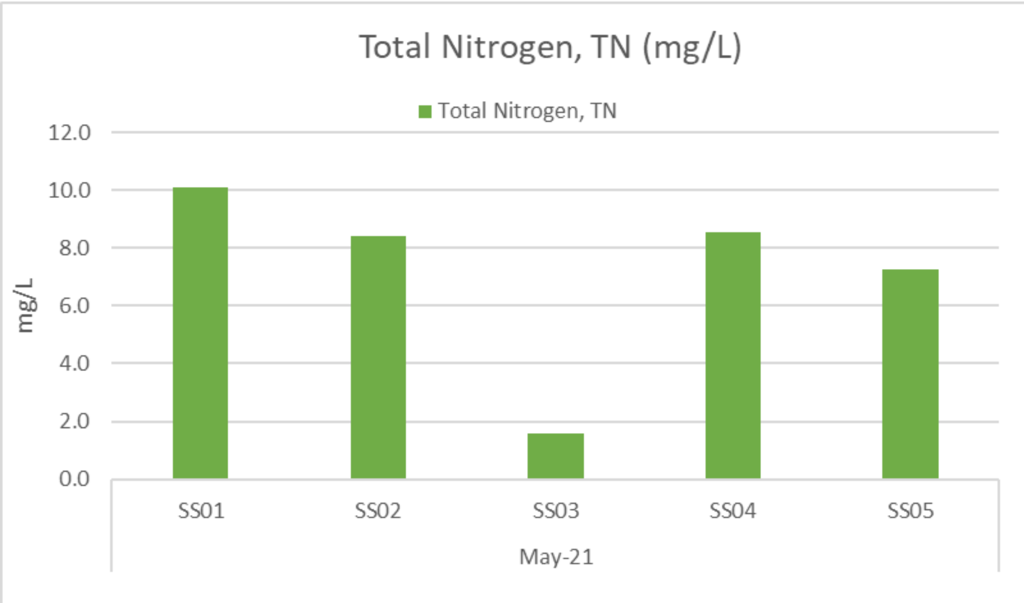

Copper as Cu (mg/L)
Copper as Cu
mg/L
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
SS01
SS02
SS03
SS04
SS05
May-21

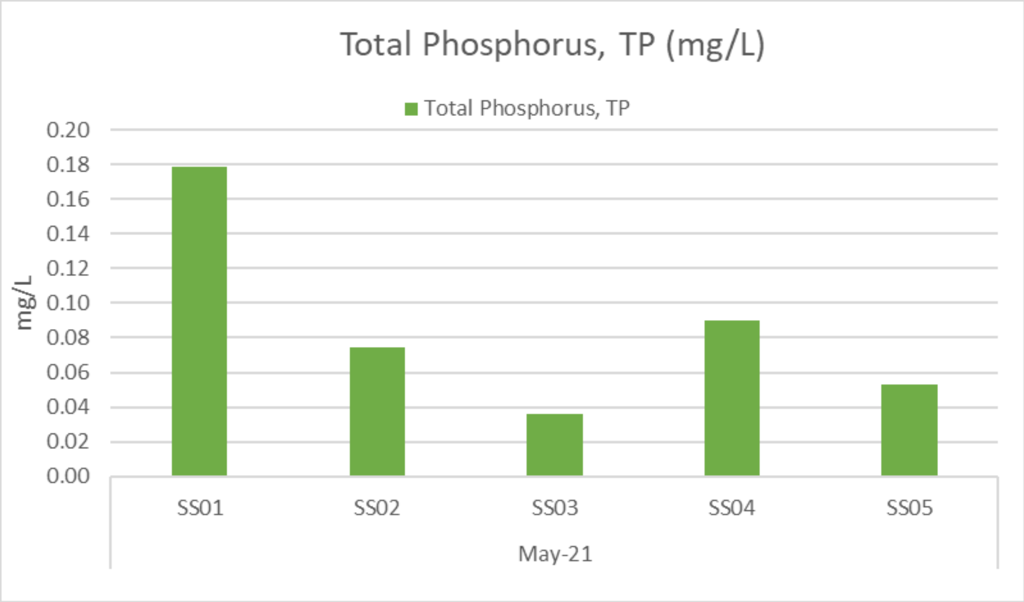
Figure 3-9: Pore water – Analysis of Reservoir Bed Surface

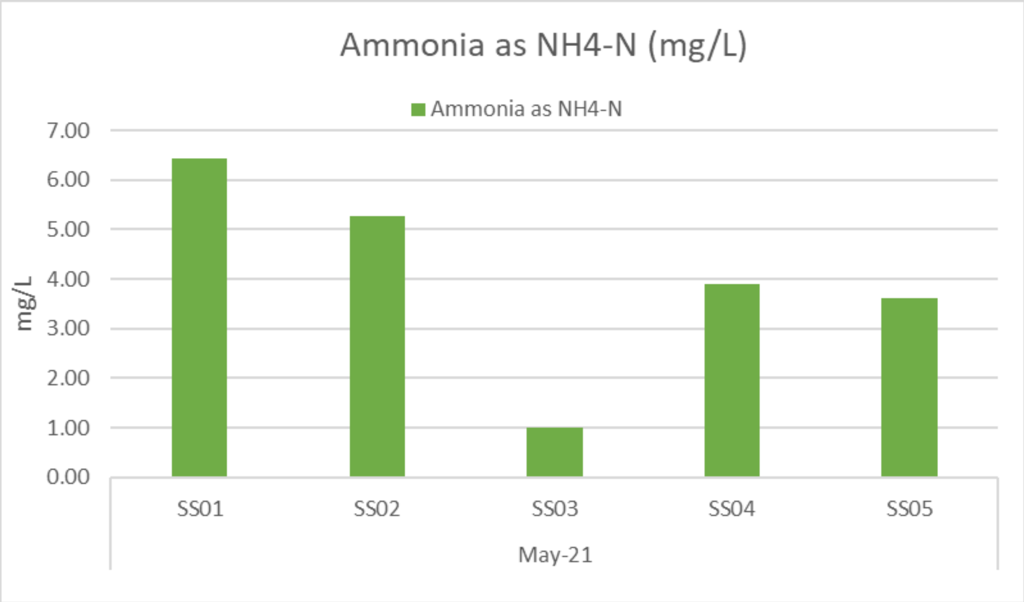





Nitrite as NO2-N (mg/L)
Nitrite as NO2-N
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
mg/L
SS01
SS02
SS03
SS04
SS05
May-21
* non-detectable, <0.002 mg/L


Total Nitrogen, TN (mg/L)
Total Nitrogen, TN
12.0
10.0
8.0
6.0
4.0
2.0
0.0
mg/L
SS01
SS02
SS03
SS04
SS05
May-21


Total Phosphorus, TP (mg/L)
Total Phosphorus, TP
mg/L
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
SS01
SS02
SS03
SS04
SS05
May-21


Ammonia as NH4-N (mg/L)
Ammonia as NH4-N
mg/L
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
SS01
SS02
SS03
SS04
SS05
May-21


Arsenic as As (mg/L)
Arsenic as As
mg/L
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
SS01
SS02
SS03
SS04
SS05
May-21

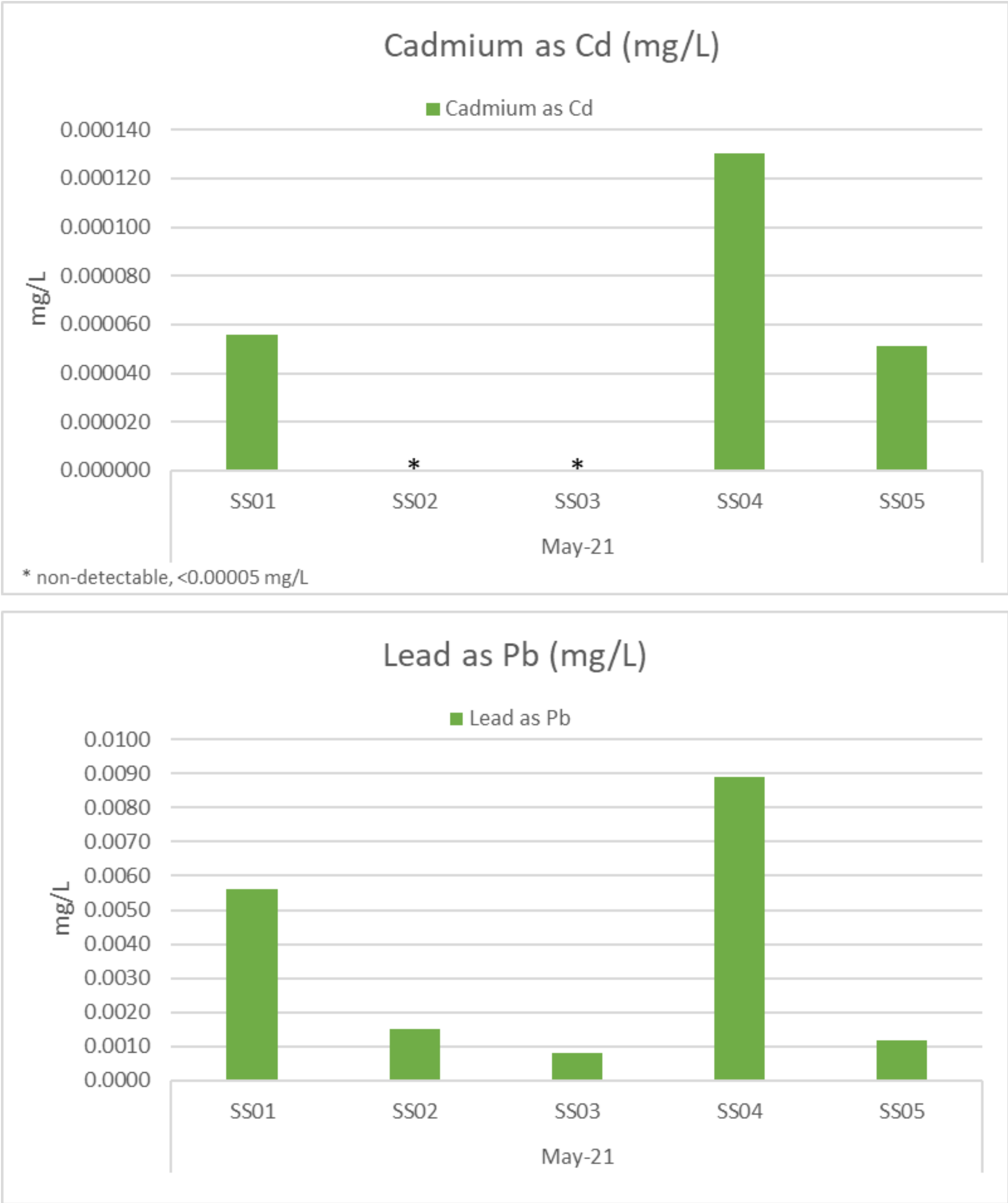


Figure 3-10: Elutriate – Analysis of Reservoir Bed Surface

3.4 Planktons

3.4.1 Zooplankton

A total of 3 zooplankton phyla belonging to Arthropoda, Rotifera and Platyhelminthes with 14 species were identified over the sampling months across 5 sampling sites (*Figure 3-13*). Dominant species included *Keratella* sp. (see *Figure 3-11*) and *Daphnia* sp, which were observed to be distributed across all sites. These dominant species are an important food source for fish and predatory invertebrates. Taxon richness ranged from 3 to 8 taxa while abundance of zooplankton species ranged from 30 to 55 individuals/ mL and were observed to vary across the sampling sites throughout the sampling months (*Figure 3-12*). Monthly variability in abundance of zooplankton types was observed, with small changes observed in species diversity. Variability in species abundances were also observed between sampling locations.

A monthly average percentage abundance for *Keratella* sp. abundance across all five sampling locations ranged from 20% to 45%, with the lowest value observed in February 2021 at 20.1% and highest abundance observed in March 2021 at 44.2%. *Keratella* are commonly found in eutrophic waters and are mostly associated with phosphates (Krupa et al., 2020). Monthly averages of *Daphnia* sp. ranged from 5% to 45%, with the lowest value observed in December 2020 and highest observed in February 2021. *Daphnia* sp. was not present in any of the water samples collected in March 2021. *Daphnia* sp. are sensitive to pollutants and are used as bioindicators for water pollution. There is a very strong negative correlation between monthly average abundances of *Keratella* sp. and *Daphnia* sp. (R^2 = 0.95), with the peak abundance of *Keratella* sp. coinciding with the complete absence of *Daphnia* sp. in March 2021, which may suggest increased pollution pressures during that month. However, phosphate concentrations in March 2021 did not stand out among the other sampling months. This observation may be influenced by other factors such as competition for food, light availability, temporal variations and increased predation pressures.

The overall Shannon-Biodiversity Index for each month across each sampling location can be found in *Table 3-7*. This indicates that the biodiversity index across the reservoir is of medium diversity, while low diversity was observed at WQ02 during the months of February, March, and May 2021. High diversity was also observed at WQ04 in Feb 2021.

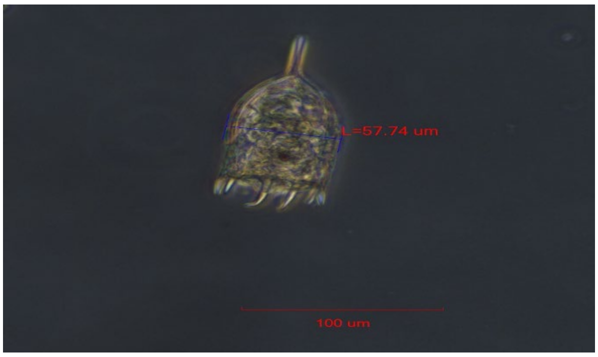


Figure 3-11: Zooplankton – Observed Under Microscopic Lens - *Keratella* sp.

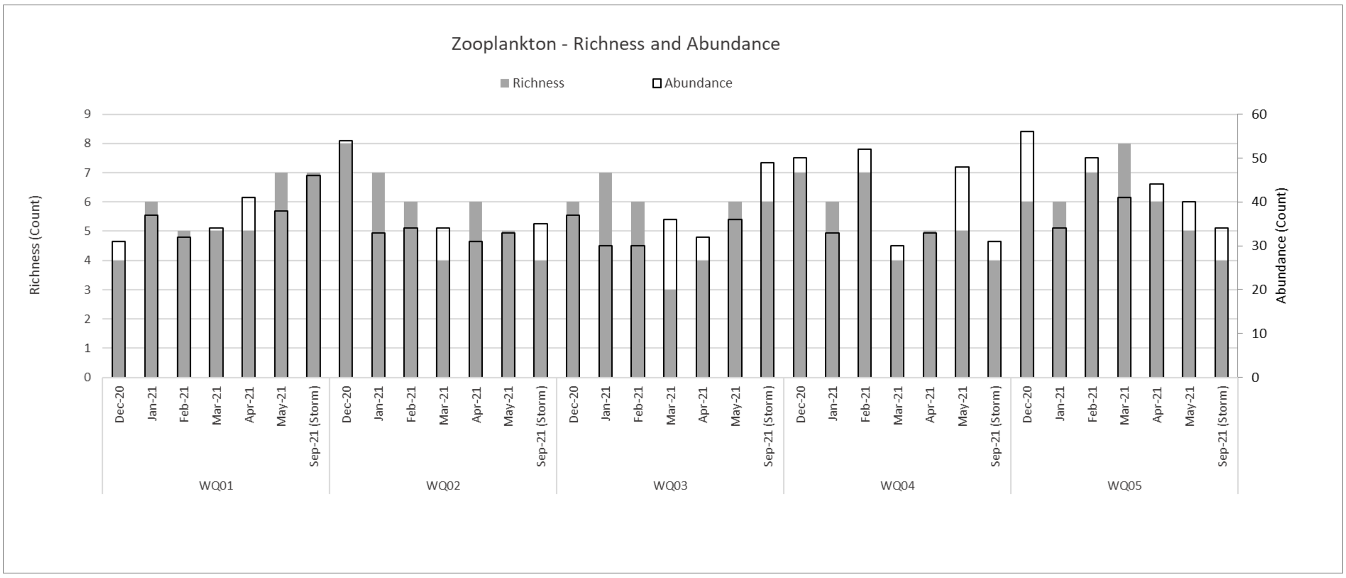


Figure 3-12: Zooplankton – Richness Versus Abundance Across Sampling Sites

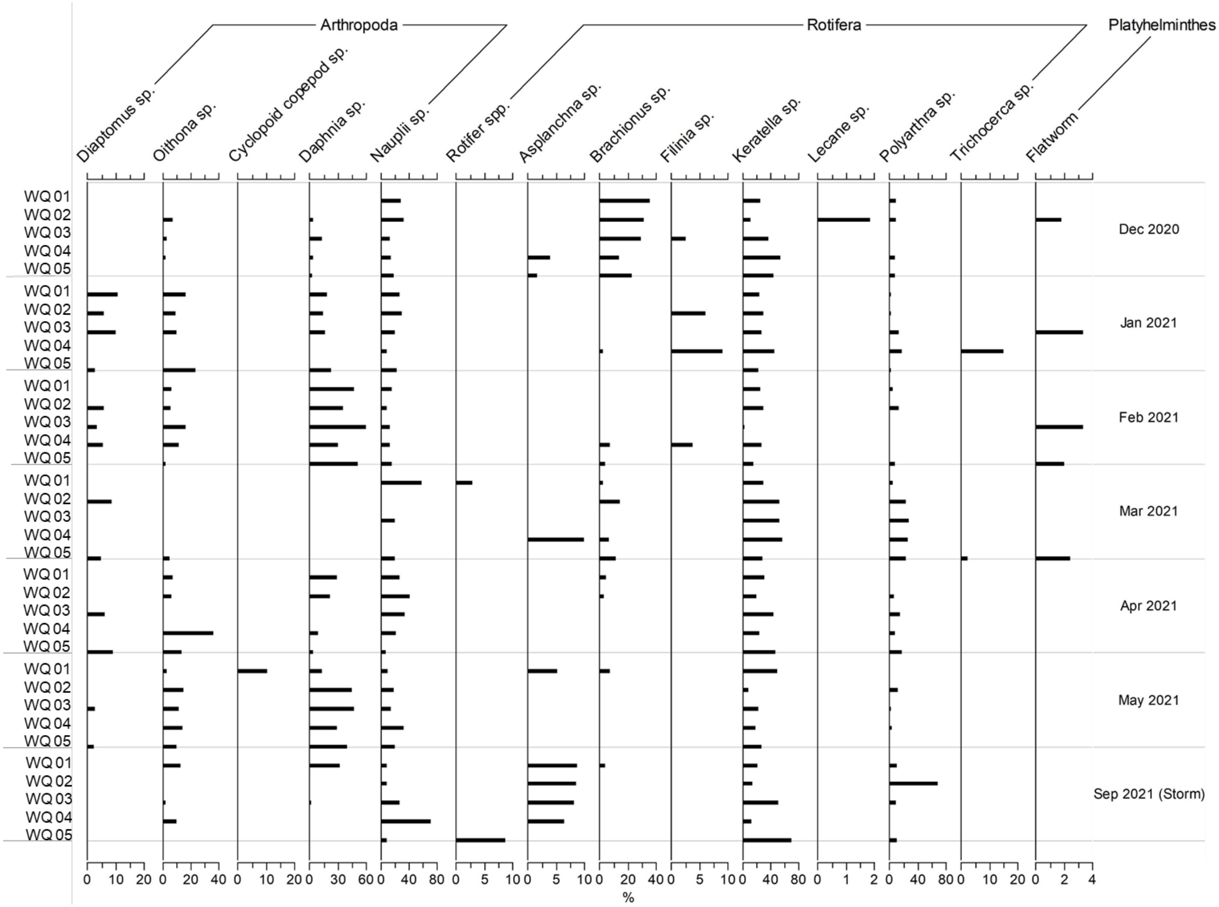


Figure 3-13: Zooplankton – Species Across Sampling Sites

Table 3-7: Zooplankton – Shannon-Biodiversity Index

	Dec 2020	Jan 2021	Feb 2021	Mar 2021	May 2021	Sep 2021 (in reservoir after storm)
	WQ01					
Shannon-Biodiversity Index	1.09	1.65	1.34	1.05	1.42	1.54
Diversity Assessment	Medium	Medium	Medium	Medium	Medium	Medium
WQ02						
Shannon-Biodiversity Index	1.66	1.59	0.71	0.83	0.81	1.36
Diversity Assessment	Medium	Medium	Low	Low	Low	Medium
WQ03						
Shannon-Biodiversity Index	1.26	1.64	1.20	1.01	1.12	1.38
Diversity Assessment	Medium	Medium	Medium	Medium	Medium	Medium
WQ04						

Shannon-Biodiversity Index	1.39	1.44	2.01	1.07	1.36	1.54
Diversity Assessment	Medium	Medium	High	Medium	Medium	Medium
WQ05						
Shannon-Biodiversity Index	1.43	1.52	1.51	1.89	1.12	1.38
Diversity Assessment	Medium	Medium	Medium	Medium	Medium	Medium

3.4.2 Phytoplankton

Between August and October 2018, plankton sampling was carried out fortnightly by Kwik et al. (2020) across 8 zones along the Kranji Reservoir shoreline, based on recommendations by PUB. A total of 7 phytoplankton phyla belonging to Cyanophyta, Bacillariophyta, Dinophyta, Chlorophyta, Chrysophyta, Euglenophyta and Xanthophyta were found across these zones and ranked by total biovolume (%), where the three most abundant algal genera were *Microcystis*, *Arthrospira* and *Pseudanabaena*. For this EIA's baseline survey, a total of 6 phytoplankton phyla belonging to Bacillariophyceae (diatoms), Cryptophyta, Chlorophyceae, Dinophyta, Euglenophyceae and Ciliata and 13 species were identified over the sampling months across 5 sampling sites located further away from the shoreline edges (*Figure 3-16).* The most abundant genera included *Aulacoseira.* (see *Figure 3-14*) which were observed to be distributed across all sites for this survey. Cyanophyta was the most abundant phyla in the phytoplankton samples collected by Kwik et al. (2020) (and reported by PUB from their routine monitoring) but it was absent from the laboratory results of water samples collected during the baseline surveys. However, Microcystin-LR and Total Microcystin (sum of congeners) detected in baseline water samples collected is an indication on the presence of Microcystis in the Kranji Reservoir. Noting there are differences in phytoplankton assemblages between these various study findings, a combination of the two approaches is therefore more appropriate for providing a better understanding of the phytoplankton assemblages present during the baseline study. To verify the findings of the EIA baseline surveys, and support the ongoing review of potential impacts of the Project on the plankton community, further plankton monitoring is proposed pre-construction, during construction and post-construction, see *Section 12* (EMMP) for further details.

Taxon richness ranged from 1 to 5 taxa while abundance of phytoplankton species ranged from 50 to 200 individuals/ mL and were observed to vary across the sampling sites throughout the sampling months (*Figure 3-15*). Monthly variability in abundance versus richness of phytoplankton types was observed between sampling locations. Higher abundance of phytoplankton species was observed in at WQ01, WQ02 and WQ05 during the months of January 2021 and February 2021 which was likely due to the time of sampling at midday.

The overall Shannon-Biodiversity Index for each month across each sampling location can be found in *Table 3-8*. The index indicated that the biodiversity index across the reservoir ranged from very low diversity to medium diversity. This indicates that while abundance of phytoplankton species may be high, the taxon variability amongst the species were considered low.

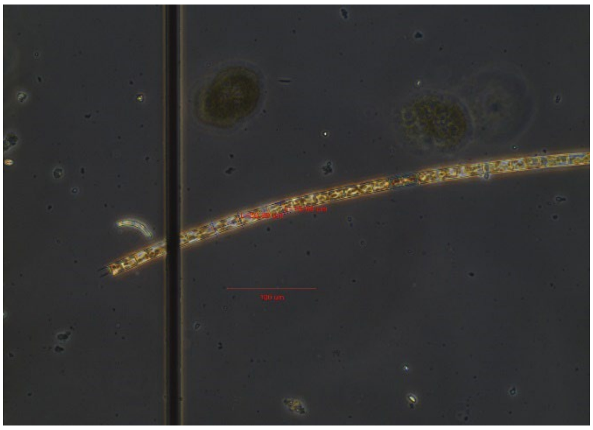


Figure 3-14: Phytoplankton – Observed Under Microscopic Lens - *Aulacoseira* sp.

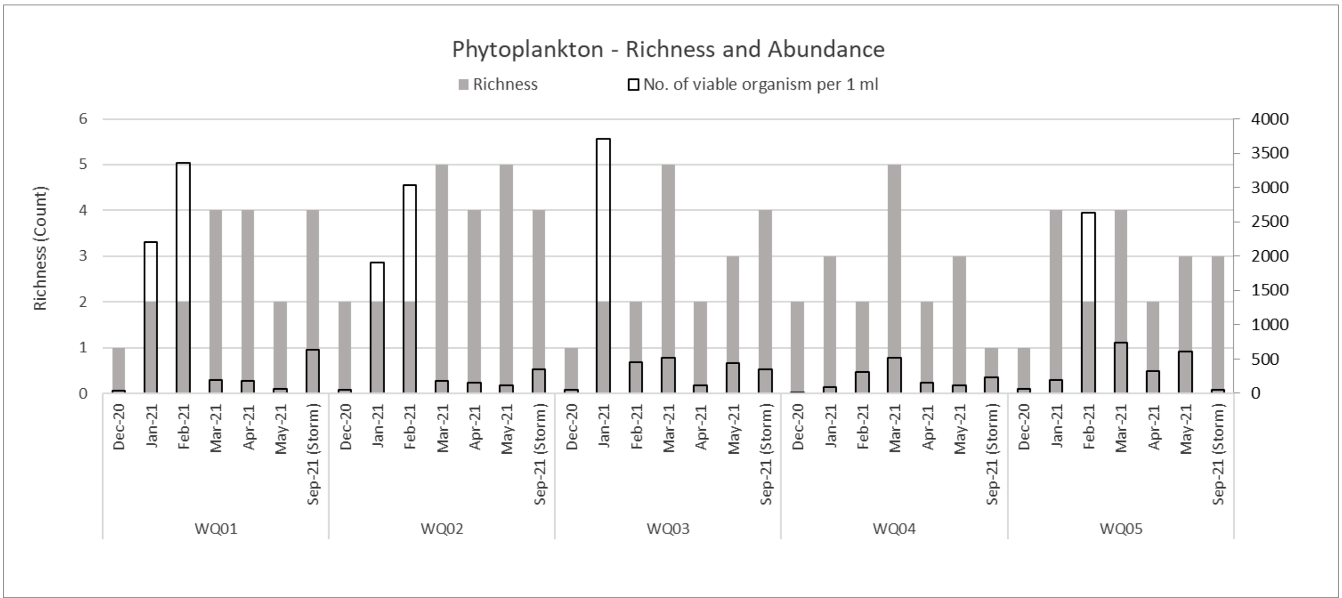


Figure 3-15: Phytoplankton – Richness Versus Abundance Across Sampling Sites

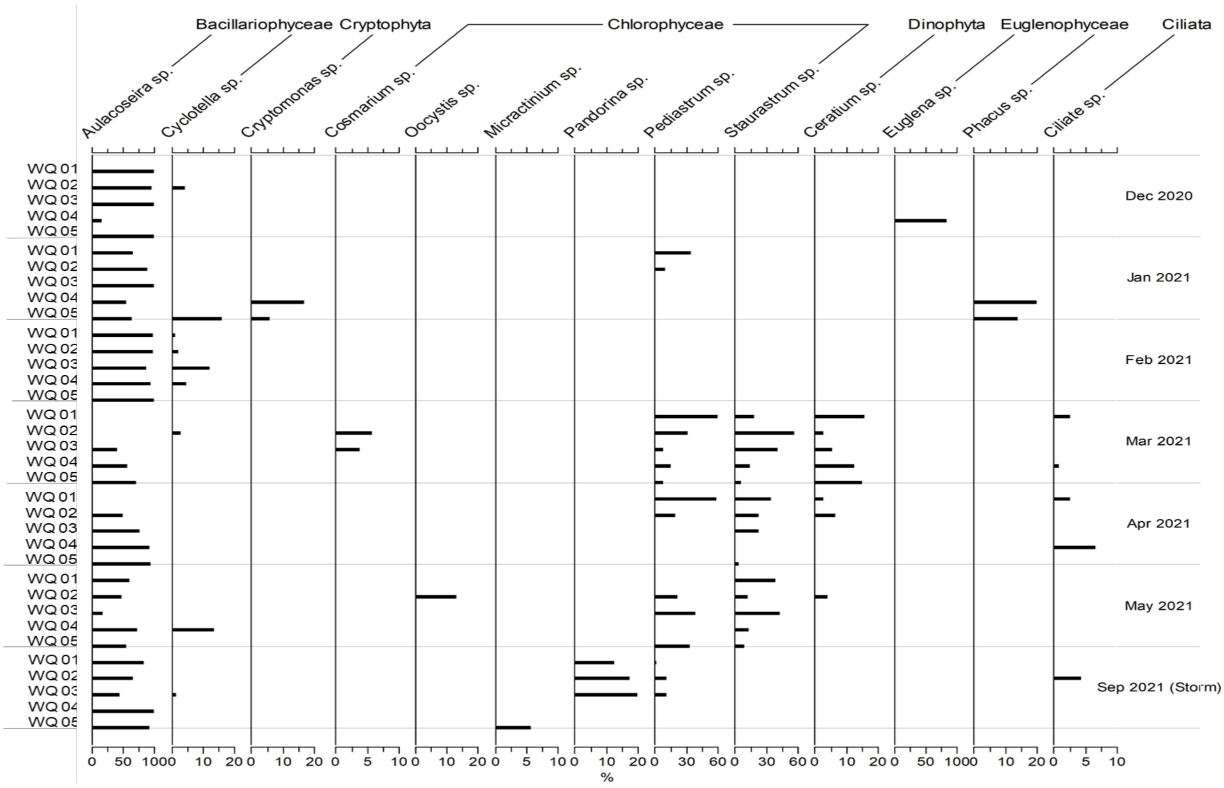


Figure 3-16: Phytoplankton – Species Across Sampling Sites

Table 3-8: Phytoplankton – Shannon-Biodiversity Index

	Dec 2020	Jan 2021	Feb 2021	Mar 2021	May 2021	Sep 2021 (in reservoir after storm)
WQ01						
Shannon-Biodiversity Index	0.00	0.65	0.05	0.99	0.87	0.67
Diversity Assessment	Very low	Low	Very low	Low	Low	Low
WQ02						
Shannon-Biodiversity Index	0.18	0.34	0.10	1.05	1.19	1.35
Diversity Assessment	Very low	Very low	Very low	Medium	Medium	Medium
WQ03						
Shannon-Biodiversity Index	0.00	0.03	0.37	1.23	0.54	1.04
Diversity Assessment	Very low	Very low	Very low	Medium	Low	Medium
WQ04						
Shannon-Biodiversity Index	0.45	0.63	0.19	1.19	0.24	0.77
Diversity Assessment	Very low	Low	Very low	Medium	Very low	Low
WQ05						
Shannon-Biodiversity Index	0.00	1.02	0.03	0.90	0.18	0.53
Diversity Assessment	Very low	Medium	Very low	Low	Very low	Low

3.5 Macroinvertebrates

3.5.1 Grab samples

A total of 3 phyla belonging to Arthropoda, Annelida and Mollusca of benthic macroinvertebrates with 11 taxa from at least 10 families were identified over the sampling months across 5 sampling sites. The families that were observed consists of Cladocera, Chaoboridae, s-f Chironominae, s-f Tanypodinae, S.O. Zygoptera Ecnomidae, Ostracoda, Oligochaeta, Unionidae, Thiaridae and Bithyniidae. A total of 629 individuals were identified and was dominated by Oligochaeta, followed by Chironominae, Chaoboridae and Tanypodinae. Mean taxonomic richness and abundance were relatively greatest in BC04 during January 2021 (*Figure 3-17*).

As compared to results for mean abundance, results for taxonomic richness were more consistent within each location, which allows for a better comparison of the biodiversity at the different sampling sites. The lowest mean taxonomic richness was observed in BC02, at 0.8 to 1.4 taxon. BC01, BC03 and BC05 have similar mean taxonomic richness, ranging from 1 – 2, 0.8 – 3 and 1.2 – 1.8 taxon respectively. BC04 generally had the highest mean taxonomic richness, ranging from 2.6 – 4.8 taxon over the three sampling events.

The abundance of benthic macroinvertebrates at BC02 was also the lowest of all sampling sites, ranging from 1.6 to 4.8 individuals retrieved per sampling event. This suggests a low biodiversity at BC02, which could be due to the depth of the location and its fluctuating oxygen levels. With depths ranging from 3.9 – 4.7 m, BC02 has the deepest depth of all sampling sites. This means that less light reaches the reservoir bed, making the conditions less favourable for vegetation growth or organic decomposition. In addition, dissolved oxygen levels at BC02 undergo large fluctuations – from 8.1 mg/L in January to 4.79 mg/L in March and 1.61 mg/L in May. Such fluctuations further made this location less favourable for benthic macroinvertebrates to inhabit. Other locations with relatively low mean abundance are BC03 and BC05, ranging from 3.4 – 10.4 and 1.6 – 10 individuals respectively. BC01 and BC04 have a relatively higher mean abundance of benthic macroinvertebrates, ranging from 4.2 – 23.8 and 6.4 – 28 individuals respectively. While BC01 and BC04 have a similar abundance of benthic macroinvertebrates, their difference in taxonomic richness suggested a different biodiversity makeup at these two locations. BC01 with the lower mean taxonomic richness, was mainly dominated by *Oligochaeta*, a taxa highly adaptable to various different sediment types (from sandy to silty), can survive in organically polluted or low oxygen environments and are useful in pollution studies (Govedich et al., 2010). In contrast, BC04 has the highest mean abundance and mean taxonomic richness. Preliminary observations suggest that this could be due to its shallow depth of 1.4 – 2.2m which allowed the accumulation of organic matter content and promoted a higher biodiversity of benthic macroinvertebrates (Graça et al., 2004).

Table 3-9 presents details and general observations from samples collected while *Table 3-10* presents observed benthic communities in their taxonomic ranks and functional feeding group (FFG), which is another classification approach that is based on behavioural mechanisms of food acquisition of the benthic communities.

Table 3-9: Macroinvertebrates (Grab) – Sample Details and Observations in Jan, Mar and May 2021

Location	Colour	Odour	Depth (m)	General observations
BC01[(a)]	Dark	Slight to no odour	3.1 to 3.3	Mostly silty, slight sandy with presence of shells
BC02[(a)]	Dark	Slight to no odour	3.9 to 4.7	Mostly silty, slightly sandy with presence of plastic materials and trash
BC03[(a)]	Dark	Slight to no odour	1.5 to 2.0	Mostly silty with presence of decomposed macrophytes, shells and woody debris
BC04[(b)]	Dark	Slight to no odour	1.4 to 2.2	Mostly silty, compacted sediment
BC05[(b)]	Dark	Slight to strong odour	1.2 to 2.3	Mostly silty, with presence of shells

Note:
(a) Locations within Reservoir Project Site
(b) Locations south of Reservoir Project Site

Table 3-10: Macroinvertebrates (Grab) – Taxonomic Ranks and Functional Feeding Guild (FFG) of the Organisms Identified in Jan, Mar and May 2021

Phylum	Class	Order	Family	Functional Feeding Group (FFG)
Arthropoda	Branchiopoda	Cladocera	Cladocera	Scrapers
	Insecta	Diptera	Chaoboridae	Predators & filtering collectors
			s-f Chironominae	Gathering & filtering collectors
			s-f Tanypodinae	Predators
		Odonata	S.O. Zygoptera	Predators
		Trichoptera	Ecnomidae	Predators & gathering collectors
	Ostracoda	Ostracoda	Ostracoda	Filtering collectors
Annelida	Clitellata	Oligochaeta	Oligochaeta	Gathering collectors
Mollusca	Bivalvia	Unionida	Uniondae	Filtering collectors
	Gastropoda	Neotaenioglossa	Thiaridae	Scrapers
		Littorinimorpha	Bithyniidae	Scrapers

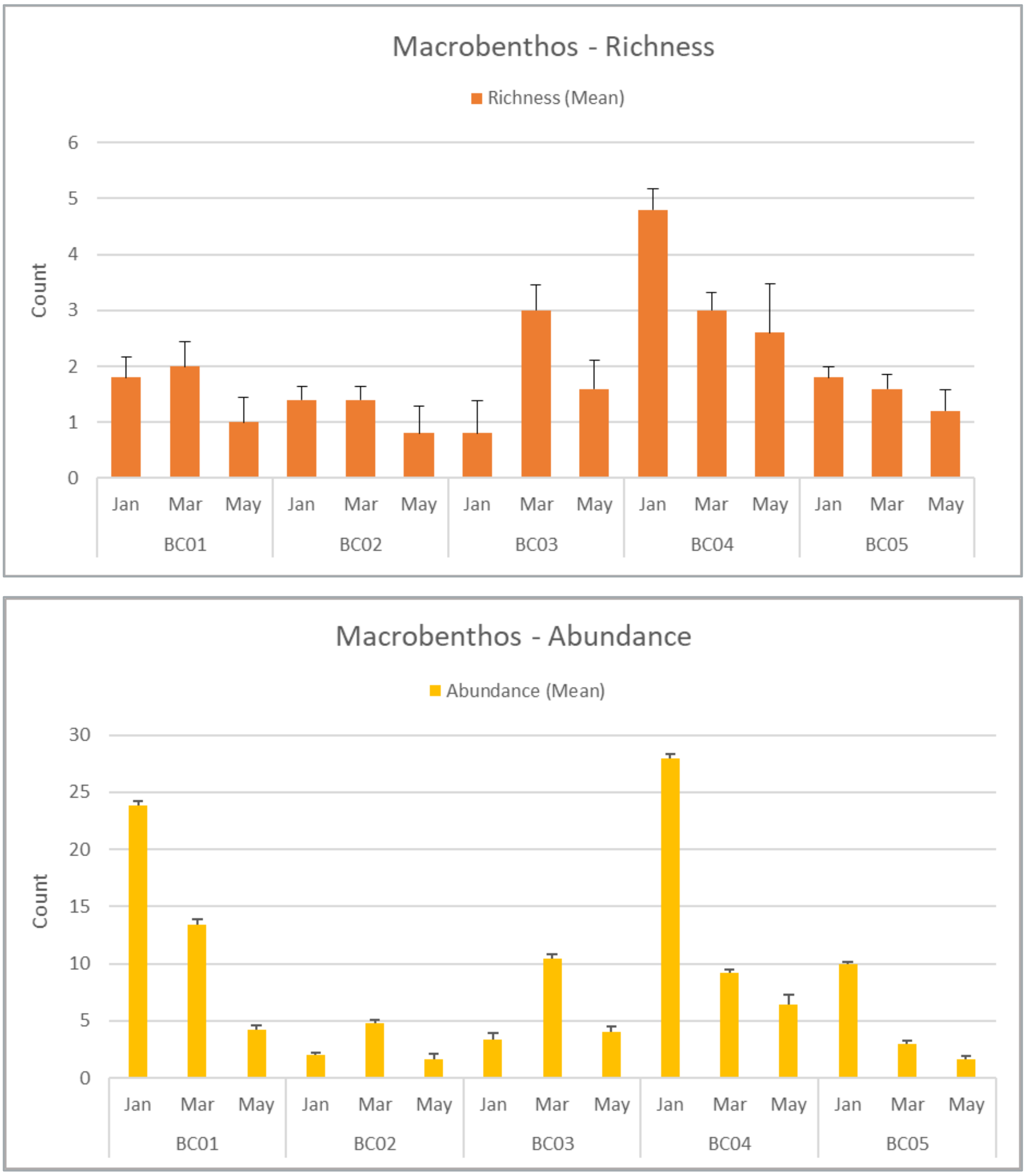


Figure 3-17: Macroinvertebrates (Grab) – Taxonomic Richness and Mean Abundance Across Triplicates at Each Location

Percentage Functional Feeding Group (FFG) was also presented to provide an understanding of the ecological interactions at the various locations (*Figure 3-18, Figure 3-19*). The major functional feeding groups observed were collectors, shredders, predators and scrapers. Scrapers feed on algae while collectors feed on fine particulate organic matter. The two modes of collectors are filtering and gathering – filtering collectors take in fine particulate organic matter through the water column while gathering collectors take in fine particulate organic matter from the reservoir bed. Shredders break down leaf litter and other coarse particulate organic matter while predators feed on the other consumers.

The number of different FFGs observed across the sampling sites varied from 5 to 7. However, the FFGs found consistently across all sampling are predators, predators and filtering collectors, gathering and filtering collectors, and scrapers, with the dominant FFG observed as collectors. This suggested that fine particulate organic matter was consistently available as the main food source within the reservoir, as compared to algae, coarse particulate organic matter or the presence of other consumers. Where other consumers can be found, predators will follow and can thus be found throughout the water body as well.

While the most represented FFG across all locations is collectors, shredders were not found at any of the five locations, suggesting a lack of coarse particulate organic matter throughout the reservoir. Presence of scrapers was observed only in certain sampling months at BC01, BC03, BC04 and BC05, but were found at BC04 throughout the sampling months. This suggests a significant presence of algae as food source at this location. BC04 generally has the highest number of FFGs. Those that were consistently observed over the three sampling events were predators, gathering collectors, gathering/filtering collectors and scrapers. Predators make up a small proportion ranging from 3% - 35% across all locations except at BC05 where it made up of 73.3%. It should be kept in mind that BC05 has a lower abundance of macroinvertebrates observed, hence the high percentage of 73.3% might be skewed.

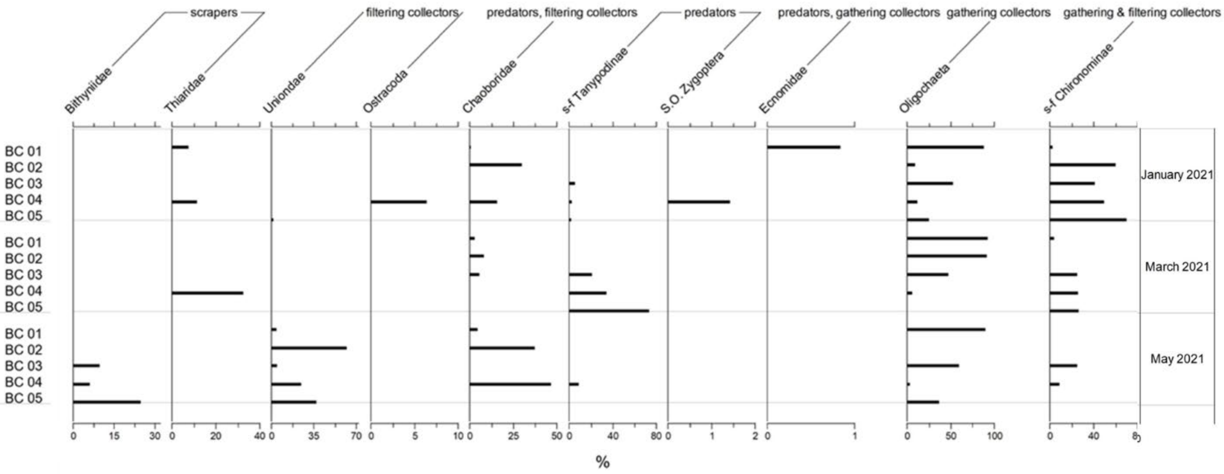


Figure 3-18: Macroinvertebrates (Grab) – FFG Classification

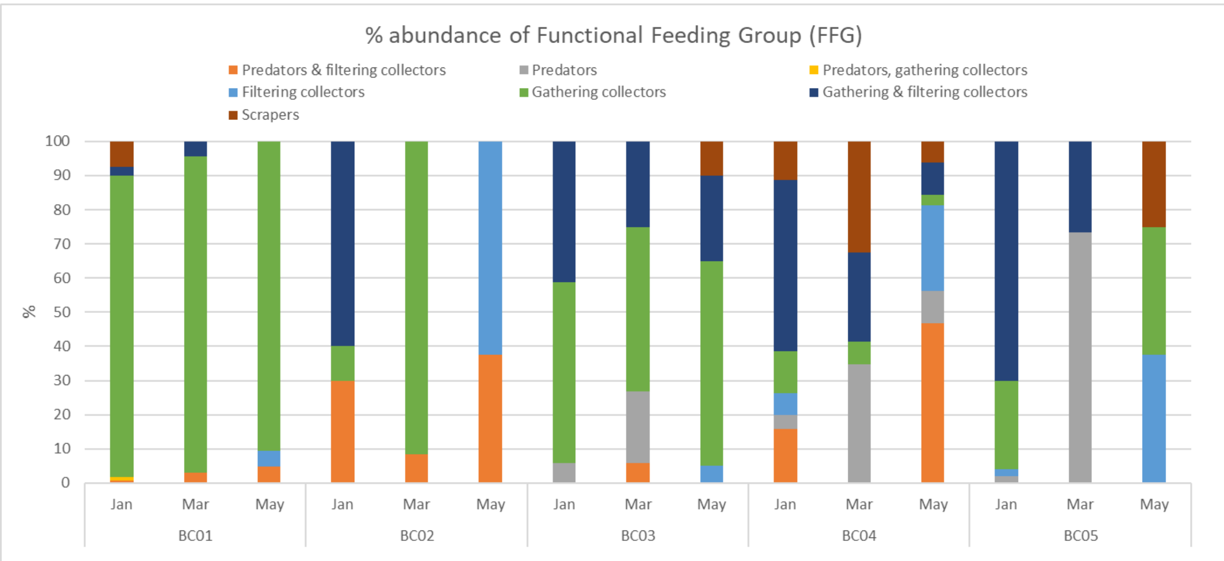


Figure 3-19: Macroinvertebrates (Grab) – Percentage FFG

3.5.1.1 Multivariate Analysis

Further analysis was conducted using Primer 6 and PERMANOVA+ software, versions 6.1.18 and 1.0.8 respectively. Abundance, richness and assemblage of benthic macroinvertebrates from each replicate at the 5 locations were first transformed with log(x+1) function to allow for better comparison of the data. Resemblance matrices using Euclidean distance were created for abundance and richness while Bray Curtis similarity was used to create resemblance matrix for assemblage data. PERMANOVA was then conducted to find out if differences among the locations are significant (i.e. p-value < 0.05).

With a degree of freedom of 4, p-value for PERMANOVA of abundance, taxonomic richness and assemblage data are 0.0001, 0.0004 and 0.0001 respectively for January samples, 0.0371, 0.0118 and 0.0001 respectively for March samples and 0.4419, 0.4392 and 0.0291 respectively for May samples. To further probe into these differences, a pair-wise test was conducted amongst locations, comparing each location as presented in (*Table 3-11*).

For abundance of macroinvertebrates, locations with significant differences for two of the three sampling events were between BC01 and BC02, BC01 and BC05, and BC04 and BC05. Locations with significant differences for only one of the three sampling events were between BC01 and BC03, BC02 and BC04, BC02 and BC05 and between BC03 and BC04. For taxonomic richness locations with significant differences for two of the three sampling events were between BC02 and BC04, as well as between BC04 and BC05. Locations with significant differences for only one of the three sampling events were between BC01 and BC04, BC02 and BC03, and between BC03 and BC04. For assemblage data, all locations were significantly different from each other for at least one sampling event. Those with significant differences for only one sampling event are between BC01 and BC02, BC01 and BC03, and between BC03 and BC05. Those with significant difference for two sampling events are between BC01 and BC04, BC01 and BC05, BC02 and BC03, BC02 and BC04, BC02 and BC05, BC03 and BC04, and between BC04 and BC05.

It should be highlighted that BC04 and BC05 were significantly different from each other in terms of abundance, taxonomic richness and assemblage, for both January and March samples. Of all the permutations, these two locations had the highest occurrence of significant differences, suggesting that the composition of benthic macroinvertebrates retrieved at these two locations have the biggest contrast from one another. Similarly, significant differences were found between BC02 and BC04 – for abundance in January, and taxonomic richness and assemblage in March. This suggested that BC02 and BC04 have significantly different populations of benthic macroinvertebrates. However, BC03 and BC05 only have significant differences in March for assemblage data therefore suggesting that these two locations have similar composition of benthic macroinvertebrates.

It is noted that there were no significant differences between all the locations for abundance, taxonomic richness and assemblage in May samples, except for the permutation of BC02 and BC03 for assemblage data.

Table 3-11: Macroinvertebrates (Grab) – Pair-Wise Test for Abundance, Taxonomic Richness and Assemblage Data

Permutation	P-values - abundance			P-values - taxonomic richness			P-values - assemblage		
	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May
BC01, BC02	**0.0067**	**0.0212**	0.4394	0.6852	0.4456	1	**0.0185**	0.082	0.2082
BC01, BC03	**0.0153**	0.4308	0.8308	0.1459	0.1941	0.5744	0.0553	**0.0088**	0.3830
BC01, BC04	0.529	0.4197	0.5738	**0.0067**	0.2018	0.2417	**0.0259**	**0.0074**	0.1384
BC01, BC05	**0.0281**	**0.0092**	0.6150	1	0.6825	0.9072	**0.0248**	**0.0107**	0.4787
BC02, BC03	0.9749	0.4418	0.1987	0.2351	**0.0493**	0.4014	0.3233	**0.0086**	**0.0322**
BC02, BC04	**0.0071**	0.1225	0.1736	**0.0075**	**0.0246**	0.1416	**0.008**	**0.0085**	0.2330
BC02, BC05	**0.0163**	0.1492	0.7678	0.5268	1	0.5249	**0.009**	**0.008**	0.3151

Permutation	P-values - abundance			P-values - taxonomic richness			P-values - assemblage		
	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May
BC03, BC04	**0.0081**	0.8292	0.6622	**0.0075**	1	0.5390	**0.0066**	**0.0074**	0.0572
BC03, BC05	0.0756	0.14	0.2650	0.0926	0.079	0.8146	0.0576	**0.0086**	0.1616
BC04, BC05	**0.018**	**0.0311**	0.2235	**0.008**	**0.0302**	0.3666	**0.009**	**0.0092**	0.1431
*Notes: **bold** represents significant difference values of p<0.05.*									

To further visualise the differences between each location, the assemblage data of the benthic macroinvertebrates was used to create non-metric Multi-Dimensional Scaling graphs *(Figure 3-20*). Sites with overlapping boundaries suggest that those sites have some similarities, while sites that form distinct clusters have rather unique assemblages. From the January graph (top in *Figure 3-20*), it was observed that all sites except BC04 form overlapping clusters, suggesting a rather unique assemblage of benthic macroinvertebrates only at BC04. In March (middle in *Figure 3-20*), all sites form rather distinct clusters, except for BC01 and BC02 which had overlapping clusters. BC03, BC04 and BC05 likely have rather unique assemblages, unlike BC01 and BC02, for the sampling event in March. In May, the assemblage between the different sites grew more alike, resulting in multiple overlaps and only a clear distinction between BC02 and BC03.

Over the three sampling events, BC04 appears to have the most unique assemblage, although less obvious in May. None of the other locations stood out as much.

To further investigate which organism was responsible for the dissimilarity, a SIMPER test (Similar Percentages – species contributions) was conducted. Results of this test can be found in *Table 3-12* where taxa contributing to the dissimilarity were arranged according to their contributing percentage.

Oligochaeta was found in BC01 and BC03, contributing the highest percentage and consistently over the three sampling events. Tolerant to organic pollution, this taxon can be found in all locations. The other taxon commonly found in all locations is *the s-f Chironominae* – observed to be contributing a high percentage in January at 90.87% in BC02 and 93.82% in BC05. However, this taxon did not consistently dominate any sampling location over the three sampling events and was also found contributing at a lower percentage in all other locations, ranging from 8.19 % to 44.52%.

BC02, BC04 and BC05 generally do not have a clear dominant taxon. The number of taxa contributing to the dissimilarity in BC02 and BC05 is one or two species while at BC04, the number of taxa is split between at least three species.

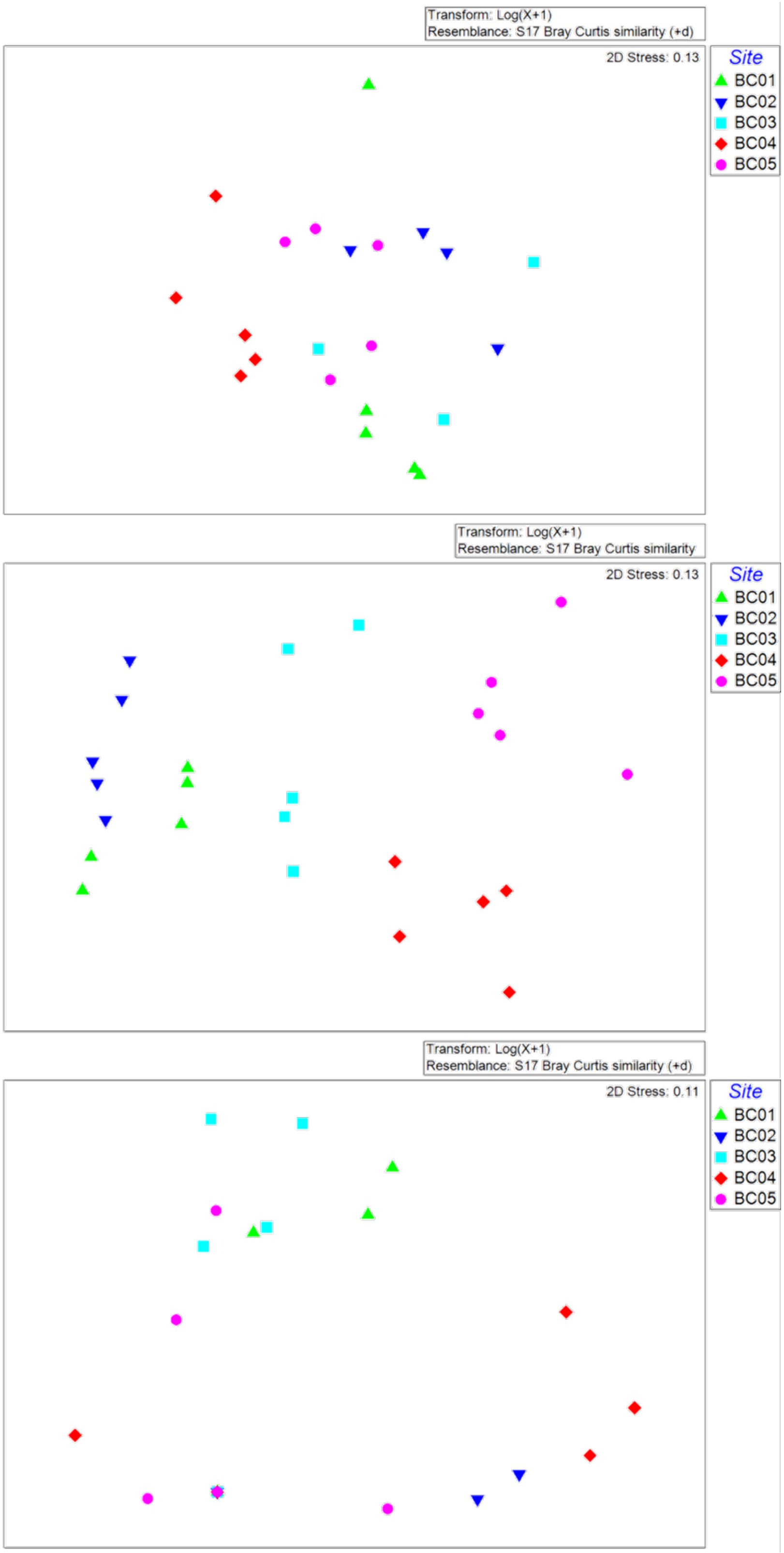


Figure 3-20: Macroinvertebrates (Grab) – Assemblage 2D graphs (from top to bottom: Jan, Mar and May 2021)

Table 3-12: Macroinvertebrates (Grab) – Highest Contributing Species to Dissimilarity Test

	January		March		May	
Location	**Species**	**Contributing %**	**Species**	**Contributing %**	**Species**	**Contributing %**
BC01	*Oligochaeta*	96.86	*Oligochaeta*	88.13	*Oligochaeta*	100
			s-f Chironominae	8.19		
BC02	*s-f Chironominae*	90.87	*Oligochaeta*	95.25	*Ostracoda*	61.31
					Chaoboridae	38.69
BC03	*Oligochaeta*	100	*Oligochaeta*	52.77	*Oligochaeta*	89.67
			s-f Tanypodinae	23.02	*s-f Chironominae*	10.33
			s-f Chironominae	22.18		
BC04	*s-f Chironominae*	44.52	*Thiaridae*	50.23	*Chaoboridae*	40.55
	Chaoboridae	19.41	*s-f Tanypodinae*	24.06	*Ostracoda*	29.73
	Thiaridae	16.75	*s-f Chironominae*	23.3	*s-f Tanypodinae*	22.33
	Oligochaeta	13.15				
BC05	*s-f Chironominae*	93.82	*s-f Tanypodinae*	76.69	*Oligochaeta*	100
			s-f Chironominae	20.31		

3.5.1.2 Diversity Indices

A summary table of the indices used to assess the ecological health of the reservoir is presented below in *Table 3-13*, while the following on Shannon-Biodiversity Index provides detailed analysis of the indices used.

Table 3-13: Macroinvertebrates (Grab) – Overall Summary of Indices Scores

Month	BC01[(a)]	BC02[(a)]	BC03[(a)]	BC04[(b)]	BC05[(b)]
Shannon-Biodiversity Index					
January	0.95 (Low)	0.96 (Low)	1.02 (Medium)	1.86 (Medium)	1.37 (Medium)
March	0.37 (Very Low)	0.27 (Very Low)	1.09 (Medium)	1.29 (Medium)	0.51 (Low)
May	0.79 (Low)	0.59 (Low)	1.29 (Medium)	1.76 (Medium)	1.42 (Medium)

Note:
(a) Locations within Reservoir Project Site
(b) Locations south of Reservoir Project Site

Shannon-Biodiversity Index

The Shannon-Biodiversity Index assesses the benthic community composition and takes into account the relative abundance of species that are present in the community. The Shannon-Biodiversity Index ranged from very low diversity to medium diversity across all locations for all sampling events, with indices ranging from 0.38 to 1.86 (see *Table 3-14*). BC01 and BC02 observed very low to low diversity while BC03, BC04 and BC05 typically observed medium diversity except for the sampling event in March at BC05 which observed a low diversity.

The Shannon-Biodiversity indices at BC01 and BC02 were similar ranging from very low to low diversity assessment.

Both sampling sites typically have deeper depths of up to 4.7 m compared to the shallower depths at the other sampling sites. This supports earlier observations of a reduced benthic macroinvertebrate density with increasing depths.

Medium diversity assessments were observed at BC03 and BC04 for all sampling events. The range of indices for BC03 was 1.02 to 1.29 while indices at BC04 were observed to be slightly higher at 1.29 to 1.86. Medium diversity was observed at BC05 for the months of January and May 2021; however, a low diversity was observed in March 2021. The mean abundance and mean taxonomic richness at BC05 in March 2021 were observed at 1.6 individuals and 1.8 counts respectively – the composition and abundance were not considered diverse. This change in diversity assessment could be a result of the change in rainfall intensity (Tumwesigye et al., 2000) in the months of March 2021 and May 2021 - the monthly rainfall being 282.8 and 88.8 mm, respectively. Heavy rainfall typically results in high discharge into the reservoir, where large amounts of stones and pebbles carried by the rain/ storm water can wash away benthic macroinvertebrates. This could support the low diversity observed at BC05 as the sampling location is located at the junction of 3 tributaries (Sungei Tengeh, Sungei Kangkar and Sungei Peng Siang) feeding into the reservoir. With the reduced average rainfall in May 2021, it was likely that the benthic environment was left to stabilise thereby promoting growth and hence a medium diversity assessment was observed in May 2021.

Table 3-14: Macroinvertebrates (Grab) – Shannon-Biodiversity Index

	BC01[a]	BC02[a]	BC03[a]	BC04[b]	BC05[b]
	January 2021				
Shannon-Biodiversity Index	0.95	0.96	1.02	1.86	1.37
Diversity Assessment	Low	Low	Medium	Medium	Medium
	March 2021				
Shannon-Biodiversity Index	0.37	0.27	1.09	1.29	0.51
Diversity Assessment	Very Low	Very Low	Medium	Medium	Low
	May 2021				
Shannon-Biodiversity Index	0.79	0.59	1.29	1.76	1.42
Diversity Assessment	Low	Low	Medium	Medium	Medium

Notes:
(a) Locations within Reservoir Project Site
(b) Locations south of Reservoir Project Site

3.5.2 Sweep Sampling and Colonisers

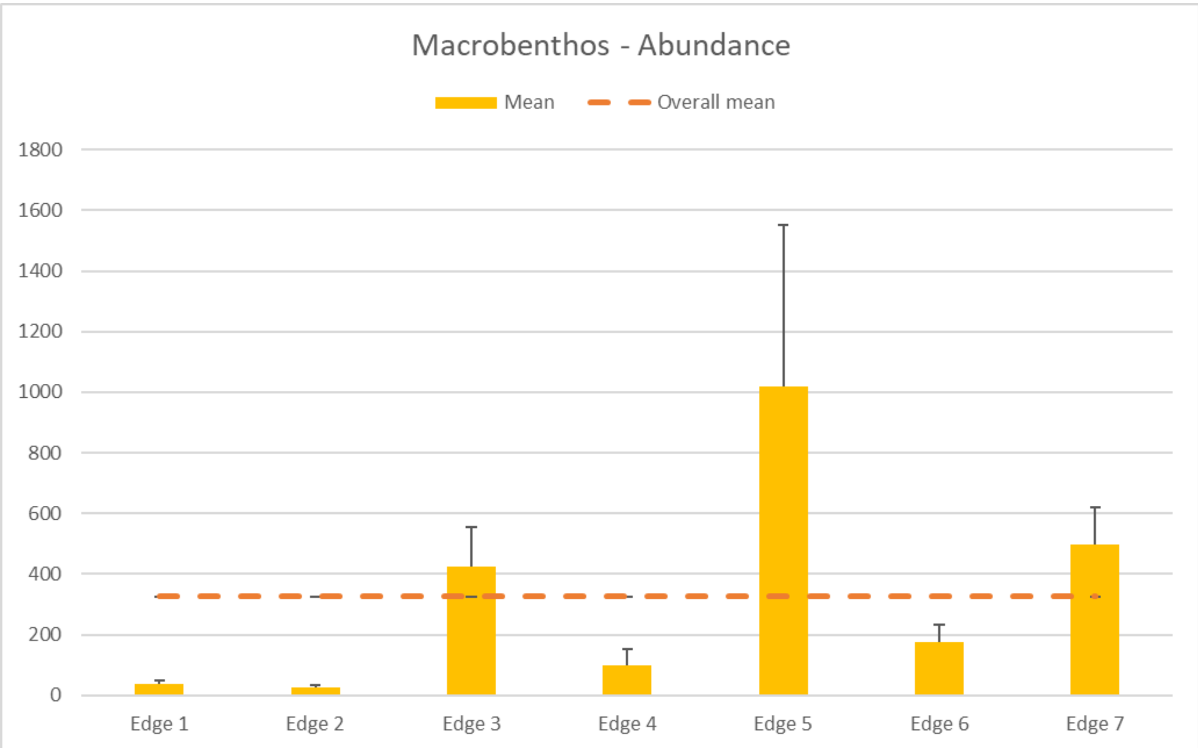
During sampling, it was noted that vegetation along Edges 1 and 2 only consist of grass patches that appear to be regularly maintained (*Figure 3-21*). Bottom substrate composition at these two sites was dominated by rocks and pebbles. Edges 3 to 7 comprised of dense riparian vegetation, some with overhanging tree cover (*Figure 3-21*). Detritus, periphyton and mud were typical bottom substrate in these sampling areas.

Figure 3-21: Vegetation in Edge 1 – 7 and Colonisers Sampling

3.5.2.1 Sweep Sampling Results

Univariate Analysis

A total of 17 phyla and 41 families were identified over the sweep sampling events conducted in May 2022, with a total of 6,828 individuals recorded (*Appendix A*). Mean taxon richness of each sampling site ranged from 5 to 16.3 while mean abundance of each sampling site ranged from 25.3 to 1,018 (*Figure 3-22*). Highest mean abundance and richness was found at Edge 5 and the lowest at Edge 2. For mean richness, Edges 3, 5, 6 and 7 were higher than the overall mean but only Edges 3, 5 and 7 had higher mean abundance than the overall mean.



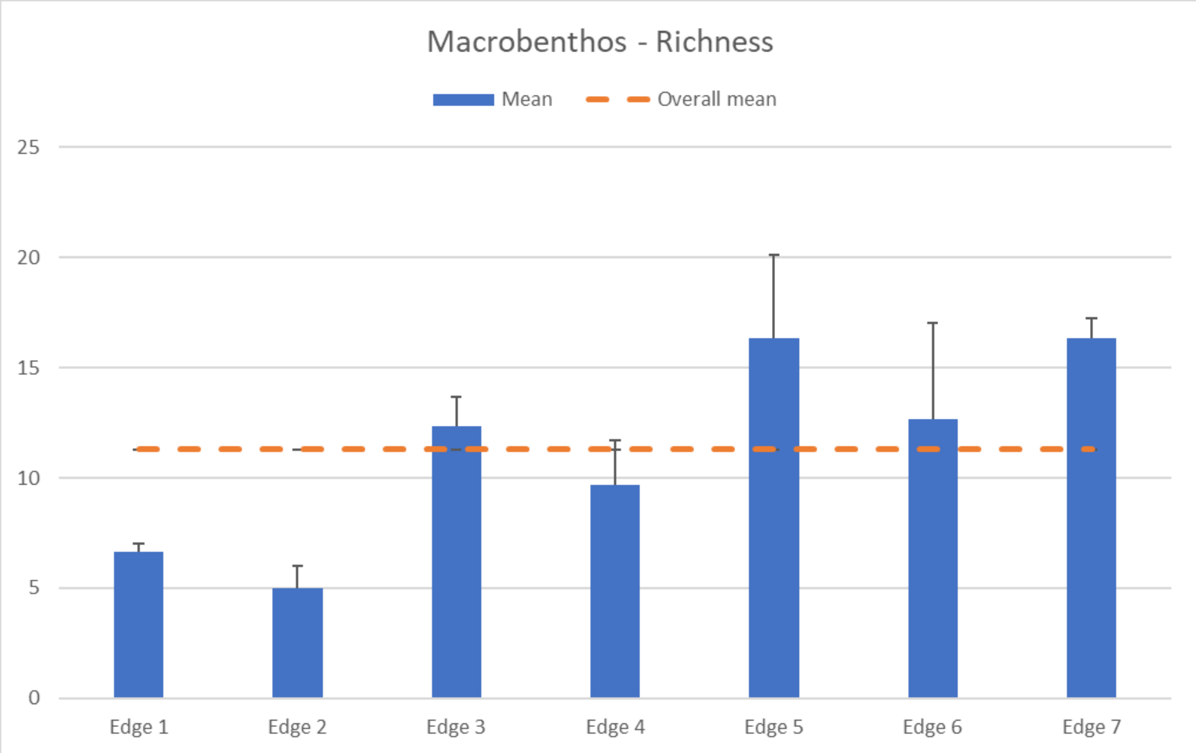


Figure 3-22: Macroinvertebrates (Sweep) – Mean and Standard Error of Abundance and Richness

Percentage functional feeding group (FFG) are also presented to provide an understanding of the ecological interactions and food web dynamics at the various locations. The major FFGs observed were scrapers, collectors, shredders and predators (see *Figure 3-23*). As also described above, scrapers feed on algae while collectors feed on fine particulate organic matter. The two modes of collectors are filtering and gathering – filtering collectors take in fine particulate organic matter through the water column while gathering collectors take in fine particulate organic matter from the reservoir bottom. Shredders break down leaf litter and other coarse particulate organic matter while predators feed on the other consumers.

The number of FFGs observed across the sampling sites varied from 5 to 13 but for visual clarity, groups with sum of less than 5% proportion were excluded from the graph (*Figure 3-24*). There was a consistent finding of FFGs across all sampling sites, included shredders and scrapers, scrapers, filtering collectors, and predators, filtering and gathering collectors.

The most represented FFG across all locations is filtering collectors, which composed of micro-crustaceans such as Conchostraca, Copepoda and Ostracoda. Their percentage proportion ranged from 29.4 – 82.8%. Scrapers were also consistently found in all sites and were mainly composed of snails and the micro-crustacea Cladocera. Their percentage FFG ranged from 5.24 – 42.3%. This was followed by shrimps (Family: Atyidae) with the FFG of predators, filtering and gathering collectors, with proportions ranging from 1.01 – 29.9% across all sweep sampling sites. Shredder-scrapers, composed of the family Ampullariidae, made up a proportion ranging from 0.13 – 18.3%.

Filtering collectors were most abundant across all sites, suggesting the availability of fine particulate organic matter (FPOM). It is noteworthy to mention that the filtering collectors (micro-crustacea) found are a common food source for upper trophic levels, explaining their extremely high numbers and reflecting a possible bias in this observation. In countering this bias, the next most abundant and widespread FFG is considered, which belongs to the predators, gathering and filtering collectors' group, followed by the FFG scrapers. Given their widespread distribution and abundance across the reservoir, the FFG scrapers may be used as an indication of sites experiencing acidification. Their proportion is expected to decrease at organically-polluted sites as they are sensitive to organic pollution (Rawer-Jost et al., 2000).

Predators, consisting of taxa like spiders, leeches, damselfly and dragonfly nymphs, beetles and water bugs, were found in Edges 3 to 7 but not in Edges 1 and 2. A similar trend observed at these sites was the amount of vegetation in the area, hence it is possible that the presence of predators are linked to the presence of moss (Heino, 2000). With an abundance of moss, scrapers are attracted to these areas which in turn act as prey for the predators. It has also been suggested that moss flora introduces an intermediate amount of environmental disturbance that encourages species richness (Vuori et al., 1999), subsequently attracting more prey for the predators.

The presence of FFG shredders in this set of surveys, as compared to its complete absence throughout the grab sampling surveys, could be due to the different variety of habitats found at the different sampling sites. Sampling sites for this round of survey were at the edge-surface water interface while those of the first survey were at least 1m underwater. The edge-surface interface is favoured by shredders since a higher concentration of its food source – dead leaves and fine particulate organic matter – would be found there.

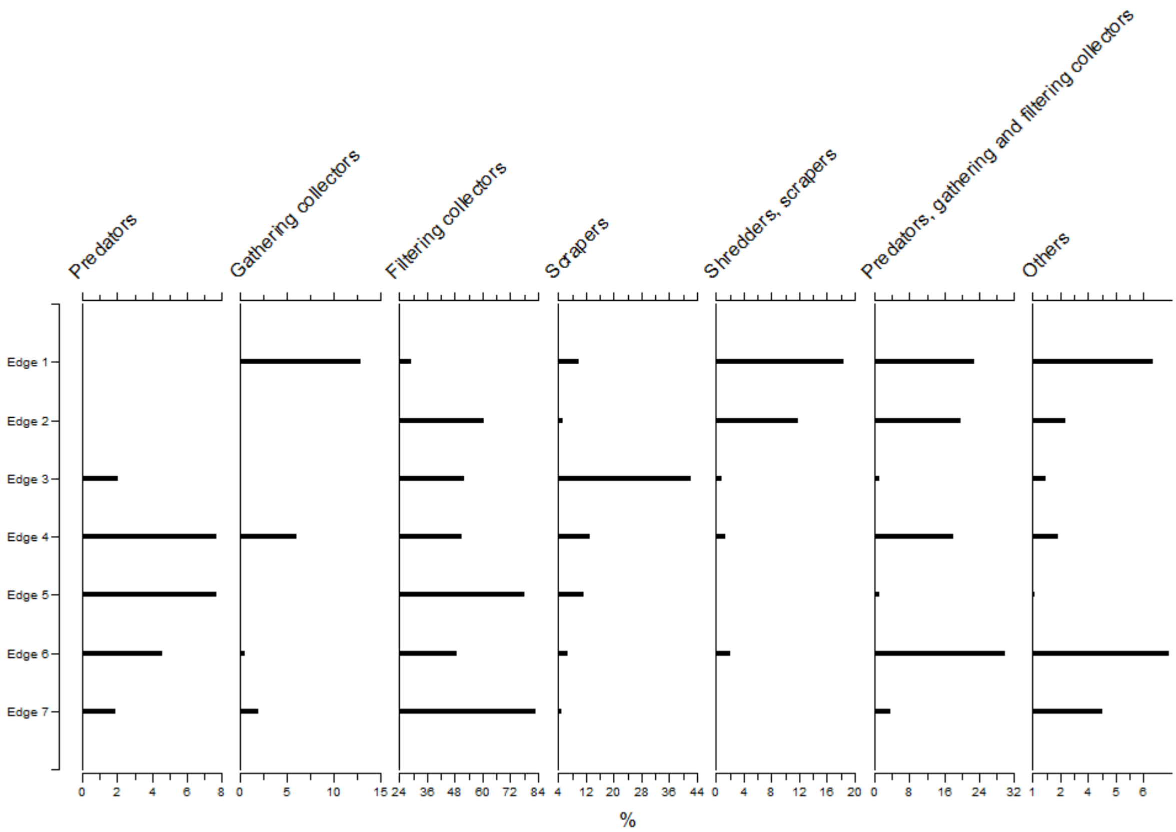


Figure 3-23: Macroinvertebrates (Sweep) – FFG classification

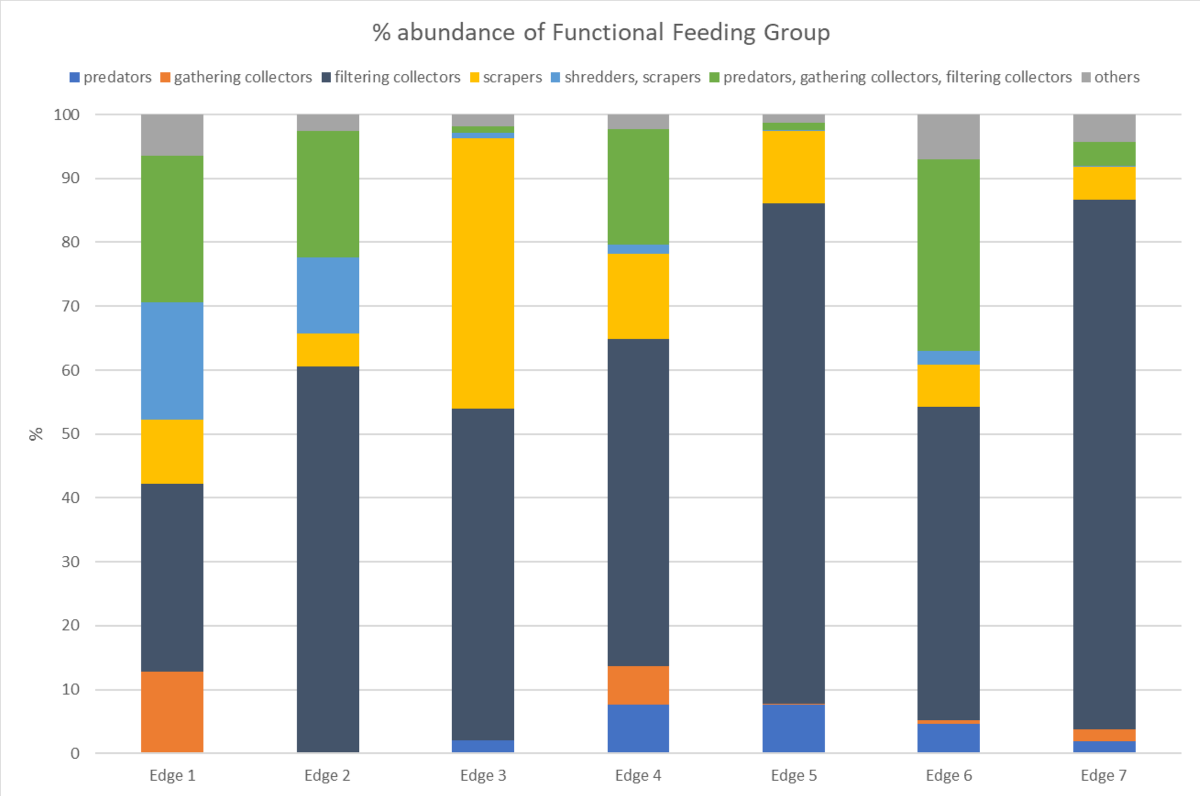


Figure 3-24: Macroinvertebrates (Sweep) – Percentage FFG

Multivariate Analysis

Further analysis was conducted using Primer 6 and PERMANOVA+ software, versions 6.1.18 and 1.0.8 respectively. Abundance, richness and assemblage of benthic macroinvertebrates of the seven locations were first transformed with log(x+1) function to allow for better comparison of the data (*Figure 3-25)*. Resemblance matrices using Euclidean distance were created for abundance and richness while Bray Curtis similarity was used to create resemblance matrix for assemblage data. PERMANOVA was then conducted to find out if differences among the locations are significant (i.e. p-value < 0.05).

With a degree of freedom of 6, p-value for PERMANOVA of abundance, taxonomic richness and assemblage data are 0.0015, 0.0269 and 0.0001 respectively. To further probe into these differences, pair-wise tests were conducted for all three parameters, but no significant differences were found between specific sites.

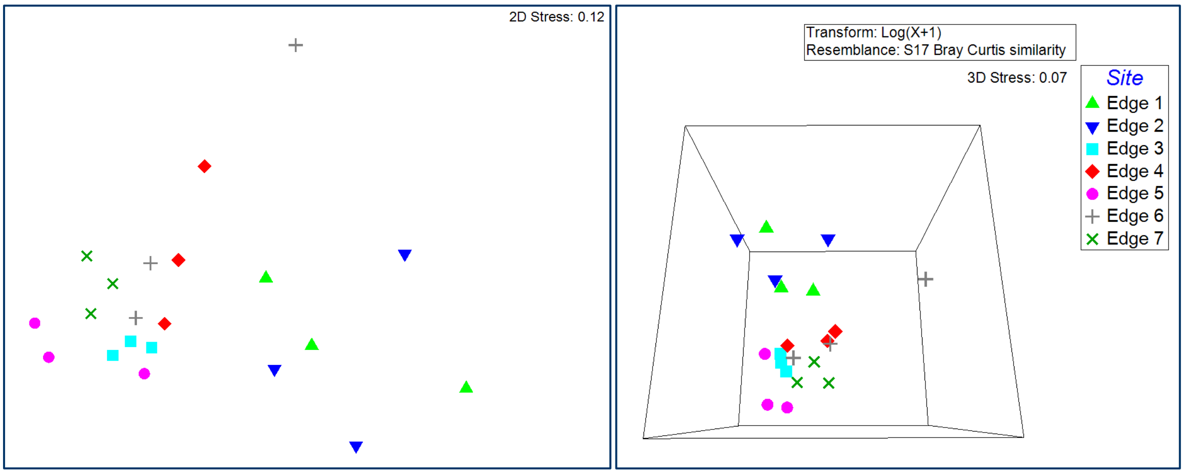


Figure 3-25: Macroinvertebrates (Sweep) – Assemblage 2D (left) and 3D (right) graphs

The different sample sites appear to be rather similar, so a SIMPER test was conducted to further investigate the common families across Kranji Reservoir's edges. Cut off for cumulative contribution was set at 70% for more concise reporting. Results of this test can be found in (*Table 3-15*), where families that contribute to the similarity are arranged from the highest to lowest percentage.

The highest contributing taxa between Edges 4, 5 and 7 is Ostracoda, ranging from 21.27 – 30.1%. This taxa also had a relatively high contributing percentage at Edges 1, 3 and 6 with at least 10.56%. A similar trend was observed for Atyidae, which was the highest contributing taxa at Edges 1 (21.29%) and 6 (40.29%). At all other sites, Atyidae contributed a range of 7.14 – 30.21% to the similarity. Another crustacea with a high contributing percentage is Copepods, with a range of 9.2 – 36.63% in six out of the seven sampling sites and was the highest contributing at Edges 1 and 2. These numbers highlight the abundance and widespread distribution of these three taxa in Kranji Reservoir.

Table 3-15: Macroinvertebrates (Sweep) – Highest Contributing Species from SIMPER Test

Location	Taxa	Contributing %	Location	Taxa	Contributing %
Edge 1	**Atyidae**	**21.29**	Edge 5	**Ostracoda**	**21.27**
	Copepoda	**21.29**		Cladocera	16.17
	Oligochaeta	16.51		Helotrephidae	16.12
	Ostracoda	16.51		Copepoda	15.28
Edge 2	**Copepoda**	**36.63**		Atyidae	7.14
	Atyidae	30.21	Edge 6	**Atyidae**	**40.29**
	Ampullariidae	20.96		Amphipoda	12.55
Edge 3	**Cladocera**	**23.16**		Ostracoda	10.56
	Ostracoda	21.8		Copepoda	9.2
	Copepoda	18.99	Edge 7	**Ostracoda**	**24.55**
	Helotrephidae	8.61		Atyidae	12.66
Edge 4	**Ostracoda**	**30.1**		Copepoda	10.55
	Atyidae	24.97		Cladocera	8.66
	Helotrephidae	19.37		Acarina	7.91
				Helotrephidae	7.37

Diversity indices

Shannon-Biodiversity Index

Shannon-Biodiversity Index was applied to the assemblage data across the sweep samples, contributing to a broader understanding of ecological conditions in Kranji Reservoir. Across the sweep samples, biodiversity of macrobenthos were assessed to be medium, with scores ranging from 1.023 to 1.960. The lowest score was from samples collected at Edge 5, while the highest score was from samples collected at Edge 1. By comparing these scores against their respective univariate analysis (*Figure 3-22*), it can be seen that the lowest Shannon-Biodiversity Index score is a result of high abundance along with high richness, while the highest Shannon-Biodiversity Index score is a result of low abundance along with high richness. The medium diversity assessment of macrobenthos from sweep samples indicate a generally favourable ecological condition in Kranji Reservoir.

3.5.2.2 Colonisers

Univariate Analysis

Five colonisers were deployed on Kranji Reservoir in May 2022 (*Figure 3-29*). A total of 13 phyla and 25 families were observed over the colonisation sampling events conducted in May 2022, with a total of 794 individuals recorded. Taxon richness of each sampling site ranged from 11 – 17 while abundance of each sampling site ranged from 62 – 284 (*Figure 3-26*). Standard error between richness of sample sites were at 1.08, while standard error between abundance of sample sites were at 38.2. When compared against the reservoir's mean, the samples typically share the same trend for both abundance and richness. Colonisers 2 and 5 have their abundance and richness above the overall mean, while Colonisers 1 and 4 have their abundance and richness below the overall mean. The only site that did not follow this trend is Coloniser 3, which has an abundance lower than the overall mean but richness higher than the overall mean. Across all sampling sites, the lowest richness was found at Coloniser 1, followed by Coloniser 4 while the highest richness was found at Coloniser 2. The lowest abundance was found at Coloniser 4, followed by Coloniser 1. The highest abundance was found at Coloniser 2. Considering both abundance and richness at the same time, Coloniser 2 seems to have a relatively high biodiversity. Coloniser 3 would likely have a high diversity as well. In contrast, both Colonisers 1 and 4 may have a relatively lower biodiversity; biodiversity indices was applied to confirm this (see below).

When compared with sweep samples, individuals picked from colonisers appear much smaller in size. Mean abundance (38) of coloniser samples were also noted to be lower than that of sweep samples (325) but mean richness (14) of coloniser samples were higher than that of sweep samples (11). Both sweep and coloniser samples had higher abundance and richness than the highest mean number of grab samples. Against Clews et al., 2014, mean richness of their colonisers in Kranji Reservoir (range from 7 to 17) were similar to this study's findings (range from 11 to 17). However, the abundance from this study's findings (range from 62 to 284) were much lower than that of Clews et al. findings (range from 470 to 2,414).

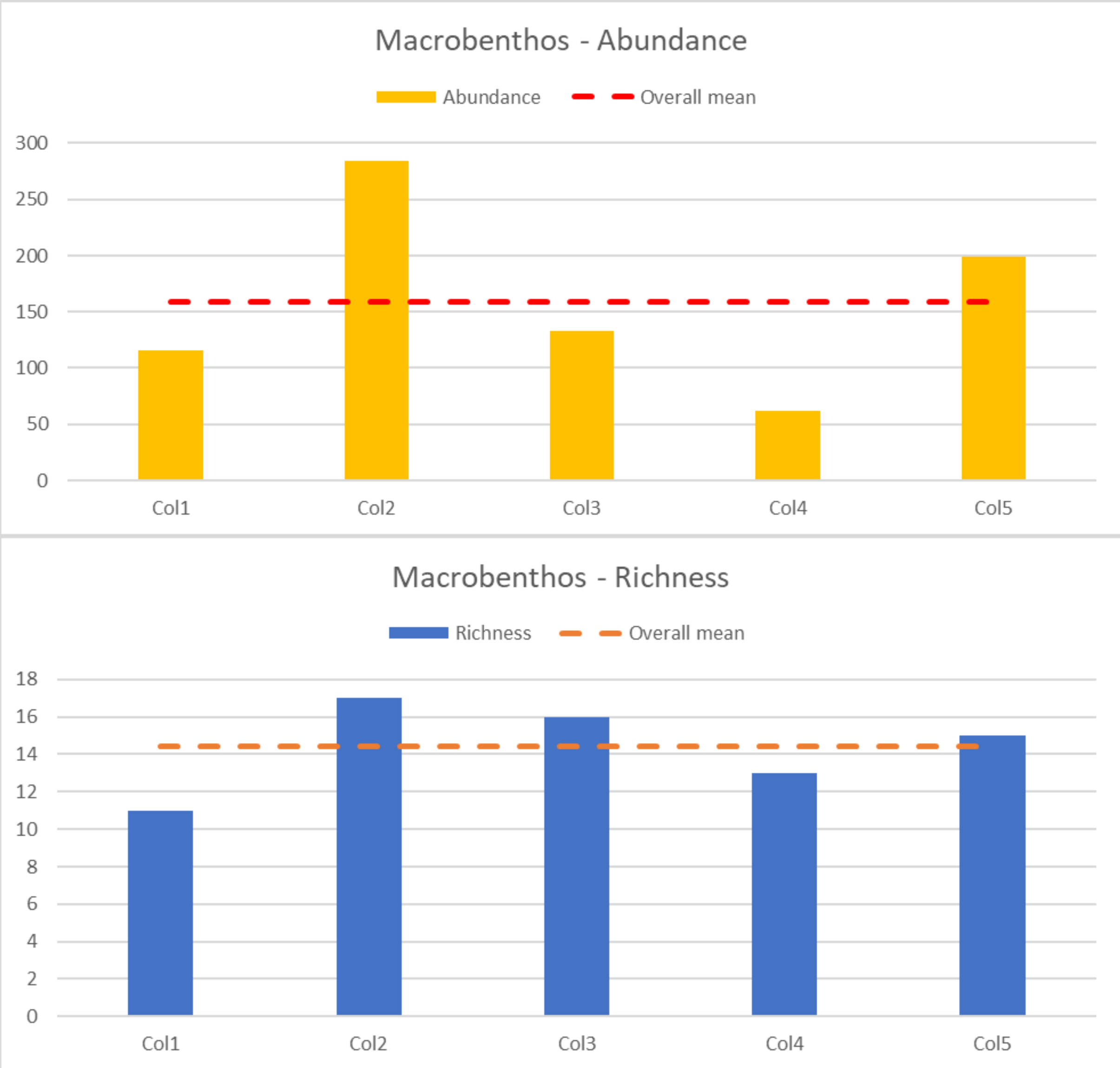


Figure 3-26: Macroinvertebrates (Colonisers) – Mean Abundance and Richness

A total of 13 different FFGs were observed across the coloniser samples. 5 to 9 different groups were observed in each coloniser but for visual clarity, groups with sum of less than 5% proportion were excluded from the graph (*Figure 3-27*). The common FFGs across all colonisers are scrapers, predators and filtering collectors. Of these FFGs, the most represented group is scrapers which composed of a number of snail taxa and *Cladocera*. Their percentage proportion ranged from 38.3 – 73.4%. This was followed by filtering collectors, made up of micro-crustaceans like Conchostraca, Copepoda and Ostracoda. The food source of scrapers and filtering collectors are algae and fine particulate organic matter in the water column respectively; therefore, their representation and abundance across coloniser samples suggest an abundance of these food sources. A high proportion of these primary consumers naturally attract predators, as seen in their percentage proportion ranging from 1.05 – 6.53%. The relatively small percentage proportion may be explained by their higher position in the trophic level.

Another factor influencing the proportion of FFG is the type of microhabitats present in the area. Plenty of riparian vegetation and moss at the colonisation sampling site provides for more feeding opportunities for predators by acting as ambush shelters, favouring the population growth of this FFG (Ono et al., 2020). Another example is the low percentage proportion of predators-gathering/ filtering collectors (i.e. shrimps) observed in the coloniser samples as compared to the sweep samples. This FFG has a preference for pools (B. S. K. Ho & Dudgeon, 2016; Rosas-rodriguez, 2016) – a microhabitat which might not have been well-captured by this colonisation-type samplers, as they are simply cages filled with coconut brushes and palm fronds that better mimic leaf packs. Another study that employed this method had a complete absence of this FFG in the same reservoir (Clews et al., 2014).

FFG of benthic macroinvertebrates may be monitored as an indication of environmental disturbances. Events like acidification, increased metals concentration or increased turbidity could result in a decrease in percentage proportion of predators (Rawer-Jost et al., 2000). With a number of predators found in all coloniser samples, this FFG could be used as an indicator in Kranji Reservoir.

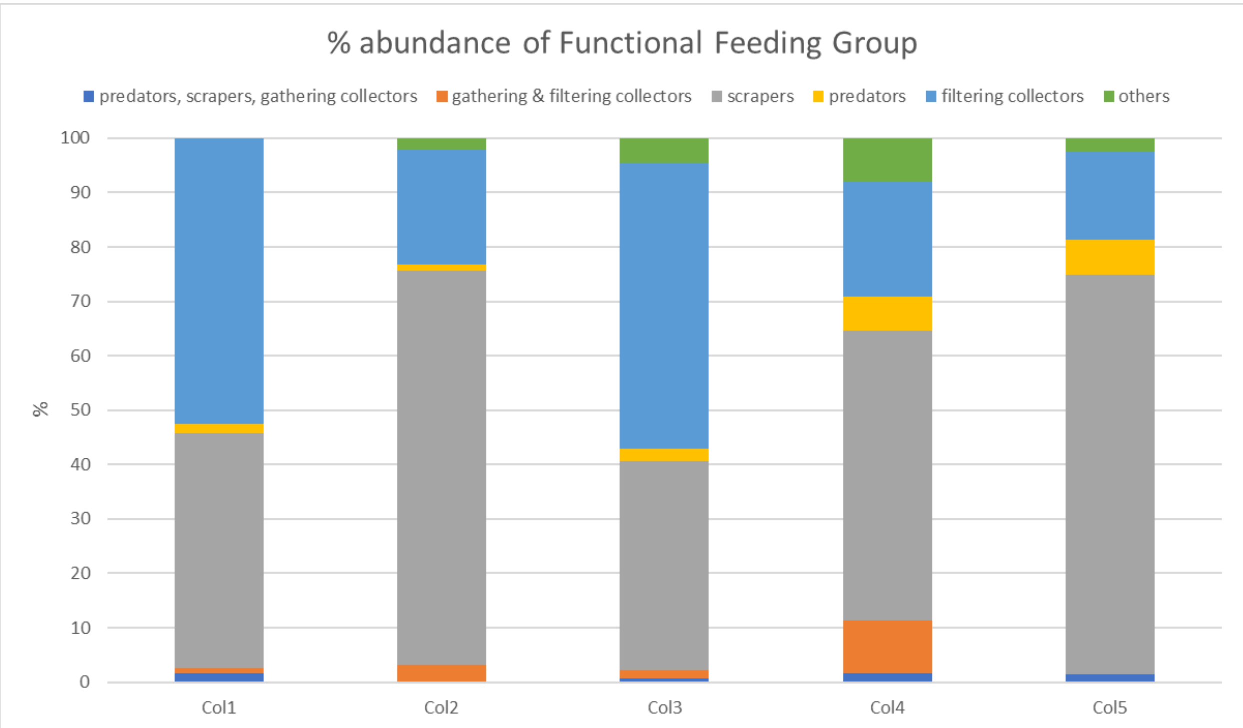


Figure 3-27: Macroinvertebrates (Colonisers) – Percentage FFG

Multivariate Analysis

Further analysis was conducted on the assemblages of macrobenthos from the coloniser samples. Assemblage data was first transformed and Bray-Curtis similarity was used to create a resemblance matrix. Non-metric Multi-Dimensional Scaling (MDS) graphs were then made to visualise the differences between each location (*Figure 3-28*). Symbols representing Colonisers 1, 2 and 3 were found close to one another, while symbols representing Colonisers 4 and 5 were not only further from one another, but also from the other 3 colonisers. From this graph, we deduce that assemblage of macrobenthos from Colonisers 1, 2 and 3 are likely more similar to each other than Colonisers 4 and 5.

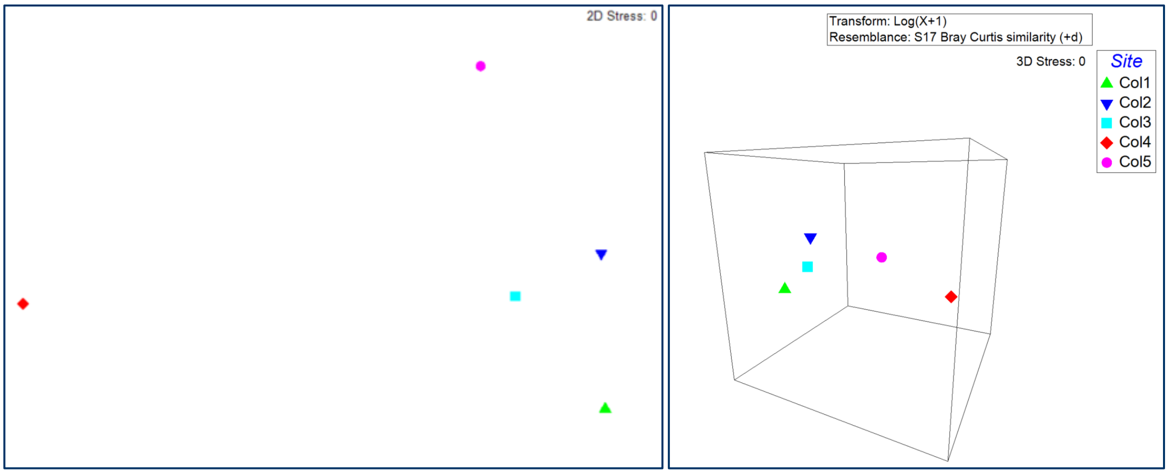


Figure 3-28: Macroinvertebrates (Colonisers) – Assemblage 2D (left) and 3D (right) graphs

Figure 3-29: Macroinvertebrates (Colonisers) – Location of Colonisers Marked Out by Buoys During Retrieval

A SIMPER test was conducted on the assemblage data to investigate the similarities between each coloniser. The five colonisers returned an average similarity of 60.36% and a breakdown of this similarity can be found in *Table 3-16*, with taxa arranged from the highest to lowest contributing percentage.

Table 3-16: Macroinvertebrates (Colonisers) – Highest Contributing Species from SIMPER Test

Family	Common Name	Contributing %
Planorbidae	Ram's horn snails	20.63
Ostracoda	Seed shrimp	18.57
Conchostraca	Clam shrimp	13.71
Physidae	Bladder snails	9.09
Copepoda	(micro-crustacean)	6.64
Cladocera	Water fleas	5.35
s-f Chironominae	Non-biting midge larvae	4.33
Ancylidae	(Limpet-like snail)	3.7
Lymnaeidae	Pond snails	3.53
Ceratopogonidae	Biting midge larvae	3.2
Erpobdellidae	Leech	3.18
Micronectidae	Pygmy water boatmen	2.91
Atyidae	Shrimp	1.43
Ecnomidae	Caddisfly larvae	1.43
Bithyniidae	Mud snails	1.25
s-f Tanypodinae	Non-biting midge larvae	0.64
Thiaridae	Trumpet snails	0.4

Planorbidae was found with the highest contributing percentage (20.63%), followed by Ostracoda (18.57%) and Conchostraca (13.71%). All members of this family in Singapore were found to be non-native, consisting of species like *Amerianna carinata*, *Ferrissia* cf. *californica* and *Indoplanorbis exustus*. The taxon Planorbidae is mostly studied in detail as an intermediate host for the trematode parasite, responsible for the disease schistosomiasis (Kazibwe et al., 2006; Rezende et al., 2018). With regards to environmental conditions, the species *Ferrissia* cf. *californica*, was found to be commonly associated with *Hydrilla verticillata* and thrives in less pristine lentic ecosystems (Chan & Lau, 2021).

Of the three taxa with the highest contributing percentage, two are shrimps, under the micro-crustaceans group. Ostracoda are typically found in shallow water bodies, sheltered by aquatic macrophytes like Hydrilla and Water hyacinth (Yule & Sen, 2004). Such conditions are commonly found around the edges of Kranji reservoir, hence why this taxon was found in most of sweep and coloniser samples. Although generally small-sized (around 0.5 – 5.0mm), Ostracoda have high ecological importance in the food chain of aquatic ecosystems as they are prey to many fish species and their larvae.

Given that the same method was employed at the same location in the study by Clews et al. (2014), a similar assemblage of taxa is expected in this study's survey. Taxa in common are shown in *Figure 3-30*; those in **bold** are the taxa with weights assigned to them for calculation of the BQI scores. By using these taxa that are more commonly found across the reservoirs in Singapore, a better comparison can be made between the different water bodies. Although there were many common taxa found between the two surveys, dominant taxon were different in Clews' study (i.e., Polymitarcyidae, followed by Chironomidae and Oligochaeta). This difference may be attributed to the change in environmental conditions since the Clews study. In 2008 when Clews collected their samples, turbidity was generally higher, pH was slightly lower and nutrient content was lower. Both turbidity and nutrient content of the water body has been known to have profound impacts on assemblages of freshwater benthic macroinvertebrates (Sosa-Aranda & Zambrano, 2020), possibly resulting in the current assemblages observed at Kranji Reservoir.

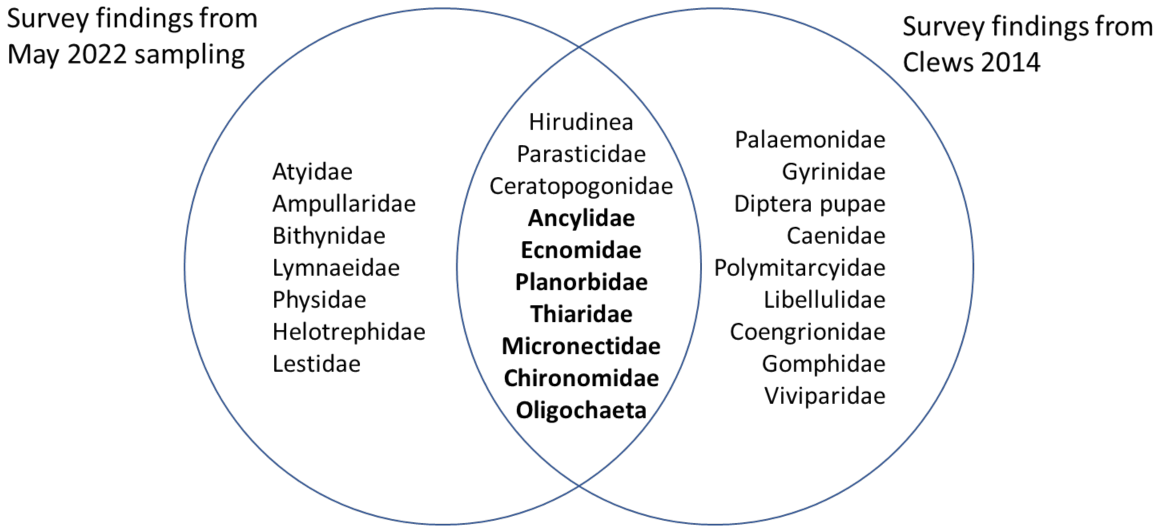


Figure 3-30: Macroinvertebrates (Colonisers) – Common Taxa Between this Study & Clews (2014) Study (In Bold – Taxa with Weights Assigned to them for the calculation of the BQI Scores

Diversity Indices

A summary table of the indices used to assess the ecological health of the reservoir is presented below in *Table 3-17*, while the following sections on Benthic Quality Index and Shannon-Biodiversity Index provide detailed analysis of the indices used.

Table 3-17: Macroinvertebrates (Colonisers) – Overall Summary of Indices Scores

Month		Col 1	Col 2	Col 3	Col 4	Col 5	Overall
Benthic Quality Index (BQI_{SING})		1.38	2.09	2.16	2.26	1.81	**1.96**
Shannon-Biodiversity	**Values**	1.89	1.72	2.00	1.80	1.92	**1.87**
	Assessment	Medium	Medium	High	Medium	Medium	**Medium**

Benthic Quality Index

BQI_{SING} score was applied to the assemblage data for all samples and they were found to be within a score range of 1.38 – 2.26. These are relatively low numbers, as compared to the highest possible score of 5 which is expected for reservoirs with high turbidity. The overall score of Kranji Reservoir is 1.96, representing conditions of rather low ecological stress.

Based on the individual scores of the various colonisers, it was noted that the highest and lowest score were mainly attributed to the taxa Chironomidae and Ancylidae respectively. The former can be found in abundance in high turbidity conditions, and vice versa for the latter, hence their different BQI weights (Clews et al., 2014). Given that a higher score suggests higher nutrient enrichment, the score of 1.96 from this survey would mean Kranji Reservoir has a rather low nutrient enrichment. However, considering the high trophic state of Kranji Reservoir (Gin et al., 2011), we should expect a high BQI_{SING} score. This same observation was made by Clews et al., 2014, where Kranji Reservoir was also found with a low BQI_{SING} score, which suggests that the BQI index may not be appropriate for predicting the trophic status of Kranji Reservoir.

Shannon-Biodiversity Index

The Shannon-Biodiversity Index was also applied to the assemblage data across the five colonisers in order to understand the aquatic biodiversity in Kranji Reservoir. Across the individual colonisers, the biodiversity of macrobenthos ranged from medium to high, with an overall biodiversity assessment of medium. It was previously postulated that Coloniser 3 has a relatively high biodiversity due to a lower abundance and higher richness when compared to the average. This postulation can now be confirmed from the results derived using Shannon-Biodiversity Index, where Coloniser 3 stood out among the coloniser samples as the one with the highest biodiversity.

3.5.3 Summary

Benthic macroinvertebrate communities present along the shoreline can be further characterised by combining results from the different surveys. Depth is an important variable for structuring benthic macroinvertebrate community (Dalu and Chauke, 2020). While the first grab survey had depths of more than 1 m, the second sweep and coloniser survey had depths around 1 m. The deeper regions were found to have diversity assessments of very low to low, while the shallower regions were from medium to high diversity. Findings from both surveys supplement one another in allowing a broader understanding of the benthic macroinvertebrate community in Kranji Reservoir.

Combining findings from the different sampling methods can also contribute to the characterisation of the community. An example is the diversity assessment of the sampling sites BC02 and Edge 5, which are in very close proximity (*Figure 2-3*). Diversity was found to be very low to low at BC02 but medium at Edge 5. This discrepancy can be attributed to the various microhabitats covered by the different sampling methods. Grab sampling can only cover one microhabitat (i.e. bottom substrate), while sweep and colonisation sampling covers a few other microhabitats (i.e. leaf packs, twigs). A wider spectrum of microhabitats sampled naturally allows for a higher diversity of benthic macroinvertebrates collected, hence the difference in results. To achieve the most representation of macrobenthos, it is therefore best to have a combination of all three sampling methods.

With reference to previous studies on macrobenthos community in Singapore, this study's findings generally coincide with those from Clews et al., 2014, such as the BQI score range of 1.38 – 2.26 for this study's survey and 2 – 2.5 for Clews' survey. A similar trend of high biodiversity and low BQI score was also observed in both study findings.

3.6 Submerged Aquatic Vegetation

3.6.1 Sonar Imaging

Figure 3-31 presents the sonar imaging track and identified underwater features which were translated into an underwater habitat map as shown in *Figure 3-32* while *Table 3-18* provides details on the area occupied by the underwater features (noting there is some overlap of the features). Features that were identified from the reservoir include smooth sand/ mud, vegetation, woody debris, rocky outcrop, artificial structures and large holes. To further investigate any relationships between depth of the reservoir and the various habitat features, a bathymetry map provided by PUB was overlaid onto the sonar-derived habitat map for review.

The initial habitat mapping survey was carried out in March 2021; with a second survey was commissioned in September 2021. The initial survey covered 80% of the study area as the coverage of water hyacinth and a semi-permanent lotus patch forest (~ 24.8 ha and 28.2 ha respectively) present at the time of survey, which hindered boat access. The second survey was commissioned once hyacinth cover had reduced, however approximately 13.62 ha was still inaccessible due to remnant lotus (*Figure 3-32)*.

Woody debris found within the Reservoir Project Site consists of twigs, branches and tree stumps. Twigs and branches were likely washed from the reservoir tributaries – canals and drains, while tree stumps were likely those along the riverbanks prior to the construction of the reservoir. They can still be found on the reservoir bed due to their large size and hence slow decomposition rates (Chambers et al., 2000). Large holes within the Reservoir Project Site were found to be around 1 m deep and might be due to imprints from heavy equipment or other structures that were previously placed there.

Judging from the light patterns of the artificial structures found in the Reservoir Project Site, they could be parts of a barrier and metal wires possibly disposed into the water body (*Figure 3-31*). Vegetation was observed over an area of 169 ha of the survey area (*Figure 3-32)*. These areas typically coincide with areas of shallow depths, where shallow depths allow for higher light penetration, encouraging the growth of aquatic macrophytes (Noleto et al., 2019).

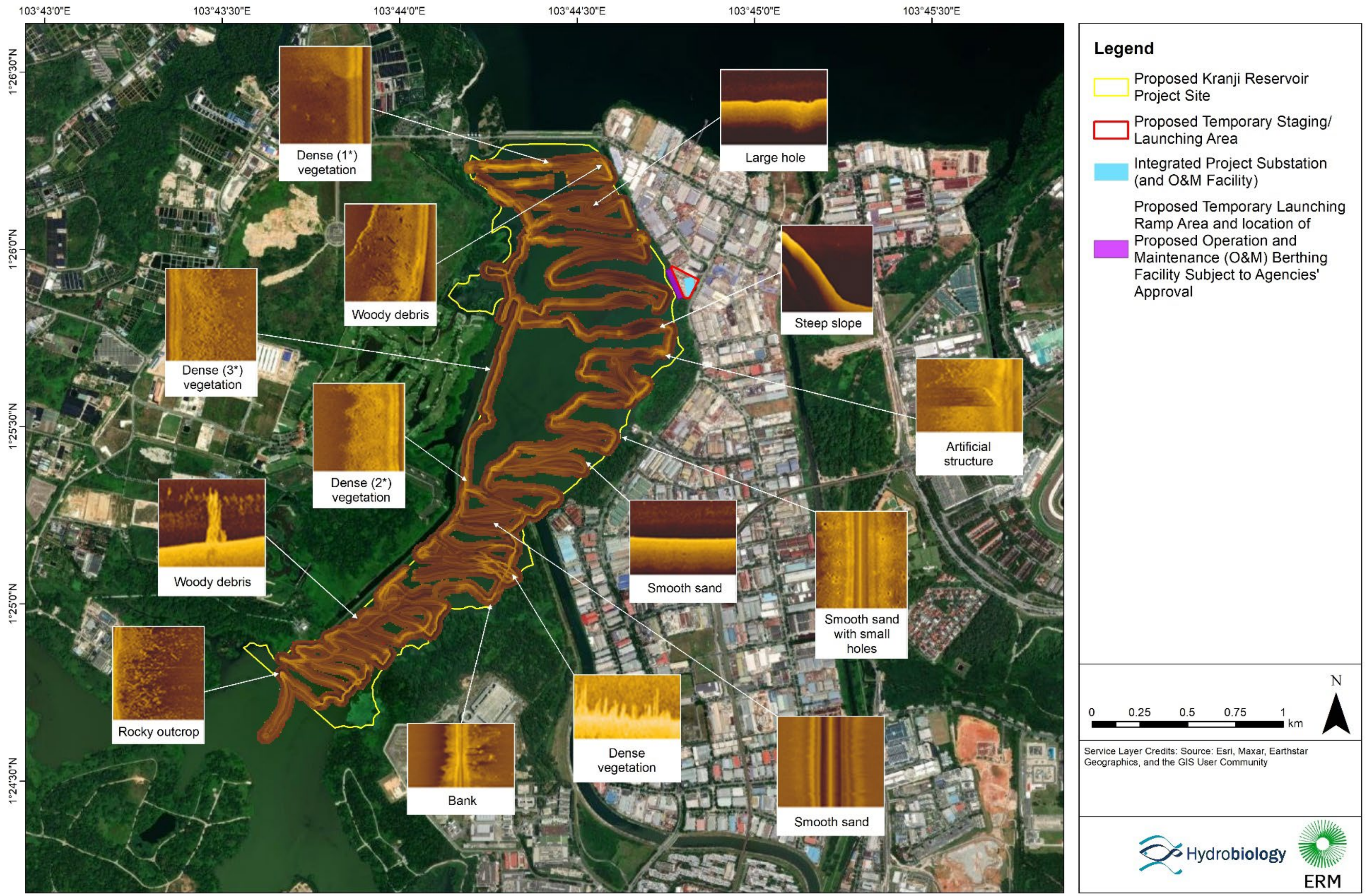


Figure 3-31: Sonar Tracks and Examples of Identified Underwater Features

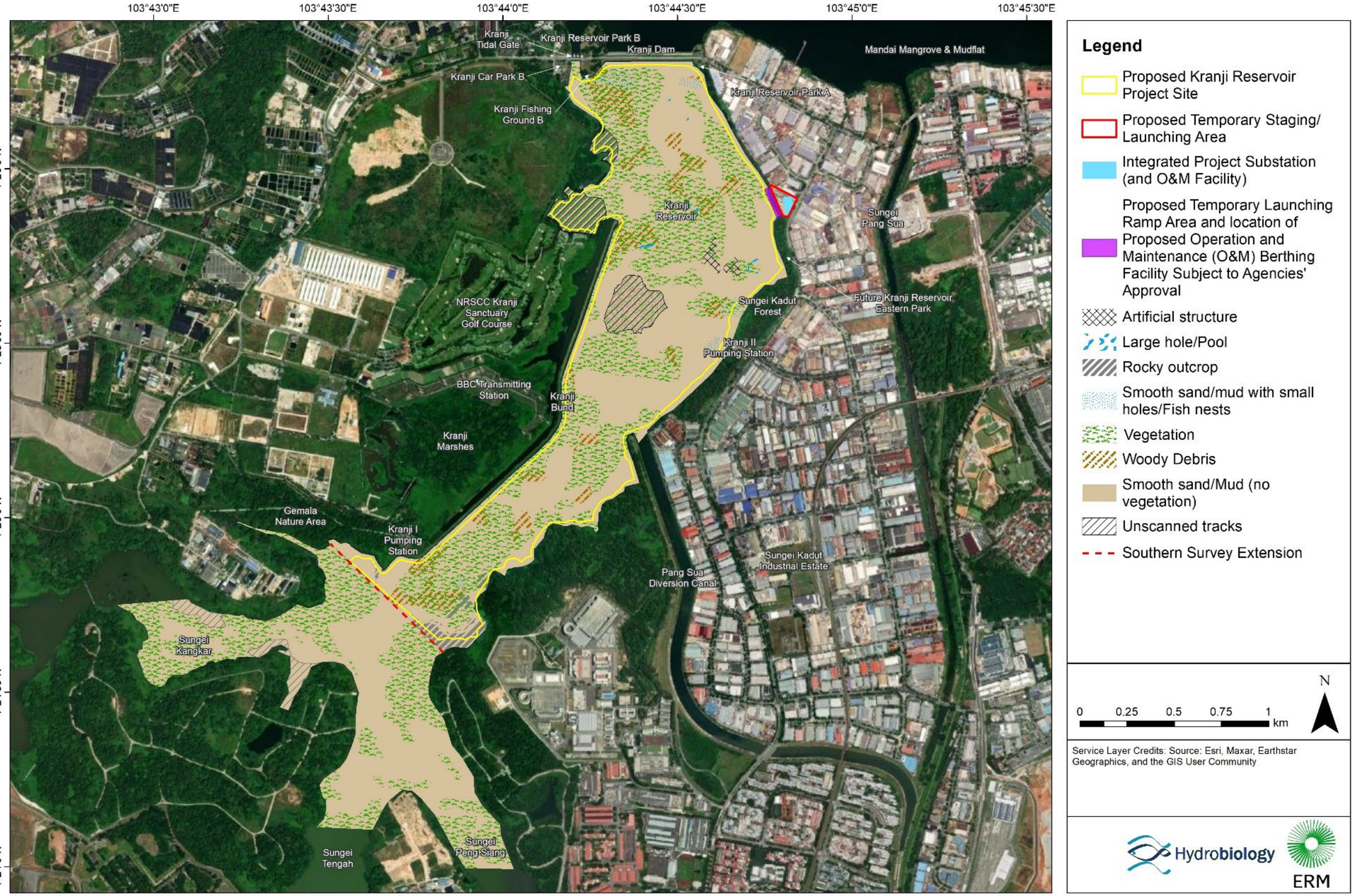


Figure 3-32: Underwater Habitat Map of Survey Area

Table 3-18: Sonar Features Observed on the Reservoir Bed

Feature	Reservoir Project Site (ha)	South of Reservoir Project Site (ha)
Smooth sand/ Mud (no vegetation)	~211	~102
Submerged vegetation	~109	~61
Woody debris	~23	~0.5
Rocky outcrop	~4.5	-
Smooth sand/mud with small holes	~4	~0.05
Artificial structure	~3	~0.05
Large hole/pool	~1.5	~0.1
Unscanned tracks	~14	~5
Note: Includes areas within shoreline setback area around the Reservoir Project Site, as well as contains some overlapping features.		

3.6.2 Aquatic Vegetation – Grab/ Rake Sampling

There were thirteen (13) different species identified during the aquatic vegetation survey of which 4 were emergent/ floating, 7 were partially submerged and 2 species were not considered aquatic plants but were identified along the reservoir banks. Based on the habitat map and site observations, most of the species were observed to be distributed along the reservoir banks, near shore or in a continuous distribution in the reservoir where the semi-permanent lotus patch was observed. These species include *Acacia auriculiformis* (Acacia tree), *Anubias lanceolata, Cabomba aquatica* (Yellow Cabomba), *Dillenia suffruticosa* (Simpoh air), *Eichhornia crassipes* (Water hyacinth), *H. verticillata*, *Ludwigia adscendens* (Water Primrose), *Mimosa pudica* (Mimosa), *N. nucifera* (Water lotus), *Philonotis spp* (Green apple moss), *P. barbatum*, *Urochloa mutica* (Para Grass) and *Vesicularia dubyana* (Singapore Moss).

Surveying and aquatic vegetation sampling identified hyacinth *Eichornia crassipes* as having pest potential at Kranji Reservoir. Despite being emergent/ floating plants, they typically end up with other submerged vegetation in the sample as they get caught in the rake. Between March 2021 and June 2021, extensive cover of hyacinth was observed on the reservoir (considered a one off event and not representative of the usual reservoir conditions where the hyacinths are mainly contained upstream). The reproductive rate of hyacinth is influenced by two major conditions - climate and water quality conditions where the invasive plant can double itself within 5-15 days (Dersseh et al., 2019). Hyacinth favour still water, shallow (<6 m), and lake/ reservoir bed sediments rich in organic matters with availability of nutrients N and P (Makhanu, 1997). Annual climatic warming has been observed since the 1980s at Kranji Reservoir and the reservoir is characterised by shallow, eutrophic waters that favour extensive hyacinth growth (Fong et al., 2019, and based on data extracted from: CRU 2021). The hyacinth mats have significant negative impacts on reservoir hydrology by enhancing the evapotranspiration of reservoir water. It can also create more favourable conditions for the breeding of snails and mosquitos that carry diseases such as Bilharzia and malaria. Ecosystem services at the site are also at risk, as hyacinth growth may be detrimental towards water quality, the aesthetic amenities of the reservoir, and fishing and potentially poses a threat to the proposed FPV infrastructure.

Subsequent to the first round of surveys, hyacinth populations were contained by PUB's Reservoir Operations team. During the second survey, the reservoir was observed to be densely populated with *Hydrilla verticillata* (Hydrilla). Hydrillas have been known to reduce dissolved oxygen concentrations when present in high coverage and density, especially in warm periods and smaller lentic systems (Bradshaw et al., 2015).

The focus of the survey in February 2022 was on the area south of the reservoir and was conducted to extend coverage beyond the Reservoir Project Site. This area is located at an intersection between three rivers (Sungei *Kangkar*, *Tengeh* and *Peng Siang*) and is separated from the Reservoir Project Site with a red line ("Southern Survey Extension") in *Figure 3-33*. Depths of this area was found to be relatively shallow (5 m or less). Zones 6 to 9 are within the Southern Survey Extension area and hence is not within the Reservoir Project Site.

Table 3-19: Aquatic Vegetation Observed in the Reservoir and Status

Scientific name	Common name	Conservation status (IUCN red list)	National status (Singapore Red Data book)	Type
Acacia auriculiformis	Acacia-tree	Least concerned	Naturalised	Not considered aquatic but found along banks
Anubias barteri var. glabra	-	Not listed	Not listed	Partially submerged/ Emergent
Cabomba aquatica	Yellow Cabomba	Not listed	Not listed	Submerged
Dillenia suffruticosa	Simpoh air	Not listed	Common	Not considered aquatic but found along banks
Eichhornia crassipes	Water hyacinth	Not listed	Naturalised	Floating
Hydrilla verticillata	Hydrilla	Least concerned	Not listed	Submerged
Ludwigia adscendens	Water Primrose	Least concerned	Not listed	Emergent
Neptunia plena	Water mimosa	Least concerned	Naturalised	Emergent/ floating
Nelumbo nucifera	Water lotus	DD[(a)]	Cultivated only	Emergent/ floating
Philonotis spp	Green apple moss	Least concerned	Not listed	Partially submerged
Polygonum barbatum	Knotweed	Not listed	Not listed	Emergent
Urochloa mutica	Para grass	Least concerned	Naturalised	Partially submerged
Vesicularia dubyana	Singapore Moss	Not listed	Least concerned	Partially submerged

Note:
(a) Data deficient (DD) species is one which has been categorized by the International Union for Conservation of Nature (IUCN) as offering insufficient information for a proper assessment of conservation status to be made.

There were 4 vegetation species identified - *Eichhornia crassipes, Hydrilla verticillata, Anubias barteri var. glabra and Ludwigia adscenden*s across all zones (see *Figure 3-33)*, while decomposed organic matter collected in all samples in Zone 3 were unidentifiable and were grouped according by root identity where possible. Sampling locations within each identified sampling zones are presented in *Figure 3-33,* while species and its respective wet, dry and net weights can be found in *Table 3-20*. The samples were observed to contain up to 98% of water content.

Individual biomass (per grab area) per identified species and the average values for the aquatic vegetation were presented in *Figure 3-34*. While *Hydrilla verticillata* accounts for the largest biomass reported here, it is noted that grab sampling and rake dragging are more likely to capture submerged vegetation, rather than floating plants. Large surface areas of floating plants, such as *Eichhornia crassipes*, were also observed at the time of sampling. However, the results presented here are successful in identifying *Hydrilla verticillata* and *Eichhornia crassipes* as two dominant species that were present and account for large amounts of plant biomass in the reservoir at the time of sampling. Dried samples were further analysed for nutrients - Total Phosphorus (TP), Total Nitrogen (TN) and Total Carbon (TC). The relationship between biomass and nutrients are shown in *Figure 3-35*. Across all zones, the TP level was observed to be the highest at 3,377 mg/kg in Zone 1 where three aquatic species were identified. TP levels of the samples from the first survey (conducted on 14 July 2021) were about 10 times higher than that of the second survey (conducted on 14 Mar 2022). A possible reason could be the increase in the biomass of *Hydrilla verticillata* during the second survey, but not in the first survey. This species is a submerged aquatic plant that colonises reservoir banks and have been found contributing significantly to TP removal from water bodies (Li et al., 2021; Wang et al., 2007). As the percentage coverage and total biomass of *Hydrilla verticillata* increases, TP available for uptake may be reduced, resulting in lower uptake by the plant. The highest biomass level was, however, recorded in Zone 5 with 33.1 ± 2.22 mg/m^2, also with the highest TN and TC levels of 5.2 % and 35.3 % respectively. The relationship between biomass, TP, TN and TC were distinct in Zone 7 and Zone 2 where the lower the biomass, its TP and TN levels were also low but with a high TC level observed.

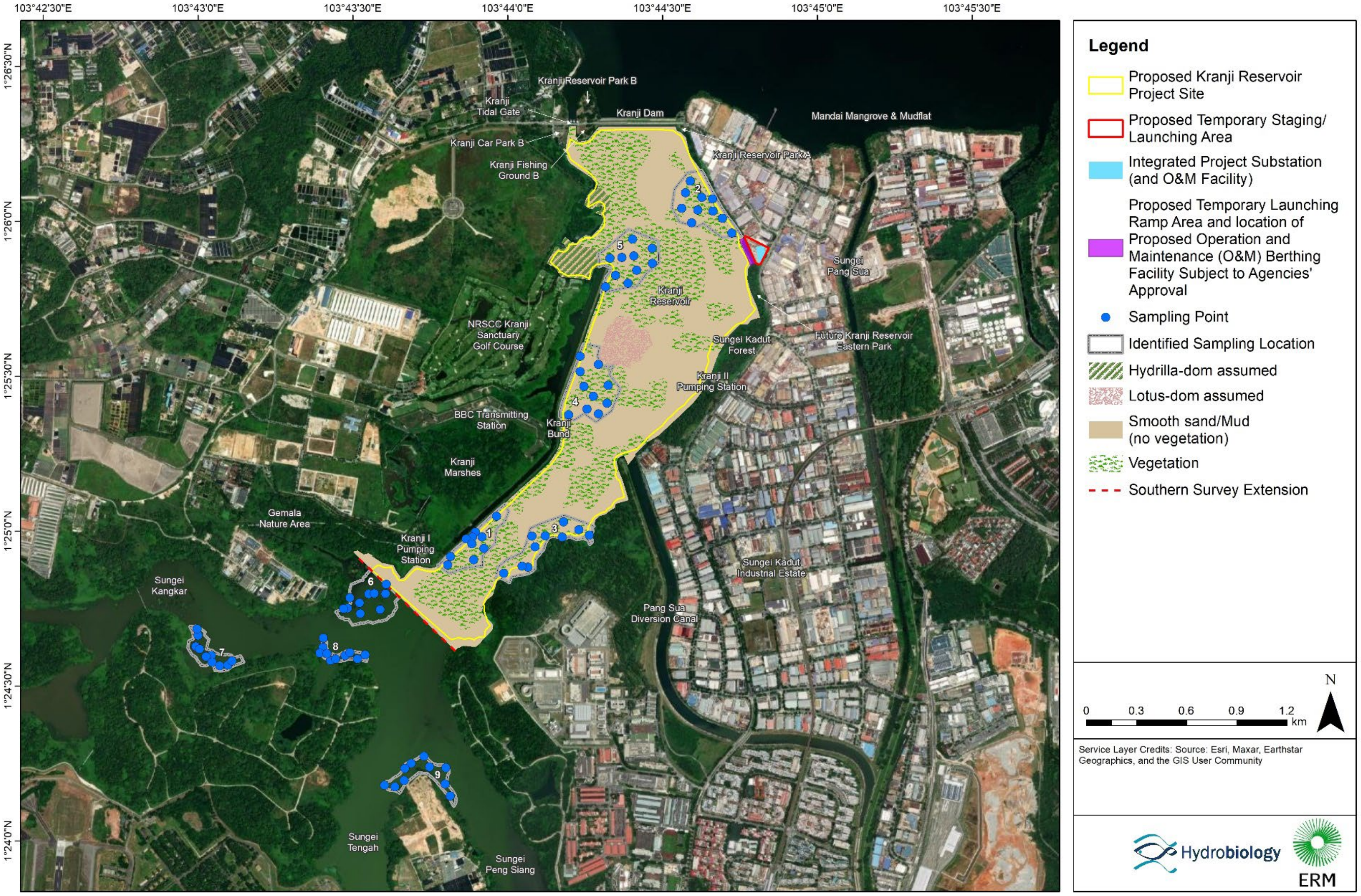


Figure 3-33: Aquatic Vegetation Areas Detected by Sonar

Table 3-20: Aquatic Vegetation Wet, Dry, and Net Weight Per Zone (n=10)

Zone	Scientific name	Wet weight (g)	Dry Weight (g)	Net weight (g)	% Wet weight
1	*Eichhornia crassipes*	266.89	33.45	233.44	87.5
	Hydrilla verticillata	14.43	0.29	14.14	98.0
	Anubias lanceolata	141.55	11.5	130.05	91.9
2	*Ludwigia adscendens*	89.39	8.61	80.78	90.4
	Eichhornia crassipes	43.66	2.01	41.65	95.4
3	Unknown (decomposed)	25.6	2.6	23	89.8
	Unknown (decomposed)	0.92	0.15	0.77	83.7
	Unknown (decomposed)	29.79	3.24	26.55	89.1
	Unknown (decomposed)	18.16	2.55	15.61	86.0
4	Unknown (decomposed)	41.65	2.82	38.83	93.2
	Hydrilla verticillata	116.58	8.82	107.76	92.4
5	*Hydrilla verticillata*	397.09	67.96	329.13	82.9
	Eichhornia crassipes	142.6	6.78	135.82	95.2
6	*Hydrilla verticillata*	768	37.54	730.46	95.1
	Eichhornia crassipes	126.97	4.73	122.24	96.3
7	*Hydrilla verticillata*	46.96	1.9	45.06	96.0
	Eichhornia crassipes	13.52	0.61	12.91	95.5
	Unknown (decomposed)	101.54	11.91	89.63	88.3
8	*Hydrilla verticillata*	650.2	27.33	622.87	95.8
	Eichhornia crassipes	340.25	17.21	323.04	94.9
9	*Hydrilla verticillata*	1029.44	52.51	976.93	94.9

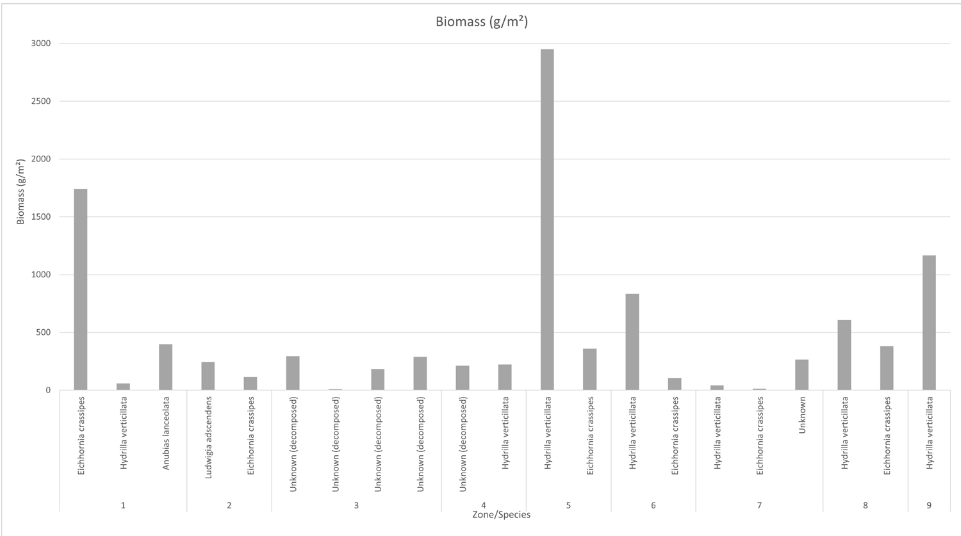


Figure 3-34: Aquatic Vegetation Species Composition Per Zone and Respective Biomass of Individual Species and Zone

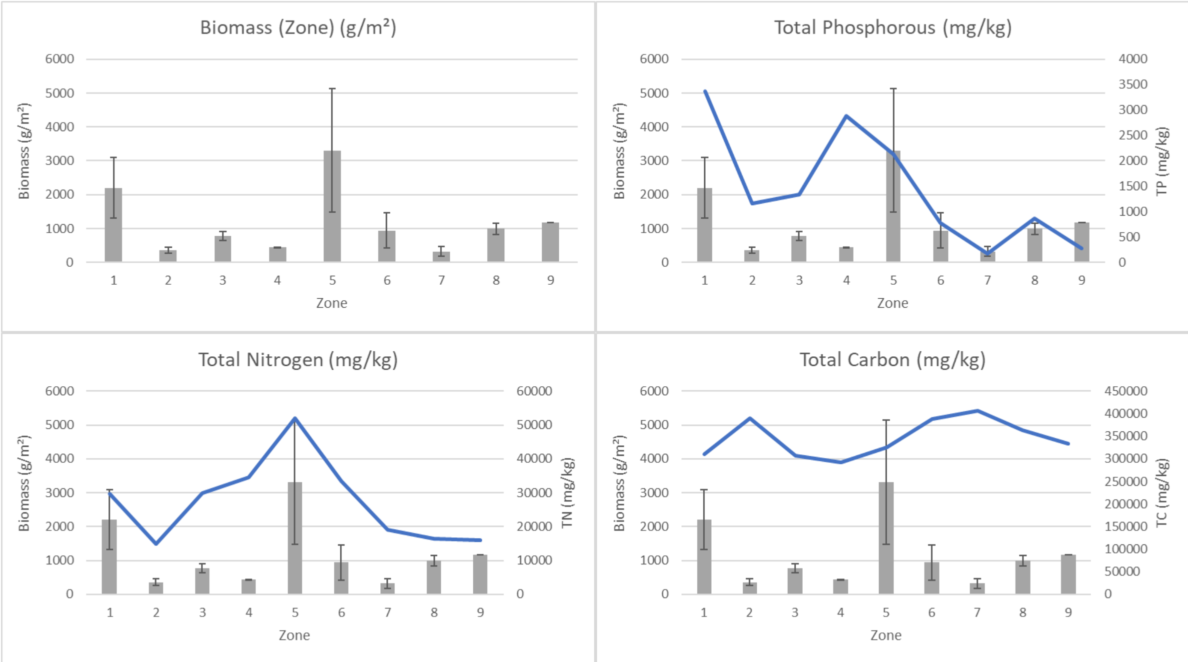


Figure 3-35: Aquatic Vegetation Relationship of Nutrients (TP, TN and TC) Compared to Biomass Per Zone (+/- Std. Dev)

3.7 Fish

3.7.1 Biomass

An extract of the hydroacoustic echograms analysis is presented in *Figure 3-36*. Most transects displayed a layer of plankton around approximately 3-4 metres depth. Generally, fish returning stronger echoes were observed in greater numbers in deeper sections of the water column. Overall, visual inspection of the echograms indicated more diversity in the size and number of fish observed in areas with greater water depth.

A total of 25 repeated transects were performed. The number of fish tracks detected were mapped in *Figure 3-36* (also see *Table 3-21* for corresponding quantitative data). The number of tracks corresponds to the number of individual fish (of any size/ weight) identified by the software on the transects performed. Quantile classification was used to classify fish biomass per volume, namely 0, 1 – 5, 6 – 10, 11 – 20, 21 – 30 and 31 – 40 g/m^3. No tracks were detected in roughly about 103.98 hectares of the reservoir, which generally coincided with areas of less than 3m depth. There were 1 – 5 tracks detected in about 34.70 hectares, 6 – 10 tracks detected in about 11.36 hectares, 11 – 20 tracks detected in about 4.96 hectares and 21 – 30 tracks detected in about 1.17 hectares. The highest range of tracks (31 – 40) covered only about 1.02 hectares and was detected in the deepest region of the reservoir. Unscanned areas accounted for about 66.03 hectares.

More tracks detected in the deeper parts of the reservoir (>3 m) could be associated with both greater fish numbers and reduced noise level at the bottom of the reservoir. It is also noted that the cone shape of the transducer emissions introduces a bias of the likelihood of encounter at depth (i.e. increasing with depth due to the increase in volume/surface area surveyed). The absence of fish track detections in the shallower areas does not mean that fish were absent from the area investigated. The hydroacoustic method has a greater probability of detecting fish through a hydroacoustic beam at depths over 3m (Steig et al., 2010), meaning that the shallower areas had a lower chance of encounter.

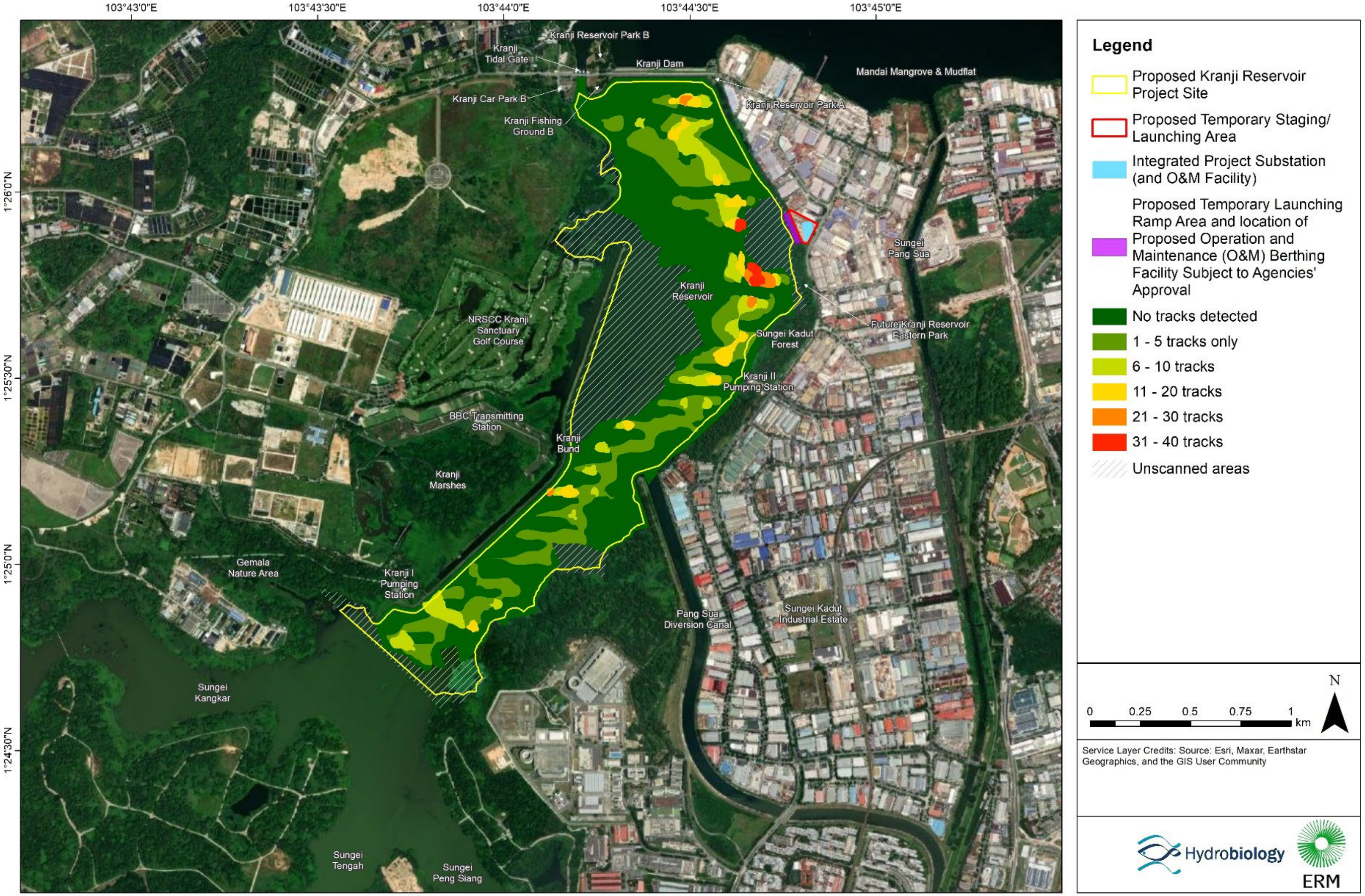


Figure 3-36: Fish Tracks in Reservoir Project Site

Table 3-21: Fish Track Categories and Estimated Area Size

Total Tracks	Area (ha)
No tracks detected	~103.98
1 – 5 tracks	~34.70
6 – 10 tracks	~11.36
11 – 20 tracks	~4.96
21 – 30 tracks	~1.17
31 – 40 tracks	~1.02
Unscanned areas	~66.03
Total Area scanned	~223.22

The volumetric biomass (g/m^3) results are presented on the map in *Figure 3-37* (also see *Table 3-22*) for corresponding quantitative data). These results provide a better understanding of potential areas of higher fish densities. The volumetric biomass was categorised using quantile classification to identify the areas hosting greater biomass in Kranji Reservoir. Biomass of fishes in Kranji Reservoir was estimated at up to 2.31 g/m^3. This measurement is based on the use of a generic algorithm to convert sound data in decibels into fish length and fish biomass. The diversity of species occurring in the reservoir are expected to return different sound signatures, therefore the biomass estimates derived in this report are relative estimates that can be used for future comparison, but fishing methods would need to be employed to validate and/ or calibrate these biomass estimates with the reality.

The relative differences in fish biomass across the reservoir was investigated. Fish biomass was distributed quite evenly across the areas where fish were detected and appeared to be the highest from the centre to towards the south of the Reservoir Project Site. The largest hotspot (in red) was found in the far South of the Reservoir Project Site survey area, where more than 0.201 g/m^3 of biomass was found. It was associated with a small number of tracks (6-10, see *Table 3-22*) which suggests that the fish encountered in that area were few but of substantially larger size compared with other areas of the reservoir. A few other similar but smaller hotspots were also reported across the whole reservoir. The central to northern region of the Reservoir Project Site had patchier biomass, with the highest estimates located to the North/ North-West. The Central-eastern region of the Reservoir Project Site with the highest number of tracks (31 – 40) was associated with a relatively low biomass per volume, up to 0.050 g/m^3. This could indicate the presence of many smaller fish in that area, but it may also be an artefact of the larger volume sampled relative to the shallower regions.

Overall, the fish distribution in the Reservoir Project Site was rather uniform, with higher fish densities in the shallower southern half of the Reservoir Project Site but likely different assemblages occurring in deeper regions (central to north region of the Reservoir Project Site).

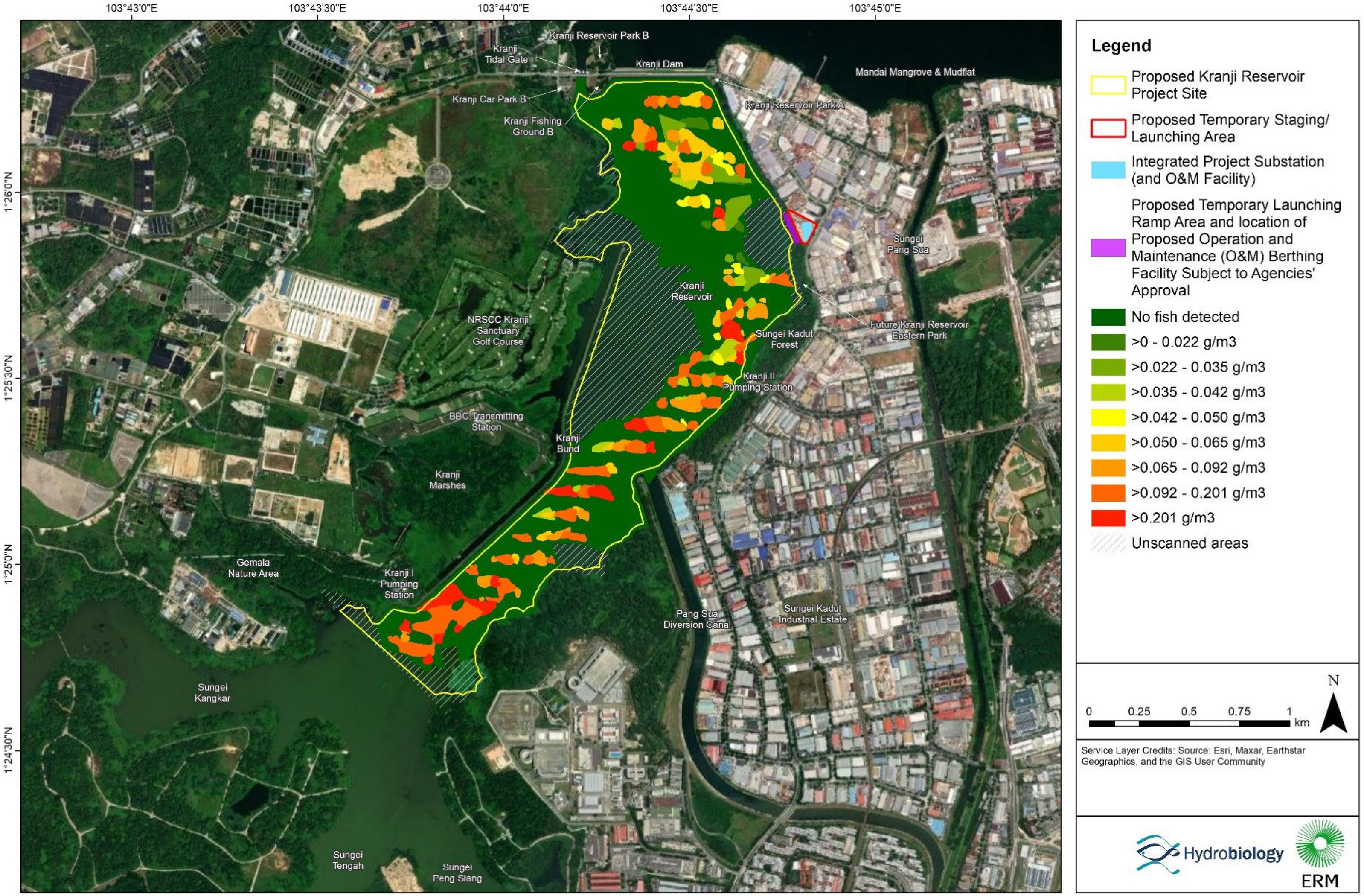


Figure 3-37: Fish Biomass per Volume (g/m^3) in Reservoir Project Site

Table 3-22: Fish Biomass Categories and Estimated Area Size

Total Biomass (g/m^3)	Area (ha)
No biomass detected [(a)]	~108.79
>0 – 0.022 g/m^3	~1.28
>0.022 – 0.035 g/m^3	~4.95
>0.035 – 0.042 g/m^3	~2.97
>0.042 – 0.050 g/m^3	~1.98
>0.050 – 0.065 g/m^3	~6.87
>0.065 – 0.092 g/m^3	~6.90
>0.092 – 0.201 g/m^3	~16.04
>0.201 g/m^3	~8.26
Unscanned areas	~66.03
Total Area scanned	~224.07

Note:
(a) Noise artefacts hamper detection in much of these shallow areas, it does not imply a lack of fish.

3.7.2 Fish Species Diversity

A survey of aquatic fauna conducted at Kranji Reservoir in January 2016 found at least 37 different species living at the site (Yeo et al., 2016). An additional 19 fish species were identified and documented in a biodiversity report for Kranji Reservoir by Kwik et al. (2020) that was conducted from August to October 2018. A compiled species list from these studies is provided in (*Table 3-23*). The species present largely consist of alien species that were introduced to the reservoir following the damming of the river mouth. For example, the South American cichlid fish, *Acarichthys heckelii*, is one of many exotic species introduced to freshwater systems in Singapore, making it the only recorded population outside its native distribution (Liew et al., 2013). The majority of all species identified in the reservoir are of least concern in terms of conservation value, although fish species such as *Amblypharyngodon chulabhornae* (Princess carplet) and *Trichopodus pectoralis* (Snakeskin gourami) are experiencing a decline in global population (IUCN Red List, 2022).

The eDNA analysis carried out for this study identified 15 fish taxa across the five locations on Kranji Reservoir (*Table 3-24*). The metabarcoding procedure was performed with a universal fish assay targeting a small region of the 12S mitochondrial DNA, hence only fish results are returned as opposed to other taxa. The laboratory analysis report is provided in *Appendix D.* The number of taxa detected were averaged for each site, with the largest average number of taxa detected at location 1 (7-13 taxa), whereas only 2-7 taxa were found at locations 2-5, which suggests location 1 is a hotspot for fish diversity. Out of the 15 fish taxa detected by eDNA analysis, only 12 of these species were identified in previous reports (*Table 3-25*). These findings suggest that the eDNA technique is useful for identifying the presence of fish species in Kranji Reservoir. However, many fish species previously found in past studies were not identified by the eDNA technique used in the current work. While a change in presence/ absence of fish species may have occurred during the past decade, a more likely explanation is that not all fish species present in Kranji Reservoir were detected. This may reflect differences in the preservation and abundance of fish DNA found in the water column for different fish species. Fish species with greater biomass are also expected to produce a greater DNA signal than smaller fish species. In addition to this, fish fauna are mobile, so while fish species may be absent from certain sampling locations, this does not indicate that these species cannot be found at these locations.

Table 3-23: Aquatic Species Historically Identified in Kranji Reservoir

Scientific Name[(a)]	Common Name	Organism	Native/Alien/Cryptogenic	Status in SG (IUCN Red List, 2022)[(b)]	Habitat [(c)]	Current population trend (IUCN Red List, 2022)
*Notopterus notopterus**^	Bronze knifefish	Fish	Alien	LC	F, M	Stable
*Amblypharyngodon chulabhornae**	Princess carplet	Fish	Alien	LC	F	Decreasing
*Puntius sophore**	Spotfin swamp barb	Fish	Alien	LC	F	Unknown
*Rasbora borapetensis**	Red-tailed rasbora	Fish	Alien	LC	F	Stable
Clarias gariepinus^	African sharptooth catfish	Fish	Alien	LC	F	Unknown
*Gambusia affinis**	Western mosquito fish	Fish	Alien	LC	F	Stable
*Dermogenys collettei**	Pygmy halfbeak	Fish	Alien	LC	F, M	Unknown
*Monopterus javanensis**	Swamp eel	Fish	Native	LC	F	Unknown
*Macrognathus zebrinus**^	Zebra spiny eel	Fish	Alien	LC	F	Unknown
*Oreochromis niloticus**^	Nile tilapia	Fish	Alien	LC	F	Unknown
*Oxyeleotris marmorata**^	Marbled goby	Fish	Alien	LC	F	Unknown
*Brachygobius sabanus**	Lesser bumblebee goby	Fish	Alien	LC	F	Unknown
*Anabas testudineus**	Climbing perch	Fish	Native	LC	F	Stable
*Betta imbellis**	Crescent fighting fish	Fish	Native	LC	F	Unknown
*Trichopodus pectoralis**	Snakeskin gourami	Fish	Alien	LC	F	Decreasing
*Trichopodus trichopterus**	Three-spot gourami	Fish	Native	LC	F	Unknown
*Trichopsis vittata**	Croaking gourami	Fish	Native	LC	F	Unknown

Scientific Name[a]	Common Name	Organism	Native/Alien/Cryptogenic	Status in SG (IUCN Red List, 2022)[b]	Habitat [c]	Current population trend (IUCN Red List, 2022)
*Channa striata**^	Common snakehead	Fish	Native	LC	F	Stable
Acarichthys heckelii^	Threadfin acara	Fish	Alien	Not listed	F	Not listed
Geophagus altifrons^	Eartheater cichlid	Fish	Alien	LC	F	Not listed
Hemigrammus rodwayi^	Golden tetra	Fish	Alien	Not listed	F	Not listed
Channa micropeltes^	Giant snakehead	Fish	Alien	LC	F	Stable
Parambassis siamensis^	Indochinese glass-perchlet	Fish	Alien	LC	F	Stable
Cichla temensis^	Speckled peacock bass	Fish	Alien	Not listed	F	Not listed
Cichla kelberi^	Kelberi peacock bass	Fish	Alien	Not listed	F	Not listed
Cichla orinocensis^	Orinoco peacock bass	Fish	Alien	Not listed	F	Not listed
Cichla spp.^	Peacock bass	Fish	Alien	Not listed	F	Not listed
Osphronemus goramy^	Giant gourami	Fish	Alien	LC	F	Not listed
Etroplus suratensis^	Green chromide	Fish	Alien	LC	F	Decreasing
Glossogobius aureus^	Golden tank goby	Fish	Native	LC	F, M	Stable
Chitala ornata^	Clown knifefish	Fish	Alien	LC	F	Stable
*Dermogenys collettei**^	Pygmy halfbeak	Fish	Native	LC	F	Not listed
Scleropages formosus^	Asian arowana	Fish	Alien	VU	F	Decreasing
*Macrognathus zebrinus**^	Zebra spiny eel	Fish	Alien	LC	F	Not listed
Xiphophorus maculatus^	Southern platyfish	Fish	Alien	LC	F	Not listed

Scientific Name[(a)]	Common Name	Organism	Native/Alien/Cryptogenic	Status in SG (IUCN Red List, 2022)[(b)]	Habitat [(c)]	Current population trend (IUCN Red List, 2022)

Notes:
*(a) * Identified in 2016 survey*
^ Identified in 2018 Survey
(b) Status in SG- LC: Least concern; VU: Vulnerable; F: Freshwater
(c) Habit- M: Marine; T: Terrestrial

Table 3-24: Fish Species Detected Using eDNA in Kranji Reservoir

Scientific names	Location 1			Location 2			Location 3			Location 4			Location 5		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3
_c:Actinopteri [(a)]	+	+	+	+	+	+	+	+	+					+	
_f:Cichlidae [(a)]	+		+	+	+			+				+	+	+	+
Barbatula sp.											+				
Chitala ornata				+					+						
Cyprinus carpio	+		+	+						+			+		
Eugnathogobius sp. [(b)]	+	+	+		+						+				
Geophagus sp.	+	+	+	+	+		+				+	+			+
Notopterus notopterus	+										+	+			
Oreochromis sp. [(c)]	+		+						+				+		
Oxyeleotris marmorata	+			+											+
Parambassis sp.	+	+	+	+	+	+	+	+	+	+		+	+		
Rhinogobius sp.	+	+	+							+					+

Trichopodus pectoralis	+		+												
Trichopodus trichopterus	+	+													
Trichopsis vittata	+	+	+				+								
Number of taxa detected	13	7	10	7	5	2	4	3	4	3	4	4	4	2	4
Average number of taxa per site	10			5			4			4			3		

Notes:
- *(a) Taxa prefixed with an underscore cannot be classified further. Abbreviations: p-phylum, c-class, o-order, f-family*
- *(b) Synonym or possible species complex with Pseudogobiopsis sp.*
- *(c) Oreochromis niloticus and O. aureus cannot be distinguished due to shared haplotypes and/or hybridisation*

Table 3-25: Comparison Between eDNA Results and Historical Data for Kranji Reservoir

Scientific names	Present in historical data?	Level of certainty in species identification	Native/ alien	Status in SG (IUCN Red List, 2022)	Current population trend (IUCN Red List, 2022)	Reference
_c:Actinopteri [(a)]	No	Less certain. Reported in Singapore waters.	Cryptogenic	Not listed	Not listed	Fishbase (2022)
_f:Cichlidae [(a)]	Yes	High certainty. Cichlidae species reported in Singapore Reservoirs.	Cryptogenic	Not listed	Not listed	Heok Hui et al. (2020)
Barbatula sp.	No	Uncertain. No reports of *Barbatula* in Singapore Reservoirs.	Cryptogenic	Not listed	Not listed	
Chitala ornata	Yes	High certainty, exact match.	Alien	LC	Stable	Heok Hui et al. (2020)
Cyprinus carpio	No	Possible, as it has been reported in other Singapore reservoirs. See Ng and Tan (2010)	Alien	VU	Unknown	Ng and Hui Tan (2010)
Eugnathogobius sp.[(b)]	Yes	Possible (*Eugnathogobius* species found in Singapore) – Larson et al. (2016)	Cryptogenic	Not listed	Not listed	Larson et al. (2016)

Scientific names	Present in historical data?	Level of certainty in species identification	Native/ alien	Status in SG (IUCN Red List, 2022)	Current population trend (IUCN Red List, 2022)	Reference
Geophagus sp.	Yes	Possible (Geophagus altifrons found here).	Cryptogenic	Not listed	Not listed	Heok et al. (2020)
Notopterus notopterus	Yes	High certainty, exact match	Alien	LC	Stable	Heok et al. (2020)
Oreochromis sp.[c]	Yes	*Oreochromis niloticus* found here	Cryptogenic	Not listed	Not listed	Heok et al. (2020)
Oxyeleotris marmorata	Yes	High certainty, exact match	Alien	LC	Unknown	Heok et al. (2020)
Parambassis sp.	Yes	Parambassis siamensis reported in Kranji Reservoir	Cryptogenic	Not listed	Not listed	Heok et al. (2020)
Rhinogobius sp.	Yes	Possible, as Rhinogobius similis reported at Kranji Marsh	Cryptogenic	Not listed	Not listed	Heok et al. (2020)
Trichopodus pectoralis	Yes	High certainty, exact match	Alien	LC	Decreasing	Heok et al. (2020)
Trichopodus trichopterus	Yes	High certainty, exact match	Native	LC	Unknown	Heok et al. (2020)
Trichopsis vittata	Yes	High certainty, exact match (Reported for Kranji Marsh) – in Singapore Biodiversity Records (2016)	Native	LC	Unknown	Heok et al. (2020)

Notes:
(a) *Taxa prefixed with an underscore cannot be classified further. Abbreviations: p-phylum, c-class, o-order, f-family*
(b) *Synonym or possible species complex with Pseudogobiopsis sp.*
(c) *Oreochromis niloticus and O. aureus cannot be distinguished due to shared haplotypes and/or hybridisation.*

4. SUMMARY

The current work presents new findings that suggest Kranji Reservoir is a turbid, hyper-eutrophic freshwater system that is being impacted by both natural and human pressures. Water clarity was found to be relatively low at Kranji Reservoir, as light measurements collected suggest light attenuation throughout the water column followed exponential decay and the light below 3 m water depth was negligible. This was supported by the relatively shallow secchi depth and high turbidity measurements that were collected during the sampling period. Turbidity was exacerbated further during periods when surface runoff and emergent/ floating vegetation cover were high, particularly in the reservoir after the September 2021 storm event.

Current flow measurements were found to be relatively consistent in terms of direction across the vertical water column, except at some depths which include the surface water layer. This suggests wind to be an important driving factor of conditions observed at Kranji Reservoir. Wind is an important driver of reservoir mixing and the water quality-depth profiles suggest the reservoir is well-mixed throughout the year, with the data showing no evidence of strong thermal stratification taking place. DO values <3 mg/L were observed at the reservoir bed in May 2021, which may suggest organic decomposition and subsequent anoxic conditions are taking place. Water quality parameters were generally within the NEA limits, although short-lived exceedances were observed in some parameters throughout the sampling period.

Sediment analyses revealed relatively high TP present in sediment samples collected from the five sampling locations, with the highest value being observed during May 2021. This presents evidence of a high potential for internal loading of P from the sediments to the water column. The relatively higher ratios of FeP:CaP observed at Kranji Reservoir supports assumptions that this reservoir has received greater anthropogenic inputs of P over time, which may be released under alkaline conditions.

Levels of total nitrogen concentrations were also found to be relatively high, reaching a peak value in May 2021. Evidence of heavy metals was also found in the sediments, although most of the metals analysed were below Dutch Standards limits, with the exception of Cu, Zn and Sb. The presence of heavy metals is expected to have implications for the functioning of biotic communities present in Kranji Reservoir, which in turn play an important role in supporting ecosystem functions and services. This can result in a negative effect on important system processes, ranging from organic matter recycling, pollutant degradation and biomass production.

Three methods were applied in the current works to assess macroinvertebrate communities in Kranji Reservoir. A total of 3 phyla with 11 families were identified by grab sampling; 17 phyla with 41 families were identified by sweep sampling; and a total of 13 phyla with 25 families were observed over the colonisation sampling events conducted in May 2022. Differences were observed between methods used, even when sampling sites were located near to each other. The mean abundance of coloniser samples was found to be substantially lower than that of sweep samples, but mean species richness was greater in coloniser samples than in sweep samples. Both methods produced greater species abundance and richness than the sediment grab samples. Depth was found to be an important driver of macroinvertebrate species diversity. Grab sampling was used to collect samples from depths greater than 1 m, whereas sweep and coloniser sampling occurred at depths of approximately 1 m. Comparison of the diversity indices found very low to low species diversity for samples collected from the deeper sites (grab sampling), compared to the medium to high species diversity found in the shallower regions (sweep and coloniser sampling). These differences between methods could reflect the different microhabitats that were sampled by each of the methods used in this study and for this reason, a combination of all three methods is recommended for future assessments of macroinvertebrate communities at this site.

Vegetation was observed across >169 ha (>50%) of the aquatic survey area of Kranji Reservoir. Field observations and sonar imaging revealed vegetation was typically found in shallower parts of the reservoir, where greater light penetration facilitated the growth of aquatic macrophytes. A total of 11 different aquatic species were identified during the aquatic vegetation survey of which five were emergent/ floating and six were partially submerged. Amongst these species, the hyacinth *Eichornia crassipes*, the water lotus (*Nelumbo nucifera*) and Hydrilla (*Hydrilla verticillata*) were noted to have pest potential. These species pose a potential risk to the overall health of the reservoir, as high abundance and distribution of these species can contribute towards greater DO consumption and organic decomposition. However, it is noted that their abundance and distribution is actively managed by PUB and the risk of these species causing undesirable, irreversible changes to this system are likely minimal. Nutrient analyses for vegetation revealed spatial variability in TP, TN and TC across the reservoir. Interestingly, TP levels measured during the first aquatic vegetation survey were tenfold compared to values recorded during the second survey, which is speculated to be driven by the presence/ absence of *Hydrilla verticillata* that contributes towards TP removal from water bodies.

The hydroacoustic surveys present new data for fish biomass at Kranji Reservoir. The findings of the current work suggest that the fish distribution in the reservoir is rather uniform. Higher fish densities are predicted in the shallower southern half of the reservoir but it is likely that different species assemblages are present in the deeper regions (central to north region of the reservoir). This work also applied a new eDNA technique to large quantities of water samples (10 litres of water per sampling site) collected at different locations and depths of the reservoir and successfully detected 15 fish species, 13 of which were previously identified in past studies that used conventional fishing techniques. These results show eDNA techniques can be used to identify fish species present in Kranji Reservoir, but not all fish species listed in the historical data were identified, which suggests that preservation and quantity of DNA available in the water column are confounding factors for cataloguing fish species present in the reservoir.

As the data available from current work is limited to a relatively short timescale (< 1 year of monitoring data), it is unclear whether the conditions at Kranji Reservoir are stable or shifting towards a potential new, alternate state. As environmental drivers (climate) and anthropogenic drivers (e.g. increasing human development at the Project Site and surroundings) continue to change, the reservoir is expected to undergo changes in abiotic and biotic components, processes and services. There is some evidence of a potential alternate stable state existing at Kranji Reservoir, as some signs of biostability were observed during the monitoring period, with the system alternating between relatively clear, macrophyte-rich conditions and a more turbid, phytoplankton-dominated state (particularly in the reservoir after the September 2021 storm). In the case of the September 2021 storm event, a short-lived disturbance shifted the reservoir system to a highly eutrophic, turbid state, although the change was relatively short-lived and the system reverted back to baseline conditions observed throughout the majority of the monitoring period. This indicates a degree of resilience in the behaviour of Kranji Reservoir, as it was able to return to its prior state following the September 2021 storm event. Longer monitoring records are required to assess the overall trajectory of abiotic and biotic factors at Kranji Reservoir, however, the data presented in this study provides a robust representation of the baseline conditions currently observed at the Reservoir Project Site.

5. REFERENCES

- Blakely, T., Harding, J. and Eikaas, H.S. (2014) The Singscore: a macroinvertebrate biotic index for assessing the health of Singapore's streams and canals. *Raffles Bulletin of Zoology*, 62, 540-548.
- Bradshaw, E.L., Allen, M.S. and Netherland, M. (2015) Spatial and temporal occurrence of hypoxia influences fish habitat quality in dense *Hydrilla verticillata*. *Journal of Freshwater Ecology*, 30(4), 491-502. DOI: 10.1080/02705060.2014.982726
- Chambers, J. Q., Higuchi, N., Schimel, J. P., Ferreira, L. V, & Melack, J. M. (2000). Decomposition and Carbon Cycling of Dead Trees in Tropical Forests of the Central Amazon. Source: Oecologia, 122(3), 380–388. http://www.jstor.org/stable/4222555
- Chan, S. and Lau, W. (2021) Biodiversity Record: The freshwater limpet, Ferrissia cf. californica, in Singapore. *Nature in Singapore*, 14, e2021033. DOI: 10.26107/NIS-2021-0033
- Clews, E., Low, E. W., Belle, C. C., Todd, P. A., Eikaas, H. S., & Ng, P. K. L. (2014). A pilot macroinvertebrate index of the water quality of Singapore's reservoirs. Ecological Indicators, 38, 90–103. https://doi.org/10.1016/j.ecolind.2013.10.030
- Climatic Research Unit (CRU) (2021) Climatic Research Unit website. Available at: http://www.cru.uea.ac.uk/ [Access date 1st June 2021].
- Dalu, T. and Chauke, R. (2020). Assessing macroinvertebrate communities in relation to environmental variables: the case of Sambandou wetlands, Vhembe Biosphere Reserve. *Applied Water Science*, 10(16), pp. 1-11. DOI: 10.1007/s13201-019-1103-9.
- Dataflow Systems Ltd (2021). Odyssey Xtreem PAR logger user manual.
- Davison, G.W.H., Ng, P.K.L. and Ho, H.C. (Eds.) (2008) *The Singapore Red Data Book: Threatened Plants & Animals of Singapore*. Singapore: The Nature Society.
- Department of Environment and Science (DES) (2018). Monitoring and Sampling Manual. Environmental Protection (Water) Policy.
- Dersseh, M.G., Melesse, A.M., Tilahun, S.A., Abate, M. and Dagnew, D.C. (2019) Water Hyacinth: Review of its Impacts on Hydrology and Ecosystem Services - Lessons for Management of Lake Tana, in A.M. Melesse, W. Abtew and G. Senay (Eds.) Extreme Hydrology and Climate Variability: Monitoring, Modelling, Adaptation and Mitigation. USA: Elsevier.
- Environmental Protection (Water) Policy - Monitoring and Sampling Manual. Biological assessment (2018). Guidance on using Photosynthetically Active Radiation (PAR) as a method to measure light availability for aquatic photosynthetic organisms facing acute impacts. February 2018. Downloaded from: https://environment.des.qld.gov.au/__data/assets/pdf_file/0017/90512/biological-assessment-measuring-light-using-par.pdf
- Fong, L. S., Leng, M. J., Taylor. David (2019) *A century of anthropogenic environmental change in tropical Asia: Multi-proxy palaeolimnological evidence from Singapore's Central Catchment.* The Holocene 2020, Vol. 30(1) 162–177. DOI: 10.1177/0959683619875808
- Gin, K-Y-H. and Gopalakrishnan, A.P. (2010) *Sediment Oxygen Demand and Nutrient Fluxes for a Tropical Reservoir in Singapore*. *Journal of Environmental Engineering*, 136(1), 78-85. DOI: 10.1061/(asce)ee.1943-7870.0000119.
- Gin, K.Y-H., Ramaswamy, U. and Gopalakrishnan, A.P. (2011) Comparison of Nutrient Limitation in Freshwater and Estuarine Reservoirs in Tropical Urban Singapore. *Journal of Environmental Engineering*, 137(10), 913-919. DOI: 10.1061/(asce)ee.1943-7870.0000397.
- Govedich, F. R., Bain, B. A., Moser, W. E., Gelder, S. R., Davies, R. W., & Brinkhurst, R. O. (2010). Annelida (Clitellata): Oligochaeta, Branchiobdellida, Hirudinida, and Acanthobdellida. In

Ecology and Classification of North American Freshwater Invertebrates (pp. 385–436). Elsevier Inc. https://doi.org/10.1016/B978-0-12-374855-3.00012-1.

- Graça, M. A. S., Pinto, P., Cortes, R., Coimbra, N., Oliveira, S., Morais, M., Carvalho, M. J., & Malo, J. (2004). Factors affecting macroinvertebrate richness and diversity in portuguese streams: A two-scale analysis. International Review of Hydrobiology, 89(2), 151–164. https://doi.org/10.1002/iroh.200310705
- Harvey, B. C., & Stewart, A. J. (1991). Fish size and habitat depth relationships in headwater streams. Oecologia, 87(3), 336–342. https://doi.org/10.1007/BF00634588
- Heino, J. (2000) Lentic macroinvertebrate assemblage structure along gradients in spatial heterogeneity, habitat size and water chemistry. *Hydrobiologia*, 418, 229-242. DOI: 10.1023/A:1003969217686
- Ho, B.S.K. and Dudgeon, D. (2016) Are high densities of fishes and shrimp associated with top-down control of tropical benthic communities? A test in three Hong Kong streams. *Freshwater Biology*, 61, 57–68.
- Ho, J.K.I., Quek, R.F., Ramchunder, S.J., Memory, A., Theng, M.T.Y.,…, & Clews, E. (2018). Aquatic macroinvertebrate richness, abundance and distribution in the Nee Soon freshwater swamp forest, Singapore. *Gardens' Bulletin Singapore*, 70, 71-108. DOI: 10.26492/gbs70(suppl.1).2018-05.
- IUCN Red List (2022) The IUCN Red List Of Threatened Species. Available at: https://www.iucnredlist.org/ [Access date: 24th March 2022].
- Johnson, J.A. and Newman, R.M. (2011) A comparison of two methods for sampling biomass of aquatic plants. *Journal of Aquatic Plant Management*, 49(1), 1-8.
- Kazibwe, F., Makanga, B., Rubaire-Akiiki, C., Ouma, J., Kariuki, C., Kabatereine,..., and Stothard, J.R. (2006) *Hydrobiologia*, 568, 433-444. DOI: 10.1007/s10750-006-0224-y
- Kwik, J.T.B., Lim, B.H.R., Saw, C.Y.A., Tan, L.Y.C., Liu, S.S., Chan, W.W.R.,…, and Yeo, D.C.J. (2020) *Biodiversity and Biological Interactions in Singapore's Reservoirs and Waterways – A study of Food Web and Trophic Structure, and Implications for Environmental and Water Quality Management (Phase 2)*. Progress Report 8: Kranji Reservoir.
- Kutty, S.N., Loh, R.K., Bannister, W. and Taylor, D. (2022). Evaluation of a diatom eDNA-based technique for assessing water quality variations in tropical lakes and reservoirs. *Ecological Indicators*, 141, 109108. DOI: 10.1016/j.ecolind.2022.109108
- Krupa. E., Romanova, Sophia., Berkinbaev, Galym., Yakoleva, Natalya., Sadvakasov, Erlan. (2020) *Zooplankton as Indicator of the Ecological State of Protected Aquatic Ecosystems (Lake Borovoe, Burabay National Nature Park, Northern Kazakhstan)*. Water 2020, 12(9), 2580; https://doi.org/10.3390/w12092580
- Li, Y., Wang, L., Chao, C., Yu, H., Yu, D. and Liu, C. (2021) Submerged macrophytes successfully restored a subtropical aquacultural lake by controlling its internal phosphorus loading. *Environmental Pollution*, 268(B), 115949. DOI: 10.1016/j.envpol.2020.115949.
- Liew JH, Tan HH, Yi Y, Yeo DCJ (2013) *Ecology and origin of the introduced cichlid Acarichthys heckelii in Singapore's fresh waters—first instance of establishment*. Environmental Biology of Fishes: 1–10, http://dx.doi.org/10.1007/s10641- 013-0201-z
- Loke, L.H.L., Clews, E., Low, E., Belle, C.C., Todd, P.A.,…, and Ng, P.K.L. (2010) Methods for sampling benthic macroinvertebrates in tropical lentic systems. *Aquatic Biology*, 10, 119-130. DOI: 10.3354/ab00274.
- Love, R. (1977). Target strength of an individual fish at any aspect. The Journal of the Acoustical Society of America, 62(6), 1397.

- Long M.H., Rheuban J.E., Berg P., and Zieman J.C. (2012). A comparison and correction of light intensity loggers to photosynthetically active radiation sensors. Limnology and Oceanography: Methods, 10, pp. 416–424.
- Makhanu, K.S. (1997) Impact of water hyacinth in Lake Victoria. Water and sanitation for all: partnerships and innovations, in 23rd Water Engineering and Development Centre Conference Durban, South Africa.
- Noleto, E. V., Barbosa, M. V. M., & Pelicice, F. M. (2019). Distribution of aquatic macrophytes along depth gradients in Lajeado Reservoir, Tocantins River, Brazil. Acta Limnologica Brasiliensia, 31. https://doi.org/10.1590/s2179-975x9317.
- Ng, P.K.L., Tan, H.T.W., Hui, T.H., Yeo, D.C.J., Hui, N.T., Yen-ling, L. and Hee, N.H. (2010) *Final Report of the Broad-Based Biodiversity Study of Singapore's Reservoirs Kranji Reservoir*. A report on biodiversity at Kranji Reservoir in 2010. Singapore: National University of Singapore.
- Olds, B. P., Jerde, C. L., Renshaw, M. A., Li, Y., Evans, N. T., Turner, C. R., Deiner, K., Mahon, A. R., Brueseke, M. A., Shirey, P. D., Pfrender, M. E., Lodge, D. M. and Lamberti, G. A. (2016) 'Estimating species richness using environmental DNA', Ecology and Evolution, 6(12), pp. 4214–4226. doi: 10.1002/ece3.2186.
- Ono, E.R., Manoel, P.S., Melo, A.L.U. and Uieda, V.S. (2020) Effects of riparian vegetation removal on the functional feeding group structure of benthic macroinvertebrate assemblages. *Community Ecology*, 21(2), 145-157. DOI: 10.1007/s42974-020-00014-7.
- Rawer-Jost, C., Böhmer, J., Blank, J. and Rahmann, H. (2000). Macroinvertebrate functional feeding group methods in ecological assessment. *Hydrobiologia*, 422, 225-232. DOI: 10.1023/A:1017078401734.
- Rezende, R., Novaes, J., Albuquerque, C., Costa, R. and Gonçalves, J. (2018) *Journal of Arid Environments*, 154, 8-14. DOI: 10.1016/j.jaridenv.2018.03.002
- Rognes, T., Flouri, T., Nichols, B., Quince, C. and Mahé, F. (2016) VSEARCH: a versatile open source tool for metagenomics. *PeerJ*, 4, e2584. DOI: 10.7717%2Fpeerj.2584
- Rosas-Rodriguez, K.G. (2016) Assemblage Structure, Production, and Food Web Dynamics of Macroinvertebrates in Tropical Island Headwater Streams. Electronic Theses and Dissertations. 1384. https://digitalcommons.georgiasouthern.edu/etd/1384
- Sosa-Aranda Inari, Zambrano Luis (2020) Relationship between turbidity and the benthic community in the preserved Montebello Lakes in Chiapas, Mexico. Marine and Freshwater Research 71, 824-831.
- Steig, T. and Nealson, P.A. (2010) Development of a method for estimating the probability of detecting fish through a hydroacoustic beam. *Environmental Science*. DOI: 10.1109/OCEANS.2010.5664422
- Tumwesigye, C., Yusuf, S. K., & Makanga, B. (2000). Structure and composition of benthic macroinvertebrates of a tropical forest stream, River Nyamweru, western Uganda. African Journal of Ecology, 38(1), 72–77. https://doi.org/10.1046/j.1365-2028.2000.00212.x
- Valdez-Moreno, M., Ivanova, N.V., Elías-Gutiérrez, M., Pedersen, S.L., Bessonov, K. and Hebert, P.D.N. (2019) Using eDNA to biomonitor the fish community in a tropical oligotrophic lake. *PLoS ONE*, 14(4), e0215505. DOI: 10.1371/journal.pone.0215505.
- Verspagen, J.M.H., Van de Waal, D.B., Finke, J.F., Visser, P.M., Van Donk, E. and Huisman, J. (2014) Rising CO2 Levels Will Intensify Phytoplankton Blooms in Eutrophic and Hypertrophic Lakes. *PLoS One*, 9(8), e104325. DOI: 10.1371/journal.pone.0104325.

- Vuori, K-M., Luotonen, H. and Liljaniemi, P. (1999) Benthic macroinvertebrates and aquatic mosses in pristine streams of the Tolvajärvi region, Russian Karelia. *Boreal Environment Research*, 4, 187-200.
- Wang, S., Jin, X., Zhao, H., Zhou, X. and Wu, F. (2007) Effects of Hydrilla Verticillata on Phosphorus Retention and Release in Sediments. *Water, Air, and Soil Pollution*, 181, 329-339. DOI: 10.1007/s11270-006-9305-9.
- Yeo, D.C.J., Ho, J.K.I., Wei, L.B., Hui, N.T., Wilkinson, C., Yiwen, Z.,…, and Yeo, (J.W.L.) (2016) *Kranji Marsh aquatic organism survey 7–8 January 2016*. An identification key of aquatic organisms identified in a Kranji Marsh survey performed in January 2016.
- Yule, C.M and Sen, Y.H. (Eds.) (2004) *Freshwater Invertebrates of the Malaysian Region*. Malaysia: Academy of Sciences.

APPENDIX A LIST OF MACROINVERTEBRATES IDENTIFIED DURING SWEEP SAMPLING EVENTS IN MAY 2022

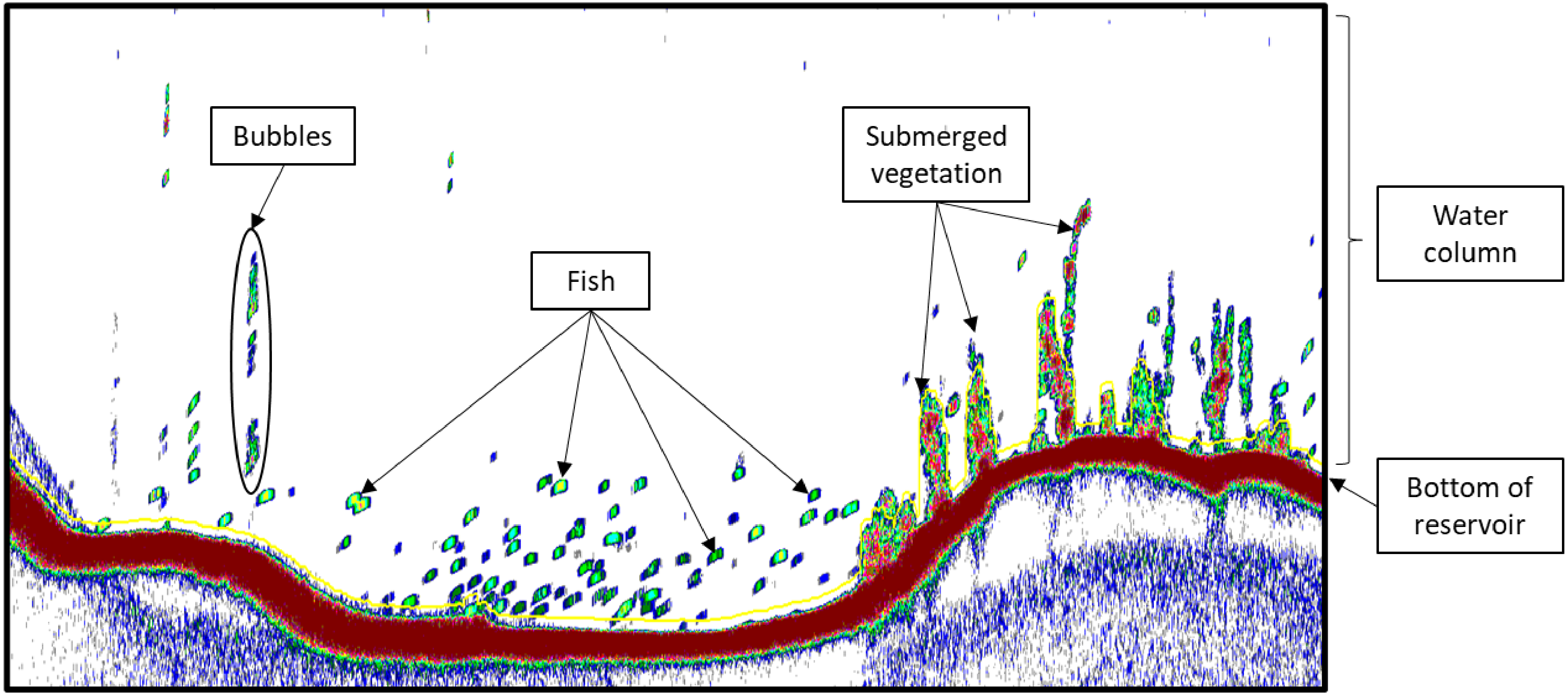
Number #	Family
1	Acarina
2	Araneae
3	Amphipoda
4	Carabidae
5	Atyidae
6	Palaemonidae
7	s-f Aphroteniinae
8	Ceratopogonidae
9	Chaoboridae
10	Chironomidae
11	s-f Chironominae
12	s-f Diamesinae
13	s-f Orthocladiinae
14	Stratiomyidae
15	Tabanidae
16	s-f Tanypodinae
17	Tipulidae
18	Baetidae
19	Ampullariidae
20	Bithyniidae
21	Lymnaeidae
22	Physidae
23	Planorbidae
24	Thiaridae
25	Viviparidae
26	Belostomatidae
27	Micronectidae
28	Naucoridae
29	Helotrephidae
30	Erpobdellidae
31	Glossiphoniidae

Number #	Family
32	Coenagrionidae
33	Libellulidae
34	Platycnemididae
35	S.O. Zygoptera
36	Oligochaeta
37	Ecnomidae
38	Cladocera
39	Conchostraca
40	Copepoda
41	Ostracoda

APPENDIX B LIST OF MACROINVERTEBRATES IDENTIFIED DURING COLONISER SAMPLING IN MAY 2022

Number #	Family
1	Acarina
2	Atyidae
3	Parastacidae
4	Ceratopogonidae
5	Chironomidae
6	s-f Chironominae
7	s-f Podonominae
8	s-f Tanypodinae
9	Ampullariidae
10	Ancylidae
11	Bithyniidae
12	Lymnaeidae
13	Physidae
14	Planorbidae
15	Thiaridae
16	Micronectidae
17	Helotrephidae
18	Erpobdellidae
19	Lestidae
20	Oligochaeta
21	Ecnomidae
22	Cladocera
23	Conchostraca
24	Copepoda
25	Ostracoda

APPENDIX C INTERPRETATION KEY FOR HYDROACOUSTIC ECHOGRAM



Bubbles
Fish
Submerged vegetation
Water column
Bottom of reservoir

APPENDIX D ENVIRODNA REPORT

CONFIDENTIAL REPORT

Project number 1915CR3
March 23, 2022

Using eDNA to detect fish species from a Lake in Singapore

Prepared for:
Simon Drummond

Hydrobiology
Regional Manager - Southeast Asia
Brisbane, QLD

Prepared by:
Andrew Weeks, Sue Song &
Rachael Impey

EnviroDNA
95 Albert St
Brunswick, VIC 3056
Australia

Disclaimer

The professional analysis and advice in this report has been prepared for the exclusive use of the party or parties to whom it is addressed (the addressee) and for the purposes specified in it. This report is supplied in good faith and reflects the knowledge, expertise and experience of the consultants involved. The report must not be published, quoted or disseminated to any other party without prior written consent from EnviroDNA pty ltd.

EnviroDNA pty ltd accepts no responsibility whatsoever for any loss occasioned by any person acting or refraining from action as a result of reliance on the report. In conducting the analysis in this report EnviroDNA pty ltd has endeavoured to use what it considers is the best information available at the date of publication including information supplied by the addressee. Unless stated otherwise EnviroDNA pty ltd does not warrant the accuracy of any forecast or prediction in this report.

EnviroDNA Pty Ltd
+61 3 9028 8753
envirodna.com
—

Summary

Protecting or enhancing biodiversity is a key objective for many conservation activities. However, measuring biodiversity particularly in aquatic environments, can be difficult, time consuming, expensive, and often highly invasive. Analysis of environmental DNA (eDNA) is a relatively new, cheap, quick and non-invasive method for detecting single species or, more recently, entire taxonomic groups (Rees *et al.* 2014; McColl-Gausden *et al.* 2019; Thomsen and Willerslev 2015). As the name suggests, eDNA refers to the genetic material that an organism leaves behind in its environment. Quantitative comparisons with traditional sampling methods indicate that eDNA methods can be superior in terms of sensitivity and cost efficiency, particularly for scarce, elusive or cryptic species (Biggs *et al.* 2015; Lugg *et al.* 2018; Smart *et al.* 2015; Thomsen *et al.* 2012; Valentini *et al.* 2016), enabling effective detection of species at low densities. More recently, direct comparisons with electrofishing have demonstrated eDNA metabarcoding is more sensitive and has higher detection probabilities for fish species generally (McColl-Gausden *et al.* 2021).

Hydrobiology undertook water sampling from a Lake in Singapore to trial the eDNA sampling approach and new ground water filters for sampling a larger amount of water. Filtering on site reduces DNA degradation that may occur during transport of water (Yamanaka *et al.* 2016). The ground water filters (Waterra eDNA filters; https://waterra.com/product-category/waterra-edna-filters/) enable a much larger volume of water to be passed over the filter, potentially collecting larger amounts of DNA and increasing detection probabilities. After sampling, the filters were stored in ethanol before being transported to the EnviroDNA laboratories. A total of 5 Waterra filters were sent to EnviroDNA.

EnviroDNA trialed various DNA extraction protocols to process the Waterra filters. Initially, a similar protocol was used as found in Tingley *et al.* (2020) and McColl-Gausden *et al.* (2021), with ATL buffer (Qiagen) and Proteinase K (Qiagen) added directly to the filters, with these incubated at 55 °C for 2 hrs to allow digestion. However, the initial first PCR in the library construction (see below) indicated very low amounts of DNA from the filters. After trialing a further extraction with a longer incubation step (overnight) and also investigating whether there was DNA in the ethanol in which the filters were stored (both returned sporadic and very low levels of DNA), we trialed a mechanical extraction method for retrieving DNA from the Waterra filter paper. This method included opening the filters with a hacksaw, cutting a portion of each filter paper (in triplicate), and then adding each to a tube with lysis buffer (ATL), proteinase K and magnetic beads. Samples were then processed in a TissueLyser (Qiagen) for 1 min to disrupt the DNA from the filter paper. DNA was then extracted from the filters using a DNeasy Blood and Tissue Kit (Qiagen), including an extraction negative.

Fish biodiversity assessments were performed with a universal Fish assay targeting a small region of the 12S mitochondrial DNA (McColl-Gausden *et al.* 2021). Library construction involved two rounds of PCR whereby the first round employed gene-specific primers to amplify the target region and the second round incorporated sequencing adapters and unique barcodes for each sample-amplicon combination included in the library. Negative controls were also included during library construction. Negative controls consisted of the extraction negative as well as PCR negatives where nuclease-free water was used in place of DNA during both rounds of PCR. Sequencing was carried out on an Illumina iSeq machine.

EnviroDNA Pty Ltd
+61 3 9028 8753
envirodna.com

Following quality control filtering to remove primer sequences, truncated reads and low-frequency reads, DNA sequences were clustered into Operational Taxonomic Units (OTUs) on the basis of sequence similarity. Taxonomic assignment was performed with VSEARCH software (Rognes *et al.* 2016) whereby each OTU cluster was assigned a species identity using a threshold of 95% by comparing against a reference sequence database built using sequences from the public repository Genbank (https://www.ncbi.nlm.nih.gov/genbank/). Where a species could not be assigned (i.e. reference database was deficient and/or taxa were poorly-characterised), taxonomic assignments were then made to the next lowest taxonomic rank without further classification.

Sequence reads were obtained for a total of 15 samples (5 filters, 3 samples per filter). Sequence reads per filter (summed over the 3 replicates) ranged from 33,436 to 256,481, although reads per replicate ranged from 231-118,060. The variation across replicates probably highlights the variation found across the Waterra filter paper. A summary of the fish species detected from each sample is provided in Table 1. Due to the low number of reads across some replicate samples, we have included species detected below the usual 0.1% threshold. While these species may be present at the site, the threshold exists to minimise false positive detections. Overall, Filter 1 had the most detections (13), although many of these detections could only be made at higher taxonomic levels due to a relatively poor reference library for the sampled region. The other 4 filters had 7 or 8 detections, with a total of 15 different detections at the species, genus or higher taxonomic levels from the lake samples.

The Waterra filters posed some challenges for processing, and overall the amounts of DNA returned from the filters were relatively low compared to other eDNA samples processed within EnviroDNA's laboratories from regular filters such as Smith Root, Sterivex or normal disc filters. While they have allowed the filtering of larger amounts of water from the lake samples, there are difficulties processing these filters and EnviroDNA recommends trialing 5 μM Smith Root filters for future sampling.

Table 1. Summary of results from the Fish biodiversity assay for each sample with number of reads for each detection.

	Filter 1			Filter 2			Filter 3			Filter 4			Filter 5		
Scientific names	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**3.3**	**4.1**	**4.2**	**4.3**	**5.1**	**5.2**	**5.3**
_c:Actinopteri	7171	12402	25019	52	269	263	487	269	270	0	0	0	0	245	0
_f:Cichlidae	220	0	78	128	38	0	0	273	0	0	0	130	77	62406	8422
Barbatula sp.	0	0	0	0	0	0	0	0	0	0	152	0	0	0	0
Chitala ornata	0	0	0	411	0	0	0	0	104	0	0	0	0	0	0
Cyprinus carpio	15	0	18	10	0	0	0	0	0	13	0	0	12	0	0
Eugnathogobius sp. (1)	8503	4013	103	0	163	0	0	0	0	0	3074	0	0	0	0
Geophagus sp.	30951	4825	14462	1753	6111	0	3546	0	0	0	2181	20821	0	0	39390
Notopterus notopterus	401	0	0	0	0	0	0	0	0	0	30	6687	0	0	0
Oreochromis sp. (2)	603	0	4079	0	0	0	0	0	2012	0	0	0	43	0	0
Oxyeleotris marmorata	15226	0	0	132	0	0	0	0	0	0	0	0	0	0	16596
Parambassis sp.	20472	15623	18186	11603	106746	112730	113245	53892	81601	14	0	53	99	0	0
Rhinogobius sp.	12900	1631	2183	0	0	0	0	0	0	281	0	0	0	0	455
Trichopodus pectoralis	3780	0	140	0	0	0	0	0	0	0	0	0	0	0	0
Trichopodus trichopterus	230	575	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichopsis vittata	15178	1302	6255	0	0	0	782	0	0	0	0	0	0	0	0
Number of taxa detected	**13**	**7**	**10**	**7**	**5**	**2**	**4**	**3**	**4**	**3**	**4**	**4**	**4**	**2**	**4**

Taxa prefixed with an underscore cannot be classified further. Abbreviations: p-phylum, c-class, o-order, f-family

Notes:

1) *Synonym or possible species complex with Pseudogobiopsis sp.*
2) *Oreochromis niloticus and O. aureus cannot be distinguished due to shared haplotypes and/or hybridisation.*

EnviroDNA Pty Ltd
+61 3 9028 8753
envirodna.com

References

Biggs J., Ewald N., Valentini A. *et al.* (2015) Using eDNA to develop a national citizen science-based monitoring programme for the great crested newt (*Triturus cristatus*). *Biol. Conserv.* doi: 10.1016/j.biocon.2014.11.029. [online].

Lugg W. H., Griffiths J., van Rooyen A. R., Weeks A. R. & Tingley R. (2018) Optimal survey designs for environmental DNA sampling. *Methods Ecol. Evol.* **9** , 1049–1059.

McColl-Gausden E. F., Weeks A. R., Coleman R. A. *et al.* (2021) Multispecies models reveal that eDNA metabarcoding is more sensitive than backpack electrofishing for conducting fish surveys in freshwater streams. *Mol. Ecol.* **n/a**. [online].

McColl-Gausden E. F., Weeks A. R. & Tingley R. (2019) A field ecologist's guide to environmental DNA sampling in freshwater environments. *Aust. Zool.* doi: 10.7882/az.2019.025.

Rees H. C., Maddison B. C., Middleditch D. J., Patmore J. R. M. & Gough K. C. (2014) REVIEW: The detection of aquatic animal species using environmental DNA – a review of eDNA as a survey tool in ecology. *J. Appl. Ecol.* **51** , 1450–1459. [online].

Rognes, T., Flouri, T., Nichols, B., Quince, C. and Mahé, F. (2016) VSEARCH: A versatile open source tool for metagenomics. *PeerJ*, 4, p.e2584.

Smart A. S., Tingley R., Weeks A. R., Van Rooyen A. R. & McCarthy M. A. (2015) Environmental DNA sampling is more sensitive than a traditional survey technique for detecting an aquatic invader. *Ecol. Appl.* **25** , 1944–1952.

Tingley R, Coleman R, Gecse N, van Rooyen A, Weeks AR. 2020. Accounting for false positive detections in occupancy studies based on environmental DNA: a case study of a threatened freshwater fish (Galaxiella pusilla). *Environmental DNA* doi:10.1002/edn3.124.

Thomsen P. F., Kielgast J., Iversen L. L. *et al.* (2012) Monitoring endangered freshwater biodiversity using environmental DNA. *Mol. Ecol.* **21** , 2565–2573.

Thomsen P. F. & Willerslev E. (2015) Environmental DNA - An emerging tool in conservation for monitoring past and present biodiversity. *Biol. Conserv.* doi: 10.1016/j.biocon.2014.11.019. [online].

Valentini A., Taberlet P., Miaud C. *et al.* (2016) Next-generation monitoring of aquatic biodiversity using environmental DNA metabarcoding. *Mol. Ecol.* **25** , 929–942.

Yamanaka H., Motozawa H., Tsuji S., Miyazawa R. C., Takahara T. & Minamoto T. (2016) On-site filtration of water samples for environmental DNA analysis to avoid DNA degradation during transportation. *Ecol. Res.* **31** , 963–967.

APPENDIX 7.3 ECOLOGICAL CHARACTER DESCRIPTION (ECD) REPORT

ERM

Hydrobiology

FLOATING PHOTOVOLTAIC SYSTEM ON KRANJI RESERVOIR – ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

BRISBANE | PERTH | **SINGAPORE** | PAPUA NEW GUINEA

ECOLOGICAL CHARACTER DESCRIPTION

S20021

—

SEPTEMBER 2023

THIS COMPANY IS REGISTERED FOR GST.

STREET
Singapore Water Exchange
84 Toh Guan Road East
#04-08/09
Singapore 608501

REGISTERED
5001 Beach Road
#04-03/A7
Golden Mile Complex
Singapore 199588

CONTACT
singapore@hydrobiology.com

www.hydrobiology.com

ACKNOWLEDGEMENTS

This Ecological Character Description (ECD) has been based on the findings of the baseline surveys. Thanks are due to the PUB, Singapore's National Water Agency, and NParks for allowing access to Kranji Reservoir and its shorelines, for providing data where possible, and for facilitating all fieldwork activities. We would also like to thank several staff at Hydrobiology, ERM, Camphora and Hydroinformatics Institute for assistance in the fieldwork, sample processing, data analysis and interpretation, and the subsequent write up of this ECD. Thanks are also due to the Nature Groups that participated in the Stakeholder meetings held to discuss the ECD. This work would not have been possible were it not for the support of the Client.

LIST OF ABBREVIATIONS

Acronym	Abbreviation
ANZECC	Australian and New Zealand Environment and Conservation Council
BOD	Biological oxygen demand
DEWHA	Department of the Environment, Water, Heritage and the Arts
DO	Dissolved Oxygen
EAAF	East Asian – Australasian Flyway
EAAFP	East Asian – Australasian Flyway Partnership
ECD	Ecological Character Description
EIA	Environmental Impact Assessment
ENSO	El Niño–Southern Oscillation
ERM	Environmental Resources Management (Singapore) Pte Ltd
EPA	Environmental Protection Agency
F	Freshwater
FFG	Functional feeding group
FPOM	Fine particulate organic matter
FPV	Floating Photovoltaic System
LAC	Limits of Acceptable Change
LC	Least common
M	Marine
NSRCC	National Service Resort and Country Club
NSS	Nature Society Singapore
NHB	National Heritage Board
NUSLHMSG	NUS Libraries Historical Maps of Singapore
P	Phosphorus
PAR	Photosynthetic Active Radiation
PUB	Public Utilities Board
RMBR	Raffles Museum of Biodiversity Research
SBWR	Sungei Buloh Wetland Reserve
TC	Total carbon

Acronym	Abbreviation
TN	Total nitrogen
TP	Total phosphorus
UVC	Underwater Visual Census
VPS	Vantage point surveys
VU	Vulnerable

LIST OF SYMBOLS

Acronym	Abbreviation
<	Less than
>	More than
%	percentage
ø	Null sign
±	Plus or minus
Al	Aluminium
As	Arsenic
Ba	Barium
B	Boron
Cd	Cadmium
cm	Centimetres
cm^2	Centimetres squared
cm^3	Centimetres cubed
Cr	Chromium
Cu	Copper
Fe	Iron
ha	Hectares
Hg	Mercury
mg/kg	Milligrams per kilogram
Mg/L	Milligrams per litre
mm	Millimetres

Acronym	Abbreviation
m	Metres
Mn	Manganese
Mo	Molybdenum
Ni	Nickel
NTU	Nephelometric Turbidity Unit
Pb	Lead
Sb	Antimony
Se	Selenium
Zn	Zinc

EXECUTIVE SUMMARY

Environmental Resources Management (S) Pte Ltd (ERM) has been appointed to undertake an Environmental Impact Assessment (EIA) for the construction and operation of a Floating Photovoltaic (FPV) System on Kranji Reservoir (herein referred to as the ‘Project’). ERM has further engaged Hydrobiology Pte Ltd (Hydrobiology), Camphora Pte Ltd (Camphora) and Hydroinformatics Institute Pte Ltd (H2i) to undertake the roles of Aquatic Specialist, Biodiversity Specialist and Water Quality Modelling Specialist for the Project, respectively. This team has collaborated to develop this Report to support the Project’s EIA. NParks and Nature Groups participated in Stakeholder meetings held to discuss the Ecological Character Description (ECD) approach.

Kranji Reservoir is a hyper-eutrophic waterbody which is used today as part of PUB’s water storage infrastructure. The aquatic habitats within the reservoir contain mostly alien and/ or invasive fauna and flora. A number of terrestrial species of conservation concern utilise the reservoir, in particular some nationally Endangered and Critically Endangered bird species, although generally their use of the reservoir for foraging is low. The reservoir is used by a relatively large number of common wetland bird species and sits in an area of surrounding high value conservation areas such as Sungei Buloh Wetland Reserve and Kranji Marshes. Sungei Kadut Forest which abuts the eastern shore of the reservoir has also been found to support a number of high value terrestrial conservation values. In addition to its local biodiversity values, the reservoir provides other values such as recreation opportunities e.g. fishing.

ECD is an ecosystem based process usually applied to inform the management of Ramsar Wetlands. Kranji Reservoir does not qualify as a Ramsar Wetland, however, the principles of the ECD process are applied to describe the reservoir ecosystem. This information is then used, in an application beyond the typical ECD process, to conceptualise the changes that may occur to the reservoir ecosystem as a result of the Project to inform the EIA.

The objectives of this ECD are to:

- Identify the components, processes and services provided by the reservoir;
- Identify current and future threats that may affect its future ecological character;
- Conceptualise how the Project in particular may affect the reservoir's future ecological character to inform the EIA;
- Recommend limits of acceptable change (LACs) which may indicate that the ecological character of the reservoir could be approaching a tipping point and trigger the need for further review, additional monitoring and investigation, and implementation of adaptive management measures, if required; and
- Propose monitoring recommendations to confirm whether the LACs are maintained or exceeded, for implementation within the Project's Environmental Management and Monitoring Plan (EMMP).

Table ES1-1 identifies the key and supporting components, processes and services identified through the study. The existing and future threats that could affect the condition and function of these were identified as being:

- Proliferation of exotic/ non-native flora;
- Proliferation of exotic/ non-native fauna;
- Loss of biodiversity;
- Future developments in and around the reservoir;
- Changes in fish habitats and nursery grounds;
- Waste production and water pollution; and
- Climate change (increased temperature and rainfall variability).

Table ES1-1 Summary of key and supporting components, processes, and services

	Components	Processes	Services
Key	• Water reservoir	• Water quality • Fish Spawning • Waterbird support	• Water reservoir • Flood control • Climate and water regulation • Public recreation and spiritual enrichment, including fisheries • Education and aesthetics • Maintenance of biodiversity
Supporting	• Aquatic vegetation • Waterbirds • Aquatic fauna • Aquatic invertebrates • Phytoplankton • Zooplankton	• Climate • Geology • Soils • Bathymetry • Hydrology and water quality • Sediment quality	• Water and nutrient cycling • Habitat for biota

In light of the above findings, the key components, processes and services that could be affected by the development of the Project were investigated further. A conceptual model (Figure ES1-1) was prepared to inform which components, processes and services could be at risk, and the magnitude and duration of any resulting changes. A multi-disciplinary team comprising hydrologists, water quality specialists and biodiversity specialists were involved in developing the model.

The analysis, based on the data available, indicates that whilst changes to the physical processes occurring in the reservoir can be expected, the key components, processes and services operating within the reservoir are unlikely to significantly change. This information has been used to inform the EIA as well as the Limits of Acceptable Change (LACs), and monitoring recommendations, needed to manage the ecological character of the reservoir.

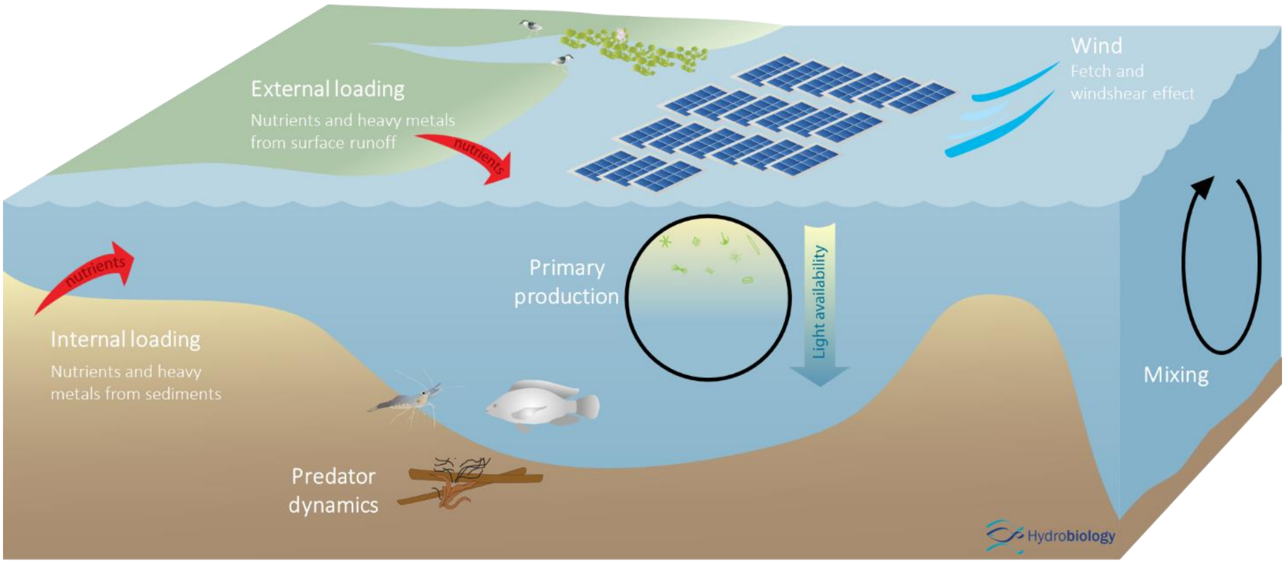
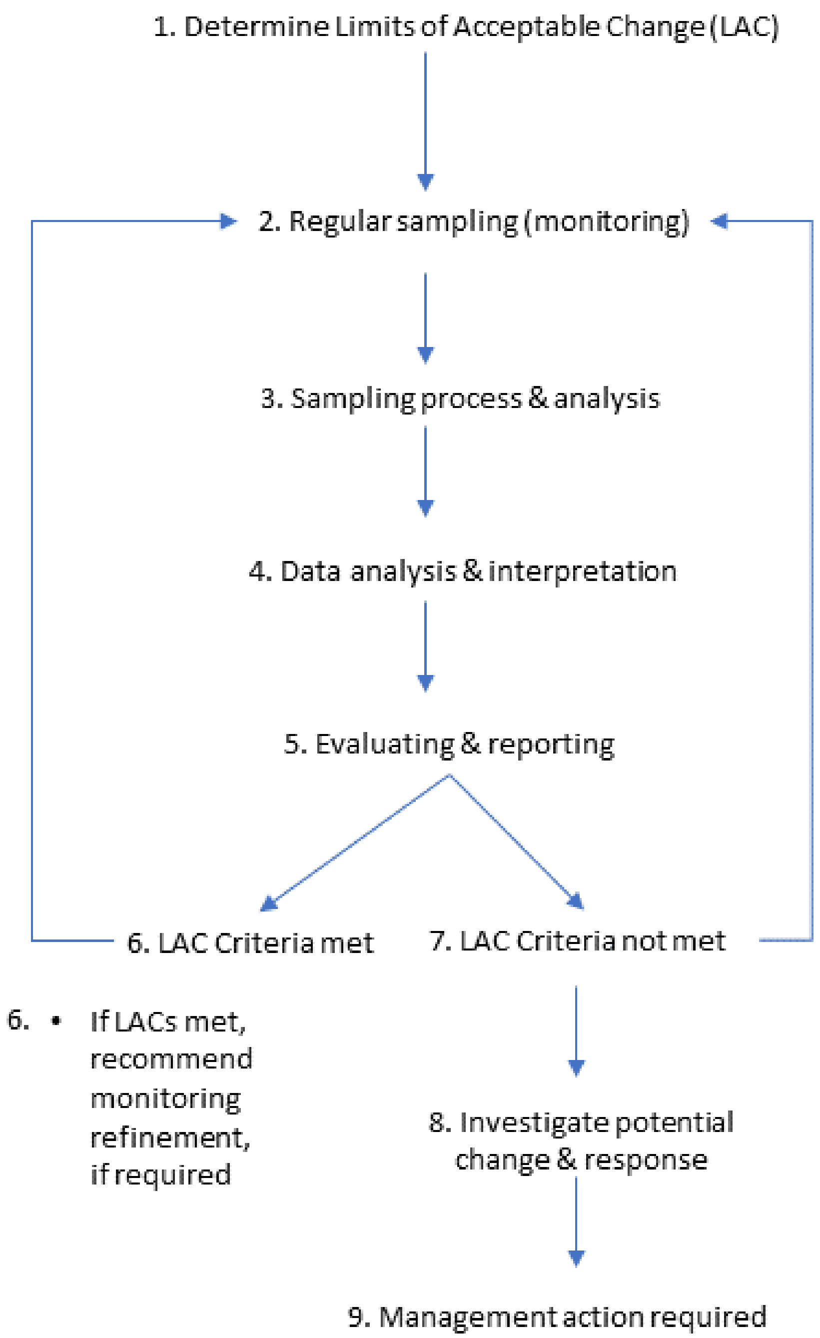


Figure ES1-1 Key components and where key changes may occur in the Kranji Reservoir after the deployment of FPVs.

Seven LACs (Table ES1-2) were then determined based on the current baseline findings, see Section 6.3 for further details. These considered the Project and how it could affect the key components, processes, and services. In addition, some LACs could be affected by activities unrelated to the Project, such as climate change effects on water temperature or run-off from the catchment affecting benthic sediment quality. The LACs therefore take a "state of nature" approach to proactively monitoring ecosystem changes and provide early indicators to enable effective adaptive management, if required. The Developer/ Owner will take responsibility for managing effects identified to be directly attributable to impacts from the Project.

Should any notable deterioration or adverse trend in the LACs and monitoring data be observed, the relevant Government agencies should be notified, and the cause should be investigated. The investigation should determine whether or not the observed deterioration / trend can be attributed to the construction or operation of the Project. If affirmative, the cause of the events should be reviewed and adaptive management through targeted monitoring and/ or mitigation. The Developer/ Owner should liaise with relevant Government Technical Agencies/ Authorities closely on monitoring results and investigation findings and seek agreement on management action(s) to be conducted. Where observations are not attributable to the Project, the Developer/ Owner will liaise with relevant Government Agencies responsible for managing the identified effect for their action.

The LAC monitoring protocol flow is depicted in Figure ES1-2.



1.
- LAC values based on quantitative information produced by relevant monitoring programs, scientific papers, technical reports and other available information or input provided by relevant scientists and experts
- LAC should be based on the known natural variability (over time) of a parameter
- Monitoring units and timescale must be determined

2.
- Monitoring according to standard or tested protocols
- All samples should be documented (date, location, sampling methods, etc)

3.
- Monitoring data analyses according to standard or tested protocols
- All analysis should be documented (date, location, sampling methods, etc)

4.
- Data are adjusted to account for modifying factors
- Mathematical/ statistical processing
- Data are evaluated in comparison to collected and available baseline information

5.
- The report should indicate whether the LACs are supported (i.e. monitoring parameters are within LACs). Reporting to document the below items 6 to 9.

7/8.
- If LACs are exceeded, or not met, investigations may be required in close collaboration with Developer/ Owner and relevant responsible Government Agencies/ Authorities, to determine whether:
  - i. there has been such a change, and the cause;
  - ii. if the change is attributable to the Project (or not); and
  - iii. what the appropriate management actions should be (whether by the Developer/ Owner, or responsible Government Agencies/ Authorities)

9.
- Management action will depend on outcomes, may be to refine LAC values, initiate remedial action, continue monitoring, cease monitoring, etc

Figure ES1-2: Monitoring Protocol of LACs (adapted from the Monitoring & Reporting Guidelines and the framework for designing a wetland monitoring program adopted by the Ramsar Wetland Convention (Ramsar Convention 1996, Finlayson 1996))

Table ES1-2 Limits of Acceptable Change (LACs) (see Section 6.3.1 for further details)

No.	Key Component / Process	Justification	LAC Criteria (against which further investigation is recommended)	Confidence Level* (based on professional judgment, refer text above for criteria)	Secondary Key Components / Processes or Services addressed through this LAC
1	Reservoir Water Temperature	Temperature governs the kinds and types of aquatic life, it partly regulates the maximum dissolved oxygen concentrations, mixing within the Kranji Reservoir and influences the rates of chemical and biological reactions, as well as the toxicity of chemicals. Temperature could be increased via the presence of the FPVs and also climate change effects.	Not more than 0.3°C increase in temperature throughout the whole water column (PUB guideline criteria). Alerts (% of agreed baseline data): - Level 1: 75th-percentile = investigation into cause (both construction and operation) - Level 2: 95th-percentile = cease works (during construction) and implement mitigation agreed with relevant stakeholders (during operation).	Medium	• Surface water quality • Fish fauna • Macrophyte growth rates • Phytoplankton and Zooplankton • Reservoir mixing & stratification
2	Nutrients	The empirical data suggest Kranji is a eutrophic system, where nutrients, in particular phosphorus (P), are readily available. Nutrients entering the reservoir, via surface runoff, appears to be driving the abundance and dominance of primary producing taxa and a main determinant of primary production. Nutrients could be affected by disturbance of the benthos during construction and run-off from the catchment.	Two-tier alert levels are proposed in discussion with PUB, during construction and operation. Limits will be based on latest baseline data sets, within an agreed time period, from PUB in Kranji Reservoir. Exact limit levels are to be agreed with PUB closer to the commencement of construction and operational stages. Parameters (monitored as part of a suite of parameters to be agreed with PUB): - Total Phosphorous (TP) - Total Nitrogen (TN) Alerts (% of agreed baseline data): - Level 1: 75th-percentile = investigation into cause (both construction and operation) - Level 2: 95th-percentile = cease works (during construction) and implement mitigation agreed with relevant stakeholders (during operation)	High	• Surface water quality • Fish fauna • Macrophyte growth rates • Phytoplankton and Zooplankton • Recreation (fishing, visual amenity)

No.	Key Component / Process	Justification	LAC Criteria (against which further investigation is recommended)	Confidence Level* (based on professional judgment, refer text above for criteria)	Secondary Key Components / Processes or Services addressed through this LAC
3	Plankton	Zooplankton and/ or Phytoplankton serve as indicators of environmental conditions, trophic status, and maximum photosynthetic rates, and are sensitive to changes in water quality in the Kranji Reservoir, either as a result of the FPV or pressures from the catchment.	Large deviations that exceed those normally found by PUB in abundance of species that are indicative of eutrophic waters should be a trigger for more frequent monitoring surveys and investigation, where appropriate. Follow up investigation should ensure that sampling is representative of the whole project and includes sampling locations both along the shoreline and sites further away from the shoreline where water depth is likely to be greater. Sampling method should be consistent throughout, and replicates expected to produce similar results.	High	• Surface water quality • Fish fauna • Macrophytes
4	Submerged aquatic vegetation	Submerged aquatic vegetation forms part of the base of the food chain (along with phytoplankton – see LAC 3 above) and provides a notable food source and habitat for fauna utilising the reservoir (e.g. invertebrates, fish, and herbivorous waterbirds). It also provides foraging habitat for insectivorous and piscivorous birds. Vegetation in the top 1 m of the water column will be trimmed as part of the construction phase (vegetation will be retained below 1 m depth). Subsequently shading of aquatic vegetation will occur under the FPVs.	Continued persistence of submerged aquatic vegetation somewhere within the Reservoir Project Site and vicinity, e.g. including shoreline buffers, subject to reservoir operational requirements to ensure FPV system and reservoir operations are not impeded.	Low	• Water quality • Fish fauna • Habitat for biota
5	Fish biomass and size class	Changes in Kranji Reservoir water quality may have an impact on the biomass of fish present in the reservoir.	Fish biomass reduction no more than 50% of baseline values (based on high levels of natural variation reported in other reservoirs and professional judgement) across Reservoir Project Site[1]. Greater biomass was recorded in deeper parts of the reservoir and to the south of the Reservoir Project Site.	Medium	• Fish fauna • Recreation (fishing) • Nature conservation (Bird habitat preservation) • Terrestrial fauna

1 Based on assumed level of tolerance to change.

No.	Key Component / Process	Justification	LAC Criteria (against which further investigation is recommended)	Confidence Level* (based on professional judgment, refer text above for criteria)	Secondary Key Components / Processes or Services addressed through this LAC
6	Focal Bird Species and overall waterbird community	Migratory and resident waterbirds use the reservoir as a foraging/ nesting/ roosting ground and are utilising the natural resources there. Potential to be impacted by changes in the system, including prey availability but also changes to habitat structure and function, as well as the change of ecosystems/ habitats outside the Kranji Reservoir.	Foraging by focal bird populations to not significantly fall below average count number recorded during baseline surveys and control site(s) (if any). Refer to Table 6-1 for species-specific targets. This includes species of conservation concern and others representative of the bird community. Waterbird assemblage to not significantly fall below average number of species recorded during baseline surveys and control sites(s) (if any). The average number during baseline surveys is 8 species.	High	• Nature conservation • Recreation (bird watching)
7	Focus Species of High Conservation Concern	Species dependent, or partly dependent, on the reservoir with a high (VU), very high (EN) or extremely high risk (CR) of extinction in Singapore (based on Singapore Red Data Book[2]). These species are likely to be affected by loss of foraging habitat, decreased prey abundance and changes within the wider catchment.	Continued presence of black-crowned night heron (nationally EN) roost, detected on at least two occasions each year, 6 months apart. Continued sighting within Kranji Reservoir and/ or active use of nest by grey-headed fish eagle (nationally VU) at Sungei Kadut Forest during this species' breeding season. Continued foraging of smooth-coated otter (nationally EN) within Kranji Reservoir and immediately surrounding habitats	High	• Nature conservation • Recreation (bird / wildlife watching)

2 Singapore Red Data Book status of species as of 28 July 2023. This may be subject to change.

Notes:

*: For each LAC a confidence level is estimated using the following scale:

- High – Quantitative site specific data; good understanding linking the indicator to the ecological character of the site; LAC is objectively measurable.
- Medium – Some site specific data or strong evidence for similar systems elsewhere derived from the scientific literature; or informed expert opinion; LAC is objectively measurable.
- Low – no site specific data or reliable evidence from the scientific literature or expert opinion, LAC may not be objectively measurable and/ or the importance of the indicator to the ecological character of the site is unknown.

Table ES1-3 provides an overview of the monitoring recommendations and threshold indicator values of the critical components, and includes details for each LAC such as the parameters, method, frequency, duration, and reporting aspects, see Section 6.4 for further details. The location of monitoring should be confirmed with relevant Government Agencies/ Authorities in advance. The LACs and the related monitoring programme are transposed into the Project's EMMP. An initial three years post-construction monitoring programme is proposed. At the end of this initial three years post-construction period, a review is recommended to be undertaken in consultation with relevant Government Agencies/ Authorities, and stakeholders, where appropriate.

The objective of the review would include, but not limited to, the following,:

- Confirm the significance of impacts predicted in the EIA;
- The data trends against the LAC criteria;
- Whether the LAC criteria are being met or not;
- The cause of any changes in LAC criteria;
- If change, if any, is attributable to the Project, or not;
- Whether adaptive management actions[3] have been carried out, and their success,
- Whether future management actions are required (and the responsible party for those actions, including relevant responsible Government Agencies/ Authorities if causes of LAC exceedance is not attributable to the Project); and
- Whether ongoing monitoring is required, and if so, whether changes, or refinement, to the monitoring programme are necessary. It is anticipated that within two years of operation any variation in site conditions as a result of the FPVs will be detected and inform the need for any ongoing monitoring after that time or not.

The review should take account of any new information, monitoring results (e.g. throughout construction and initial three years post-construction), or changes in the conservation context of the site. Any monitoring programme upon decommissioning should be reviewed in advance of decommissioning commencing.

3 Adaptive management actions may include, in addition to physical mitigation measures: refinement of LAC criteria, initiation of remedial action, continued monitoring, ceasing monitoring, etc.

Table ES1-3 Recommended Monitoring for LAC

No.	Aspects	Project Phase (PC, C, O)	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
1	Surface Water Quality (physio-chemical)	PC, C, O	Temperature (°C)	In-situ measurement via calibrated YSI probe, 0.5 m below water surface, mid-depth, and 0.5 m above reservoir bed. Water sampling for lab analyses will be carried out at mid-depth and 0.5 m above the reservoir bed. Vertical profiles using Fine Scale instrument at <0.1 m vertical resolution using Fine Scale profiler (e.g. high end YSI or Seabird). Temperature probe to detect 0.1 °C differences. All equipment to be calibrated according to manufacturer's guidelines. Analysis completed at accredited laboratory. Also, continuous online monitoring meters at multiple locations (at least three locations).	At least 3 months pre-construction Monthly throughout construction Post-construction monitoring monthly for initial three years. Online water quality profilers will be used throughout the abovementioned periods and throughout operation (including decommissioning). Reassess frequency/ duration and location after initial 3 years post-construction. Locations to be confirmed with relevant Government Agencies/ Authorities based on final design.	Developer/ Owner	Informs LAC 1. Temperature informs LAC accuracy. Reporting of trends, monthly during construction and monthly during operations. Compare data against meteorological data and any available complementary biological monitoring (e.g. plankton) Supplement data set with ongoing PUB water quality monitoring results If guideline or LAC criteria not met, then investigation process to be initiated (which may include additional water quality parameters not listed). LAC 1 Criteria: Not more than 0.3°C increase in temperature throughout the whole water column (PUB guideline criteria).
2	Light penetration into water column	PC, C, O	Light (PAR)	Self-cleaning PAR logger Underwater PAR to facilitate Extinction coefficient (cf with Secchi depth measurements) All equipment to be calibrated according to manufacturer's guidelines. Analysis completed at accredited laboratory. Regularly serviced for cleanliness, power, malfunctions Deployment of paired loggers (for failsafe and data correlation) deployed coincidentally under 3 scenarios at depth of 1m: - Beneath panel array	Continuous measurements taken during daylight hours every 10 minutes At least 3 months during Pre-construction Throughout construction - Reassess the number of sites after the first 6 months of construction. If there is little variability between the then consider reducing number of PAR loggers. 6-monthly post-construction for three years Reassess frequency/ duration and location after initial 3 years post-construction. Locations to be confirmed with relevant Government	Developer/ Owner	Informs LAC 4 & 5. Reporting of trends, monthly during construction and 6 monthly during first 3 years of operations. Compare against meteorological data and any available complementary biological monitoring (e.g. plankton).

No.	Aspects	Project Phase (PC, C, O)	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
				- Within corridors between panel arrays - Distant from panel arrays and other shading factors - At 1 site within each scenario, additional paired loggers deployed at 2 m depth. - N= 14 loggers (at 1 m) 6 loggers (at 2 m) + another pair deployed above water surface away from shading factors = 20 loggers Regularly serviced for cleanliness, power, malfunctions Number of sites could be reassessed after the first 6 months of construction. If little variability between the replicates then consider reducing to 1 site per scenario instead of 2 to 3.	Agencies/ Authorities based on final design		
3	Nutrients	PC, C, O	Nutrients (TP, TN and TOC)	Water sampling can be carried out and reported alongside S/N 1, if appropriate All equipment to be calibrated according to manufacturer's guidelines. Analysis completed at accredited laboratory. Supplement with data from ongoing PUB WQ monitoring program	At least 3 months pre-construction Monthly throughout construction Monthly post-construction monitoring for three years: monthly for total nitrogen, total phosphorous and TOC Reassess frequency/ duration and location after initial 3 years post-construction, as monitoring may be able to taper off once biotic and abiotic relationships is well established/ understood. Locations to be confirmed with relevant Government Agencies/ Authorities based on final design.	Developer/ Owner	Informs LAC 2. TP concentration informs LAC accuracy. Reporting of trends, monthly during construction and monthly during first 3 years of operations. Compare TP trends against any water quality monitoring data, meteorological data and any available complementary biological monitoring (e.g. plankton). Supplement data set with ongoing PUB water quality monitoring results If guideline or LAC criteria not met, then investigation process to be initiated. LAC 2 Criteria: Two-tier alert levels are proposed in discussion with PUB, during construction and operation, based on latest baseline data sets from PUB, within

No.	Aspects	Project Phase (PC, C, O)	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
							an agreed time period, for Kranji Reservoir. Exact levels are to be agreed with PUB closer to the commencement of construction and operational stages. Parameters: - Total Phosphorous (TP) - Total Nitrogen (TN) Alerts (% of agreed baseline data): - Level 1: 75th-percentile = investigation into cause (both construction and operation) - Level 2: 95th-percentile = cease works (during construction) and implement mitigation agreed with relevant stakeholders (during operation)
4	Sediment Quality	PC, C, O	Nutrients, contaminants/metals and hydrocarbons	Sediment sampling via Ekman grab sampler Analysis completed at accredited laboratory.	A single sample event during pre-construction at various locations At least one sampling event within 24 hours after unplanned event (spill) during construction or operation. Additional monitoring as per unplanned event, as agreed with relevant Government Agencies/ Authorities Locations to be confirmed with relevant Government Agencies/ Authorities	Developer/ Owner	Monitoring to be included in Spill Prevention and Emergency Response Plan, including unplanned event management process.
5	Plankton (Zooplankton and/or Phytoplankton)	PC, C, O	Zooplankton and/or Phytoplankton	Method to be aligned with PUB's existing survey method statement, I.e. 1L water sample collection at 0.5m from water surface without the use of plankton net, alongside water sampling programme.	At least 3 months pre-construction Monthly throughout construction Quarterly post-construction for three years. Reassess frequency/ duration and location after initial 3 years post-construction.	Developer/ Owner	Informs LAC 3 & 4. Reporting of trends, monthly during construction and quarterly during first 3 years of operations. Compare against water quality (chlorophyll-a) measurements

No.	Aspects	Project Phase (PC, C, O)	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
				Supplement with PUB ongoing monitoring program data	Locations to be confirmed with relevant Government Agencies/ Authorities		(fluorescence-based spectrophotometer and lab analysis) and meteorological data and any available complementary monitoring. Supplement with PUB ongoing monitoring program data If guideline or LAC criteria not met, then investigation process to be initiated. LAC 3 Criteria: Large deviations that exceed those normally found by PUB in abundance of species that are indicative of eutrophic waters should be a trigger for more frequent monitoring surveys and investigation, where appropriate. Follow up investigation should ensure that sampling is representative of the whole project and includes sampling locations both along the shoreline and sites further away from the shoreline where water depth is likely to be greater. Sampling method should be consistent throughout, and replicates expected to produce similar results.
6	Fish	PC, C, O	Fish biomass & size class	Hydroacoustic survey A minimum of ten tracks around the reservoir edges and access between panels repeated using the same technique as Baseline surveys (as allowed within final project footprint) to determine whether biomass is increasing or decreasing. Location of tracks that will be assessed to be based on final FPV layout. Consideration to be given to ongoing PUB	A single sample event during pre-construction Annually throughout construction in areas that are accessible Annually for three years post-construction. Reassess frequency/ duration and location after initial 3 years post-construction, as monitoring may be able to taper off once biotic and abiotic relationships is well established/ understood.	Developer/ Owner	Informs LAC 4 & 5. Reporting of trends, annually during construction and three years post-construction. Compare to fish biomass data from previous years. If guideline or LAC criteria not met, then investigation process to be initiated. LAC 5 Criteria: Fish biomass reduction no more than 50% of baseline values

No.	Aspects	Project Phase (PC, C, O)	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
				management of aquatic vegetation outside of Reservoir Project Site (subject to further discussions between PUB and the Developer/ Owner)	Locations to be confirmed with relevant Government Agencies/ Authorities		(based on high levels of natural variation reported in other reservoirs and professional judgement) across Reservoir Project Site. Greater biomass were recorded in deeper parts of the reservoir and to the south of the Reservoir Project Site.
7	Focal Bird Species and overall waterbird community	PC, C, O	Minimum counts of species richness (focal birds) and species abundance (waterbirds)	Point counts of focal bird species foraging and waterbirds by Vantage Point Survey (VPS). Focal bird foraging events: - 3 hrs per month per VP (36 hrs per VP per year). Waterbirds number of species: - 20-minute count for waterbirds from each VPS each month. Mapping of flight paths to identify if any behavioural changes post construction	At least 1 sample event at each VP during pre-construction. Monthly at each VP throughout construction. Monthly at each VP for three years post-construction. Reassess frequency/ duration and location after initial 3 years post-construction, as monitoring may be able to taper off once biotic and abiotic relationships is well established/ understood. Locations to be confirmed with relevant Government Agencies/ Authorities.	Developer/ Owner	Informs LAC 6. Reporting of trends, annually during construction and three years post-construction. Compare to focal species and overall waterbird community data from previous years. If guideline or LAC criteria not met, then investigation process to be initiated. LAC 6 Criteria: • Foraging by focal bird populations to not significantly fall below average count number recorded during baseline surveys and control site(s) (if any). Refer Table 6-1 for species-specific targets. This includes species of conservation concern and others representative of the bird community. • Waterbird assemblage to not significantly fall below average number of species recorded during baseline surveys and control sites(s) (if any). The average number during baseline surveys is 8 species.
8	Focal Species of high Conservation Concern	PC, C, O	Continued presence at Kranji Reservoir	Focal birds: - Point counts via VPS (see above).	At least 1 sample event (i.e. for birds, see above) during pre-construction	Developer/ Owner	Informs LAC 7. Reporting of presence/ trends, annually during

No.	Aspects	Project Phase (PC, C, O)	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
				Black-crowned night heron (BCNH): - Incidental observations during bird point counts (see above) to confirm BCNH continue to roost at eastern and western shoreline. Grey-headed fish eagle: - Incidental observations during bird point counts (see above) to confirm breeding behaviour at recorded nest site (during breeding season). Smooth-coated otter: - Incidental observations during bird point counts (see above) of smooth coated otter activity on reservoir.	Throughout construction (i.e. monthly for birds, see above). Monthly at each VP for three years post-construction (i.e. monthly for birds, see above). Reassess frequency/ duration and location after initial 3 years post-construction, as monitoring may be able to taper off once biotic and abiotic relationships is well established/ understood. Locations to be confirmed with relevant Government Agencies/ Authorities.		construction and three years post-construction. If guideline or LAC criteria not met, then investigation process to be initiated. LAC 7 Criteria: • Continued presence of black-crowned night heron (nationally EN) roost, detected on at least two occasions each year, 6 months apart. • Continued sighting within Kranji Reservoir and/ or active use of nest by grey-headed fish eagle (nationally VU) at Sungei Kadut Forest during this species' breeding season. • Continued foraging of smooth coated otter foraging within Kranji Reservoir and immediately surrounding habitats.

Contents

Tables

Figures

1. INTRODUCTION

1.1 BACKGROUND

Environmental Resources Management (S) Pte Ltd (ERM) has been appointed to undertake an Environmental Impact Assessment (EIA) for the construction and operation phase of a Floating Photovoltaic (FPV) System on Kranji Reservoir (herein referred to as the 'Project'). ERM has further engaged Hydrobiology Pte Ltd (Hydrobiology), Camphora Pte Ltd (Camphora) and Hydroinformatics Institute Pte Ltd (H2i) to undertake the roles of Aquatic Specialist, Biodiversity Specialist and Water Quality Modelling Specialist for the Project, respectively. This team have collaborated to develop this Report to support the Project's EIA. NParks and Nature Groups participated in stakeholder meetings held to discuss the Ecological Character Description (ECD) approach.

Much, but not all, of the contemporary data presented in this report is based on surveys conducted for this Project, and they focus on the Reservoir Project Site and BIA Study Area, including supplemental surveys south of the Reservoir Project Site (Figure 1-1).

This document serves as an Ecological Character Description (ECD) that provides an ecosystem based understanding of the Kranji Reservoir and sets a framework for the impact assessment in the EIA. The objectives of the ECD are to:

- Identify the components, processes and services provided by the reservoir;
- Identify current and future threats that may affect its future ecological character;
- Conceptualise how the Project in particular may affect the reservoir's future ecological character to inform the EIA;
- Recommend limits of acceptable change (LACs), which may indicate that the ecological character of the reservoir could be approaching a tipping point and trigger the need for further review, additional monitoring and investigation, and implementation of and adaptive management measures, if required; and
- Propose monitoring recommendations to confirm whether the LACs are maintained or exceeded, for implementation within the Project's Environmental Management and Monitoring Plan (EMMP).

The ECD framework is a process adopted from the international Ramsar Convention. This convention aims to halt the worldwide loss of wetlands to conserve (through wise use and management) those that remain. The framework is typically used by Governments to assist in the implementation of this Convention by characterising the baseline conditions of Ramsar sites and to determine whether those conditions have changed, or are likely to change, as the result of pollution or other human activities, including development projects. While Singapore is not currently a signatory to this international Ramsar treaty, and no sites in Singapore are designated Ramsar Sites (including Kranji Reservoir), Singapore is a member of the comparable *Partnership for the East Asian – Australasian Flyway* which adopts Ramsar assessment processes. The Kranji Reservoir is predominantly considered open water, however the shorelines are wetland in nature, and thus, the use of the principles of Ramsar's ECD approach is considered most applicable. This Project has adopted the ECD approach given its relevance to management of similar ecosystems, whether designated a Ramsar site or not (the latter being the case for Kranji Reservoir). This concept was presented and agreed with relevant authorities and stakeholders for the application to this Project. This Report adapts the ECD tool to go further than describing baseline conditions, to assessing the potential changes which could occur due to the Project on the reservoir. The LACs selected are those which are most likely to represent changes in lieu of this specific Project.

1.2 BRIEF PROJECT DESCRIPTION

The Project will involve the deployment of up to approximately 112.5 MWac (or 141 MWp)[4,5] (+/- 10%) FPV System on Kranji Reservoir.

Key Project components upon commissioning are described in Table 1-1, and the Project Sites are illustrated in Figure 1-1. A schematic overview of a large-scale FPV System is presented in Figure 1-2, and the conceptual layout of the FPV System components in-reservoir is indicated in Figure 1-3.

4 Subject to final detailed design and technologies available at the time of construction, e.g. PV panel capacities are continually improving and becoming more efficient, thus more capacity (i.e. MWac) can be achieved within the same size PV module and footprint.

5 MWp (or MWdc) is a measure of the Direct Current (DC) output of PV panels. MWac is a measure of the power output from PV panels after its DC output has been converted to Alternating Current (AC). This conversion is necessary as our power grid and most of our equipment/ systems/ appliances run on AC.

Figure 1-1 Overview of Project Area at Kranji Reservoir and Project Component Locations, and BIA Study Area

Table 1-1 Main In-Reservoir and Land-based Project Components

No.	Key Component	Sub-Components	Key Descriptor

1	FPV System (in-reservoir)	• PV Panels/ Modules
		• Mounting System – floats/ fixed systems
		• Power Conversion Units (PCUs)
		  ◦ Transformers
		  ◦ Central inverter
		  ◦ Ancillary equipment – e.g. switchgear, weather station etc
		• Mooring and Anchoring Systems – bottom anchoring/ piles
		• Connector Cables – laid on reservoir bed between FPV islands, and to eastern shore (to connect to integrated Project Substation).
			• Capacity: 112.5 MWac (or 141 MWp) (+/- 10%)
			• Kranji Reservoir Project Site is 201 hectares (ha) (38.5% of Kranji Reservoir area, 522 ha).
			• The FPV islands and PCUs are expected to cover approximately 21.5% (112 ha) of the total Kranji Reservoir surface area. 78.5% (410 ha) of the Kranji reservoir area will not be covered by Project infrastructure.
			• FPV panel blocks (which form the FPV islands) assumed to be approximately 50 m x 170 m.
			• PCU/ Central inverters: approximately 18 – 36 number
			• Connector cables: medium voltage, 11 – 33 kV, with a shoreline landing point near the integrated Project Substation.

2	Integrated Project Substation (with O&M facility)	• Connector Cables – shoreline connection to the integrated Project Substation.
		• Integrated Project Substation:
		  ◦ Control centre/ SCADA system
		  ◦ Transformers
		  ◦ Ancillary equipment – e.g. switchgear, spare equipment.
		• Other potential integrated O&M facilities(a):
		  ◦ FPV System control centre
		  ◦ Office/ staff facilities
		  ◦ Visitor centre
		  ◦ Maintenance/ spare equipment store to support regular inspections and maintenance activities.
			• Site: approximately 0.44 ha
			• Building: 9 m high with 3.5 m deep basement.
			• Location: on eastern shoreline in Sungei Kadut Industrial Estate.

2	O&M Berthing Facility (in-reservoir) (location to be agreed with relevant Agencies)	• Berthing facility to facilitate mooring of O&M work boats	• Size: approximately 20 m x 5 m • Location: on eastern shoreline in close proximity to integrated Project Substation.

Note: All main components listed above are indicative and subject to change during detailed design. The need for additional buildings for O&M warehousing/ facilities within the existing Sungei Kadut Industrial Estate, if any, will be determined during detailed design by the Developer/ Owner, and relevant Government agencies will be consulted as appropriate.

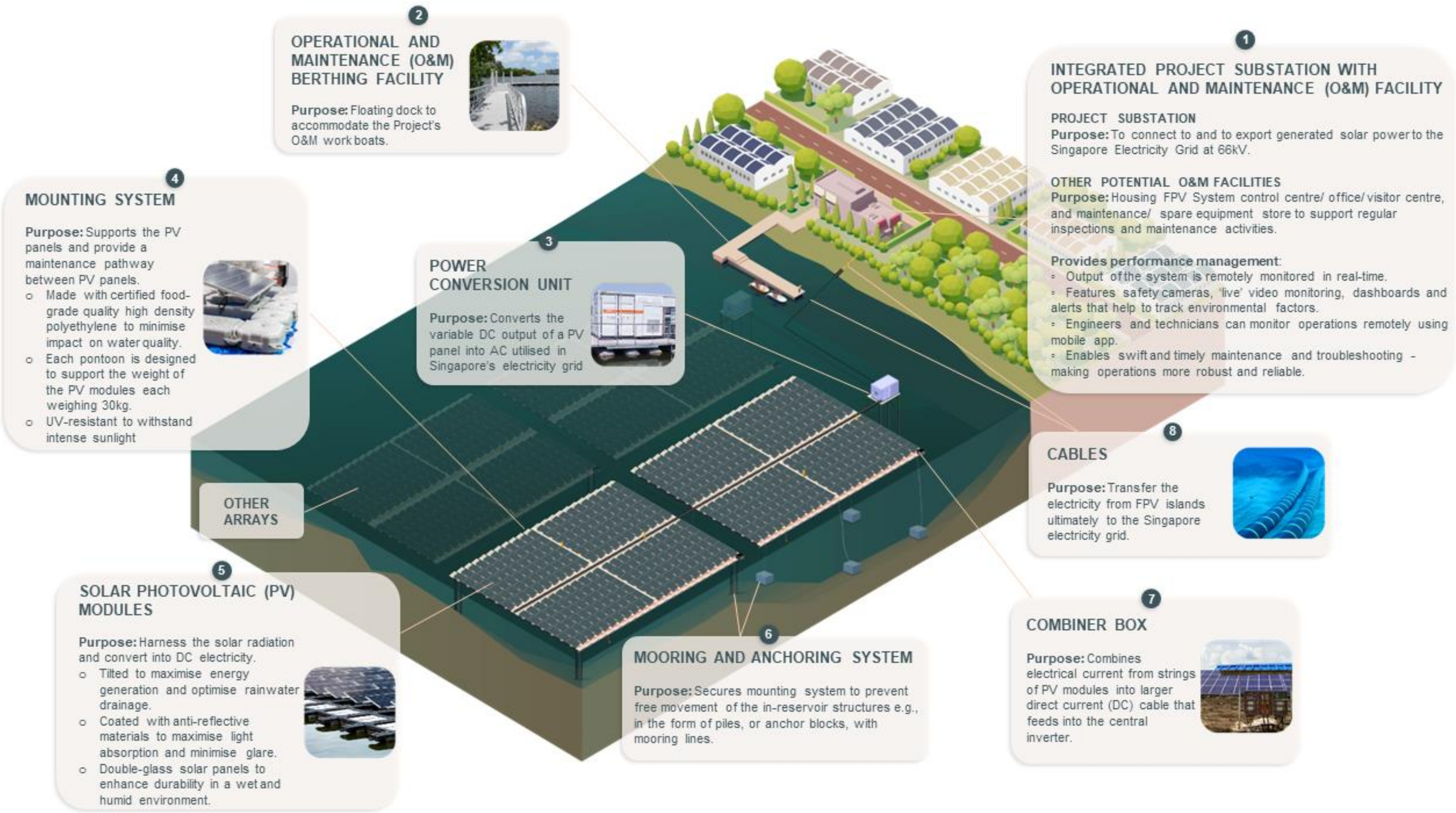


Figure 1-2 Schematic Overview of a Large-scale FPV System

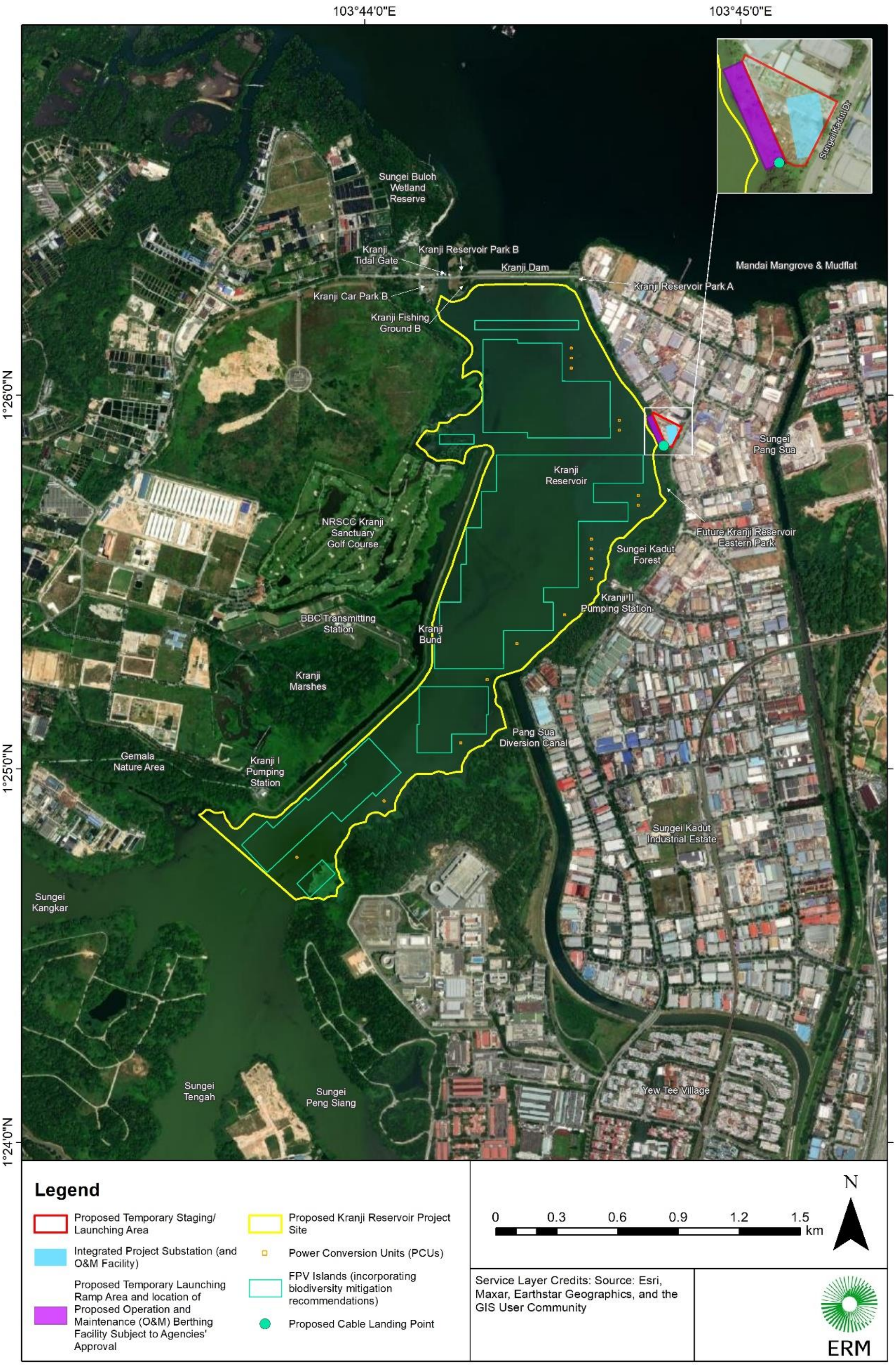


Figure 1-3 Indicative Layout of Main Project Components

1.3 REPORT STRUCTURE

Following this introduction, this ECD report follows the below structure:

- Section 2 - Description of the Kranji Reservoir - provides an overview of the Kranji Reservoir, including a brief description, tenure and adjoining land use, and an overview of the ecosystem elements.
- Section 3 - Ecosystem Elements: Components, Processes and Services - summarises the elements (components, processes and services) that support the ecosystem values at Kranji Reservoir. These supporting elements are developed into Conceptual Models that illustrate the interactions between the biotic and abiotic factors identified at the reservoir.
- Section 4 - Overview of Current and Future Threats – discusses the current and future threats to the ecological character of Kranji Reservoir that vary substantially across multiple spatial and temporal scales and in terms of their potential severity.
- Section 5 - Critical Components and Processes in Relation to the Project - building on the ECD, this section scopes which key components, processes and services could be affected by development of the Project at Kranji Reservoir. It also assesses how these aspects may change following development of the Project; to inform development of LACs and monitoring recommendations.
- Section 6 - Limits of Acceptable Change - This section presents the limits of acceptable change (LAC) for the key components, processes and services/ benefits of Kranji Reservoir based on available data and proposes monitoring of such LACs.
- Section 7 - Conclusions.
- Section 8 - References.

2. DESCRIPTION OF KRANJI RESERVOIR

This Section of the ECD provides an overview of the Kranji Reservoir, including a brief description, tenure and adjoining land use, and an overview of the ecosystem elements.

2.1 SITE DETAILS SUMMARY

Summary details of Kranji Reservoir are highlighted in Table 2-1.

Table 2-1 Summary of site details for the Kranji Reservoir.

Attribute	Details
Kranji Reservoir Area[6]	522 ha
Coordinates (WGS84)	103.7271, 1.4107
Altitude (m)	Sea level
General Location	Northwest of Singapore

2.2 LOCATION AND BRIEF DESCRIPTION

Kranji Reservoir is a tropical man-made reservoir situated on the northwest coast of Singapore, adjacent to the Johor Straits. To the north of the main Kranji Reservoir Project site is the Kranji Reservoir Park, Sungei Buloh Wetlands Reserve, the Johor Straits and Mandai Mangrove and Mudflats; to the east is the Sungei Kadut industrial estate; to the south is the remaining areas of Kranji Reservoir and an area for military training; and to the west is the National Service Resort and Country Club (NSRCC) Kranji Sanctuary Golf Course, the Kranji Marshes, and Government Land.

2.2.1 PRE-RESERVOIR

In 1819, the Project area was characterised with mangrove forest present along the edges of the then Kranji river, in addition to the northern coastline (Yee et al., 2010). Lowland dipterocarp forest was present, with small patches of freshwater swamp forest (Yee et al., 2010). This area was treated as a nature reserve by the colonial government (Ho, n.d.) and remained uninhabited (NUSLHMSG, 2021). The Kranji Reservoir area is also situated adjacent to Kranji Beach, where the Battle of Kranji occurred during the Japanese invasion in 1942, which may suggest the area was historically used for military activities (NHB, n.d).

Maps dating from 1953 and 1958 show the presence of freshwater or tidal habitats along the edges of present-day Kranji Reservoir, as well as mangroves and mudflats (Figure 2-1; NUSLHMSG, 2021). Buildings, structures, trails and tracks were already present, suggesting early indications of human activity.

Maps dating from 1953 and 1958 show the presence of freshwater or tidal habitats along the edges of present-day Kranji Reservoir, as well as mangroves and mudflats (Figure 2-1A; NUSLHMSG, 2021). On the other hand, along the western bank of the Kranji River, roads, buildings or structures were present around the approximate location of today's Kranji Marshes and Kranji BBC radio transmitting station. On the eastern bank, trails or tracks were also present in the forest in the southeastern shoreline of the Kranji Reservoir, suggesting early signs of human use. By 1958, more trails and tracks were established within Kranji Camp III (NUSLHMSG, 2021).

Since independence, two major reclamation and development works have taken place in the area. The first took place at the eastern foreshore of Kranji River mouth in 1965 for the creation of a sawmill estate (Figure 2-1B; Saparudin & Omar, 2007), which was subsequently developed into the present-day Kranji Industrial Estate. For this endeavour, the mangroves on Kranji River's east bank were cleared, and map records show that this was completed by 1969 (Figure 2-1C). Second, the

[6] Per Public Utilities (Reservoirs, Catchment Area and Waterway) Regulations (2006) First Schedule

mouth of Kranji river was dammed in 1972 to create the Kranji Reservoir (Figure 2-1C). The conversion of Kranji River into a freshwater habitat caused the mangroves of Kranji River's western bank to be converted into a swampland by 1975, and the riverbed was subsequently dredged with the dredged materials used to fill up the swamp area (The Straits Times, 1972). This resulted in a widening of the river channel that took place between 1978 and 1998 (Figure 2-1D).

The damming of the river flooded low-lying areas within Kranji Reservoir, and formed freshwater marshes which attracted and provided habitats for wildlife (Ho, n.d.). In recent years, the development of a NSRCC golf course (2002) along the marshlands of Kranji Reservoir's western bank has also caused a 72% reduction (60 ha) in the size of the original marshland (Ho, n.d.). Engagement between the Nature Society Singapore (NSS) and NSRCC resulted in a compromise, with a 60 m stretch from the edge of the marshes being retained as a buffer for the wetland birds (NSS, 2009).

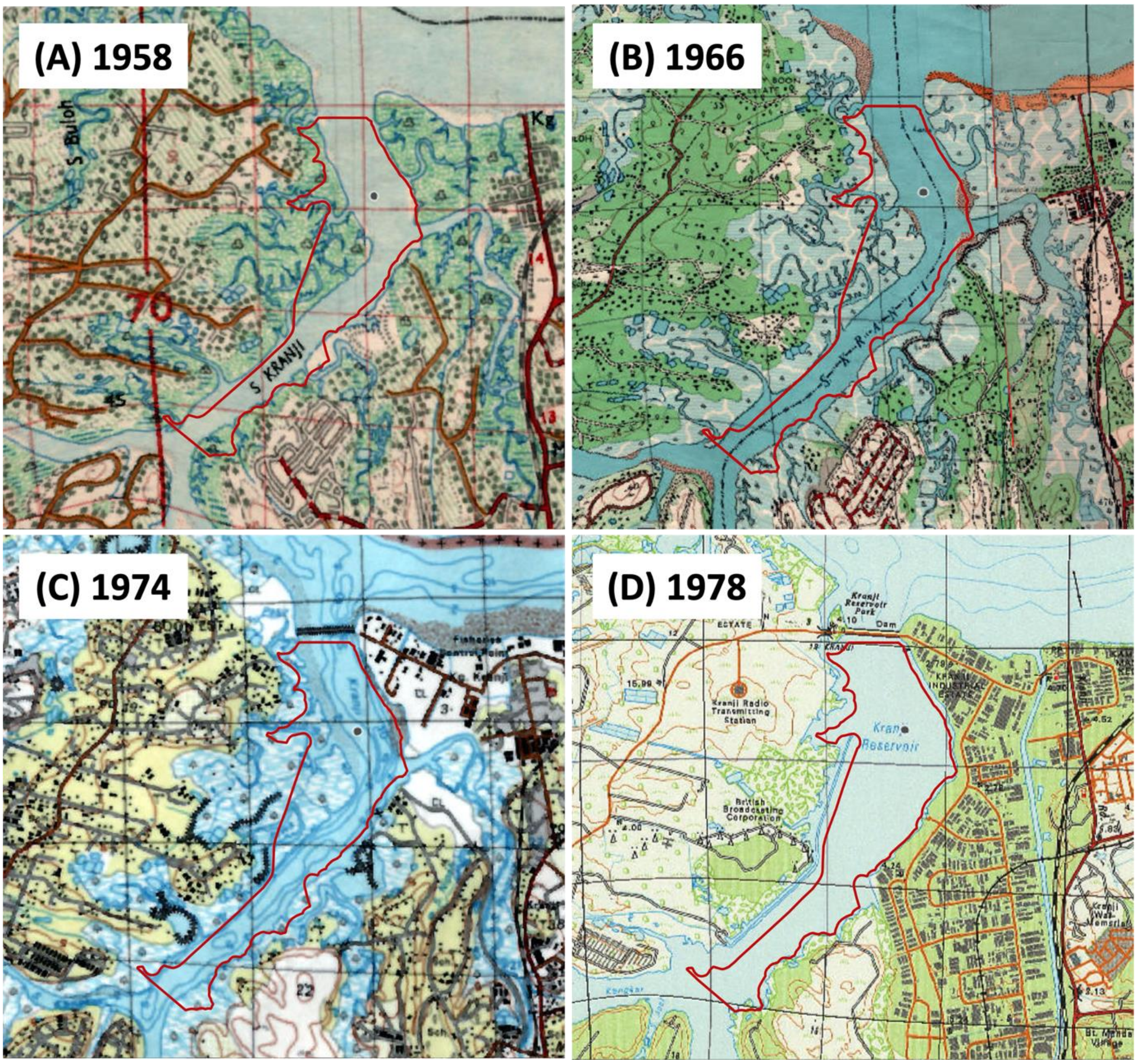


Figure 2-1 Historical Maps of Project Area Showing: (A) Freshwater or tidal habitats along Kranji River in 1958; (B) Land reclamation works in Kranji River's eastern foreshore in 1966; (C) Clearing of mangroves from Kranji River's eastern foreshore and subsequent damming across the river mouth from 1974; and (D) widened channel of Kranji Reservoir in 1978.

2.2.2 RESERVOIR FORMATION

The reservoir was formed in 1972 by damming the estuary of the Kranji River. The dam is approximately 975 m in length and 17 m high, with a 21 m width at its top. Extensive dredging took place at the Sungei Kranji riverbed and at the left bank near its mouth. Mangrove swamps in the area were filled using the dredged materials. Completion of the dam resulted in the formation of the Kranji Reservoir. The damming of the river flooded low-lying areas within Kranji Reservoir, the result being new freshwater marshes which attracted and provided habitats for wildlife (Ho, n.d.), known as Kranji Marshes. The Sungei Buloh Wetland Reserve located to the west of the dam was formerly mangrove swamps that were cleared for prawn farming due to the high nutrient availability in the waterlogged and muddy mangrove swamps in the 1980s. The area was later developed in 1993 into a nature reserve following the discovery of rich bird biodiversity within the Sungei Buloh wetland area. The Kranji Reservoir Park was also established close to the dam and two fishing grounds were introduced when the reservoir was opened for fishing in 1985, namely the Kranji Fishing Ground A and B, one with a rocky bank and the other with a grassy bank. These fishing grounds are located along the northern shoreline of the reservoir, in close proximity to Kranji Dam.

In recent decades, the development of a National Service Resort and Country Club (NSRCC) golf course (2002) along the marshlands of Kranji's western bank has caused a 72% reduction (60 ha) in the extent of the original marshland (Ho, n.d.). A compromise was made between the Nature Society Singapore (NSS) and NSRCC, with a 60 m stretch from the edge of the marshes being retained as a buffer for the wetland birds (Nature Society Singapore, 2009). Since its construction, Kranji Reservoir has experienced different trophic states. This current stable state is a shallow, hyper-eutrophic turbid waterbody that is currently managed by PUB. The management actions taken, such as PUB's ongoing removal of invasive aquatic vegetation, are expected to prevent the reservoir from being smothered and drying out, and thus, it is unlikely that the reservoir will transition to another alternate stable state.

Prior to legislation in 1976 the site has a history of very high water pollution levels, in particular high concentrations of dissolved phosphate, as a result of pig farming wastes and commercial effluents from manufacturing processes (Appan and Wang, 2000). The concentration of dissolved phosphate at this time had increased to 0.33 – 1.22 mg/L (Appan, 1994) but since 1976, the quantity of industrial and domestic effluents entering the reservoir has been controlled by legislation and wastewater treatment projects (Appan and Wang, 2000). Water quality of Kranji Reservoir had improved substantially, and the concentration of dissolved phosphate was measured at a range of 0.0007 – 0.0073 mg/L in the study by Appan and Wang (2000). However in 2022 the reservoir remains in a eutrophic state and at present, experiences invasive *Pontederia crassipes* (water hyacinth) growth.

2.3 LAND USE AND TENURE

Seven vegetation types were identified within the Project's terrestrial flora survey area, including the reservoir edge (Figure 2-2; Table 2-2).

Less information is known for the upper reaches of the reservoir; it contains a forested fringe which varies in width from as little as 10 m to more extensive tracts. Land use towards the confluence of the tributaries in the south consists mainly of various government land and infrastructure. In the upper reaches of the tributaries there is extensive agriculture industry.

Industrial activity primarily takes place along the eastern shoreline. The Sungei Kadut Industrial Estate, one of the oldest industrial estates in Singapore, is located in the east and houses a large number of businesses in the timber, furniture, construction and waste management industries. An area for military training is situated in the south. Nature areas are focused on the western and northern shorelines, such as Kranji Marshes and SBWR, and Mandai Mangrove and Mudflats to the northeast. Collectively, these complementary wetland[7] habitats strengthen the conservation of wetland biodiversity in the northwestern part of Singapore and form the Sungei Buloh Nature Park Network (NParks, 2023). To the west is the NSRCC Kranji Sanctuary Golf Course, the Kranji Marshes, and Government Land.

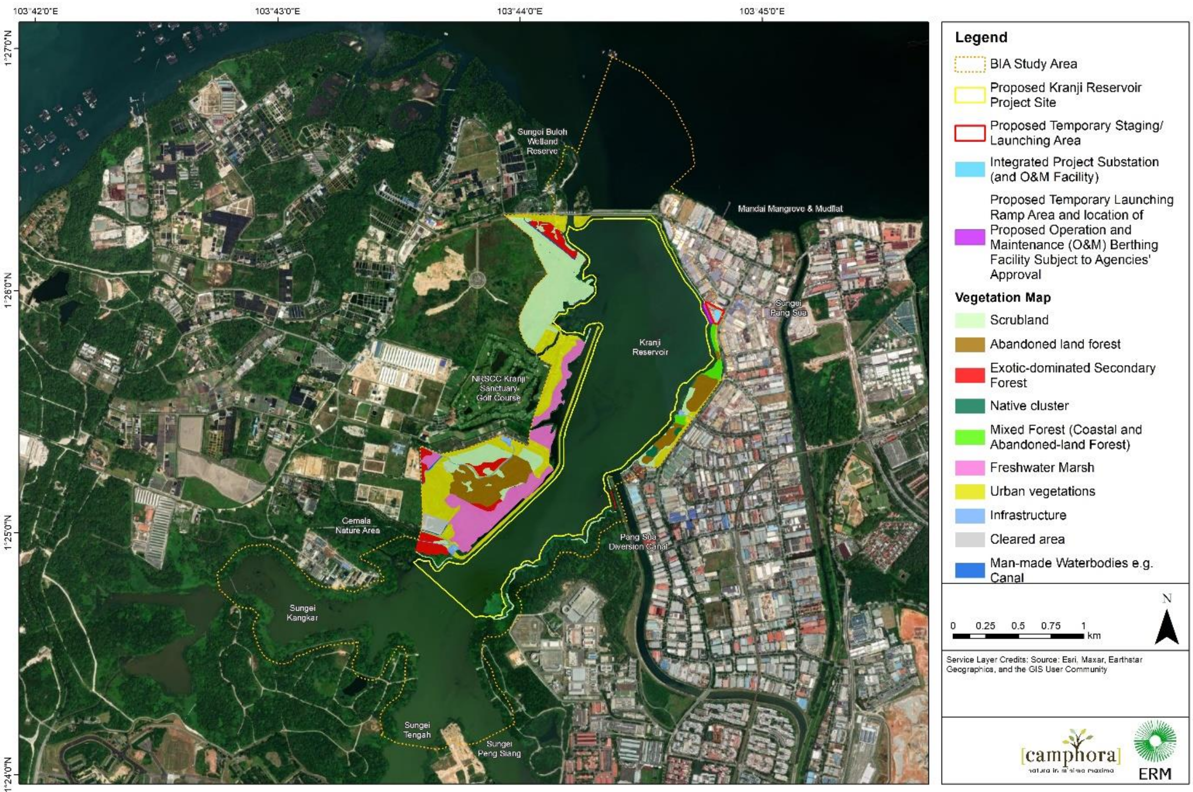


Figure 2-2 Distribution of Habitat and Vegetation Types in the Flora Sampling Area in vicinity of Kranji Reservoir.

Table 2-2 Habitat and vegetation types, along with their absolute (ha) and relative size (%) at Kranji Reservoir.

Habitat and Vegetation Type	Absolute Size (ha)	Relative Size (%)
Scrubland	~36.4	28.1
Urban vegetation	~34.2	26.4
Freshwater Marsh	~22.6	17.5
Abandoned-land forest	~18.1	14.0
Exotic-dominated secondary forest	~8.7	6.7

[7] Ramsar convention definition of wetland which is: “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.”

Habitat and Vegetation Type	Absolute Size (ha)	Relative Size (%)
Mixed forest	~2.4	1.9
Cleared area (non-vegetated area)	~2.3	1.8
Infrastructure (non-vegetated area)	~2.2	1.7
Native cluster	~1.8	1.4
Man-made waterbodies (non-vegetated area)	~0.8	0.6
Total	**~129.5**	**100.0**

3. ECOSYSTEM ELEMENTS: COMPONENTS, PROCESSES AND SERVICES

This Section summarises the elements (components, processes and services) that support the ecosystem values at Kranji Reservoir. These supporting elements are developed into Conceptual Models that illustrate the interactions between the biotic and abiotic factors identified at the reservoir. A full baseline description is provided in the Project's EIA Appendices 7.1 and 7.2.

3.1 ECOSYSTEM ELEMENTS

Ecosystems can be described through three elements (based on DEWHA 2008):

- Their components - the physical, chemical and biological parameters or features of an ecosystem;
- Their processes - the dynamic interactions within an ecosystem between organisms (biotic), populations and the non-living environment (abiotic); and
- Their services - the interactions between humans and the environment, specifically the benefits that people receive from ecosystems. These ecosystem services can be directly beneficial to humans (e.g. source of food and water) or indirectly beneficial (e.g. the role played by ecosystems as habitats for biota which contribute to biodiversity).

3.1.1 INTERACTION OF RESERVOIR ECOSYSTEM ELEMENTS

Reservoir ecosystem components, processes and services can be summarised as a conceptual framework (Figure 3-1). The model illustrates the interactions between reservoir ecosystem processes and components to generate a range of reservoir ecosystem services. These services are broadly true for all reservoir ecosystems (such as primary productivity) or specific to a site (e.g. habitat for an important species or population at a given site).

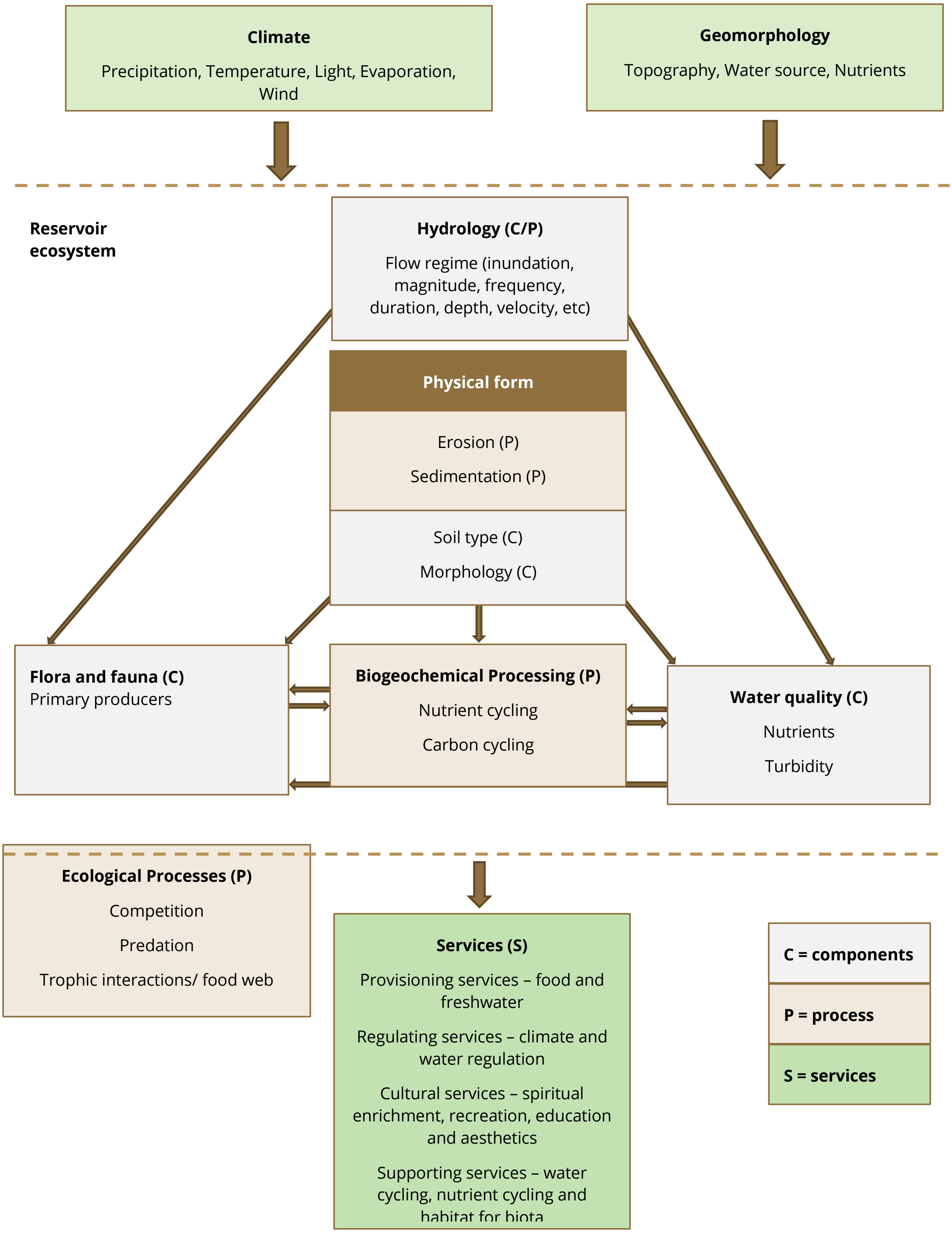


Figure 3-1 Generic conceptual framework showing interactions between reservoir ecosystem processes, components and services (adapted from DEWHA 2008).

3.2 STUDY APPROACH

Key components, processes and services were identified adapting the method provided by DEWHA (2008) and informed based on historical data and the most recent findings from the Project's baseline surveys. Considerations relating to Ramsar criteria were excluded given the fact that this is not appropriate to Kranji Reservoir as it is not proposed or designated to be such a Ramsar site and nor does baseline data suggest it could qualify as a Ramsar site.

The assignment of key ecosystem components, processes or services was guided by the following questions:

- Is the component, process or service an important determinant of the unique ecological character of the site?
- Is a change in a component, process or service likely to occur over a short timescale (e.g. ten years)?
- Will a change to the component, process or service result in significant negative impact(s) on the ecosystem system?

For each of the key components, processes and services (C, P, S respectively), a brief description is given for (i) the rationale for inclusion as a "key" C, P, S; (ii) a description of the element; and (iii) a description of how patterns vary over time.

Using the above, a summary of the key and supporting ecosystem components, processes and services for Kranji Reservoir site have been identified and include, in summary (see Table 3-1):

- One key component and six supporting components;
- Three key processes and six supporting processes; and
- Six key services and three supporting services.

Table 3-1 Summary of key and supporting components, processes, and services.

	Components	Processes	Services
Key	C1 - Freshwater storage	P1 - Water quality P2 - Fish Spawning P3 - Waterbird support	S1 - Water reservoir S2 - Flood control S3 - Climate and water regulation S4 - Public recreation and spiritual enrichment, including fisheries S5 - Education and aesthetics S6 – Maintenance of biodiversity, including fish spawning
Supporting	Aquatic vegetation Waterbirds Aquatic fauna Aquatic invertebrates Phytoplankton Zooplankton	Climate Geology Soils Bathymetry Hydrology and water quality Sediment quality	Water and nutrient cycling Habitat for biota

The following sections provide a more detailed description of key components, processes, and services for Kranji Reservoir. Where possible, information on natural variability for the components, processes, and services at the time of writing is given.

Given this appendix is presented in the Project's EIA as a standalone report, the content of the Project's key terrestrial biodiversity and aquatic survey findings (also see the Project's EIA Appendices 7.1 & 7.2) are repeated below for completeness.

3.3 KEY COMPONENTS

3.3.1 WATER RESERVOIR

The water reservoir was selected as the key component, as the primary purpose of the reservoir is as water storage infrastructure (with water provided for human consumption after PUB's treatment). The water reservoir supports key species and wildlife populations that characterise the site's ecological character and determine the key services as described below.

Six other supporting components were identified, reviewed, and considered: Aquatic vegetation, waterbirds, aquatic fauna, aquatic invertebrates, phytoplankton and zooplankton.

REASONS FOR SELECTION AS 'KEY'

The primary purpose of Kranji Reservoir is water provision i.e. the reservoir was created and is managed as PUB storage infrastructure. Thus, the inherent structure and condition of the reservoir is managed primarily for water storage, and it is this that determine the ecological character of the site.

DESCRIPTION

Kranji Reservoir is a permanent, man-made freshwater reservoir that covers a total area of 522 ha. Water is continuously extracted as a water supply and provide services and benefits to humans, plant and animal species.

PATTERNS IN VARIABILITY

Following the damming of Kranji River and the formation of Kranji Reservoir, it is likely that historical LACs were exceeded, and a new equilibrium state occurred. The water reservoir is predicted to experience natural variability over time, although it is unclear whether changes are likely to be linear or non-linear. These changes due to natural variability (e.g. climate change) are expected to be exacerbated further by increasing anthropogenic pressures. Historical maps show changes have occurred in the extent of Kranji Reservoir since 1958 and it is likely that its extent varies over both short and long timescales. Historical data is limited at this site and it is not possible to provide definitive descriptions of variability in wetland habitats over longer timescales. At present, no substantial human development is present on Kranji Reservoir. In the future, new pressures could occur due to climate change and/or additional development activities.

The main driver controlling the state of highly eutrophic tropical reservoirs is nutrient concentration.

3.4 SUPPORTING COMPONENTS

3.4.1 AQUATIC (AND TERRESTRIAL) VEGETATION

TERRESTRIAL VEGETATION

Terrestrial surveys of vegetation at Kranji Reservoir were carried out by Camphora. Terrestrial flora was identified using habitat mapping, walking surveys and boat surveys. Seven habitat types were recorded. The dominant habitat was scrubland and herbaceous vegetation, and managed vegetation and marshland. Floristic baseline surveys found a total of 222 terrestrial species and two terrestrial species groups (i.e. plants that could not be identified to species with certainty) within flora sampling areas adjacent to Kranji Reservoir and along the reservoir edge.

In total, 10.36% (23 species) of the total flora species counted are characterised as native threatened species. A tabulation of the total flora species is presented in Table 3-2.

Table 3-2 Number of Flora Species Recorded within the Entire Flora Sampling Area in the vicinity of Kranji Reservoir along with their Statuses.

Origin	Status	Number of Species	Percentage (%)
Native	Common	88	39.64
	Vulnerable	12	5.41
	Endangered	3	1.35
	Critically Endangered	8	3.60
	Data Deficient	1	0.45
	Subtotal	112	50.45
Exotic/ Non-native	Cultivated Only	10	4.50
	Casual	16	7.21
	Naturalised	65	29.28
	Not Assessed	1	0.45
	Subtotal	92	41.44
Cryptogenic		18	8.11
Total		**222 (220 species + 2 species group)**	**100.0**

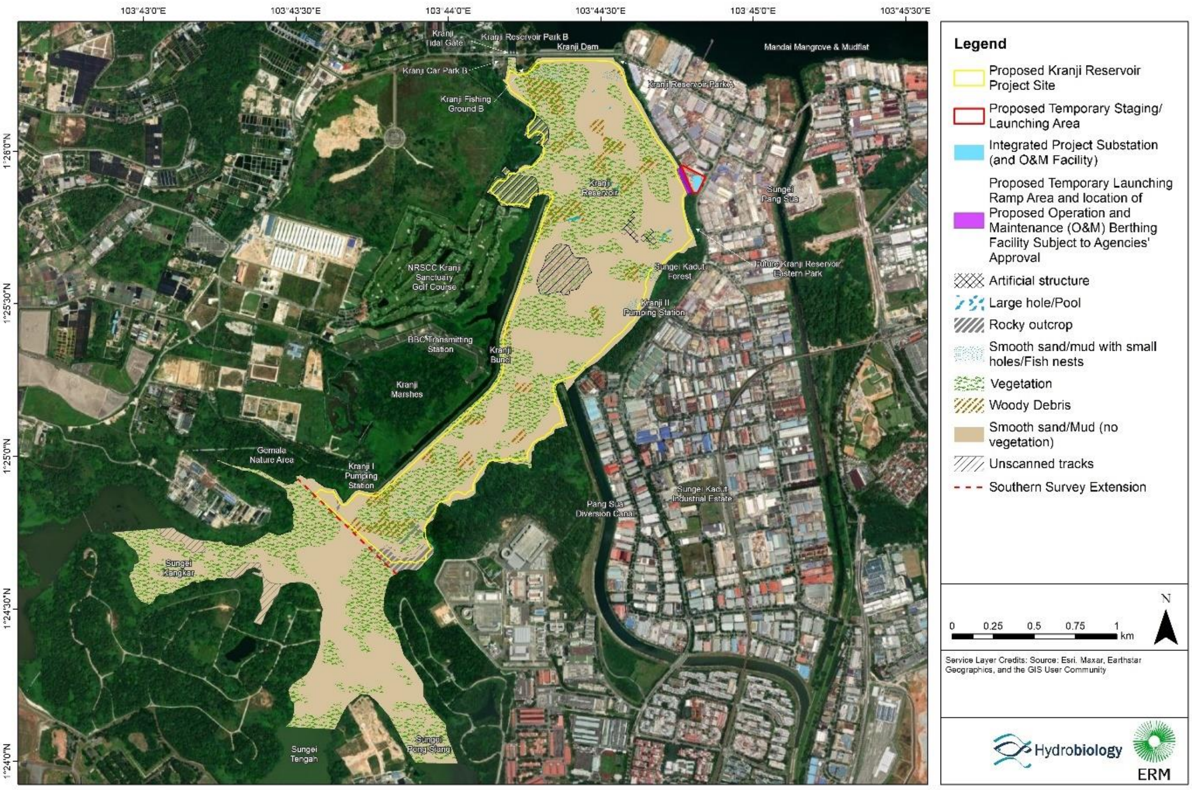
Of the 23 nationally threatened species found in the BIA Study Area, 16 were considered as species of conservation significance. Despite being nationally threatened species, the remaining 6 species were not considered to be of conservation significance as they are most likely escapees from present-day cultivation, relics of past cultivation and/ or were cultivated for roadside planting. These species are:

1. *Bouea oppositifolia;*
2. *Calophyllum inophyllum;*
3. *Carallia brachiata;*
4. *Gnetum gnemon var. gnemon;*
5. *Peltophorum pterocarpum;* and
6. *Syzygium myrtifolium.*

AQUATIC VEGETATION

Aquatic vegetation plays an important role in Kranji Reservoir. It supports various organisms like invertebrates, fishes and waterbirds by providing physical structure, increased habitat complexity and heterogeneity. It is an important source of food for aquatic organisms, providing both living (grazing food webs) and dead organic matter (detritivorous food webs). Further, it is crucial for spawning, nursery and feeding habitat for the majority of fish in the reservoir.

A combination of sonar and field survey techniques were used to map the distribution of floating, submerged and emergent/ floating vegetation. Habitat mapping of aquatic vegetation at Kranji Reservoir was carried out by Hydrobiology in March 2021. The distribution of submerged and emergent/ floating vegetation are presented in Figure 3-2. Unscanned areas are sites that could not be accessed by boat and reflect the area of emergent/ floating vegetation and/ or submerged vegetation growing throughout the water column. A total of 108 ha of aquatic vegetation was mapped by sonar in the Reservoir Project Site and 61 ha in the southern reservoir survey area (outside the Reservoir Project Site), an additional 17 ha of the Reservoir Project Site and southern study area were also considered to be vegetated but were inaccessible due to dense submerged vegetation growth throughout the water column.



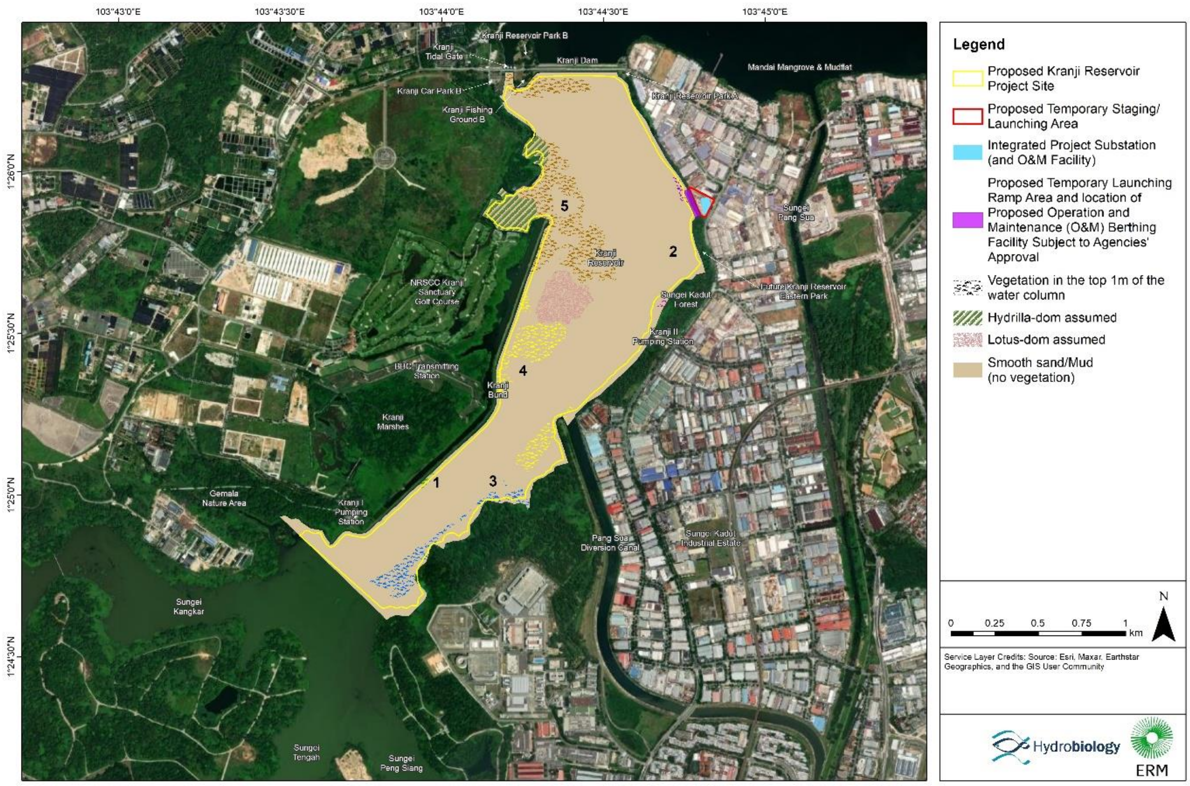


Figure 3-2 Underwater habitat maps of the study area

While sonar mapping of aquatic submerged vegetation is a relatively inexpensive and efficient technique that can provide estimates of biomass or biovolume estimates (Yin and Kreiling, 2011), it cannot differentiate plant species (Madsen, 1993). For this reason, aquatic vegetation sampling was conducted by Hydrobiology in July 2021 at five (5) sampling locations. The sampling locations were chosen based on criteria determined by the echosounder habitat mapping, which included areas where water depth was relatively shallow (<3 m) and vegetation was abundant. Once a vegetated area was identified and photographed, aquatic vegetation samples were collected from the top surface sediments of the reservoir bed (0-5 cm) using either a standard Ekman surface grab sampler (15 cm^3) (e.g. Hossain et al., 2020) or an approach referred to as the "rake method" (Johnson and Newman, 2011). Five zones were identified, with ten samples collected within each zone. Aquatic vegetation was identified to species level, when possible, using available identification keys for Singapore flora (Davison et al., 2008; Ng et al., 2010; Yeo et al., 2010), in addition to the online database for plants found in Singapore (NParks, 2021). At least twelve (12) different species were identified; five (5) were emergent/ floating, five (5) were partially submerged and two (2) species that are not aquatic plants were identified along the reservoir banks (Table 3-3).

Table 3-3 Flora species identified at Kranji Reservoir during the aquatic vegetation survey.

Species identification	Common name	Classification	Invasive/ native
Acacia auriculiformis	Acacia tree	Not considered aquatic but found along bank	Invasive
Anubias barteri var. glabra	-	Partially submerged/Emergent	Invasive
Cabomba aquatica	Yellow Cabomba	Emergent	Invasive

Species identification	Common name	Classification	Invasive/ native
Dillenia suffruticosa	Simpoh air	Not considered aquatic but found along bank	Native
Pontederia crassipes	Water hyacinth	Floating	Invasive
Hydrilla verticillata	Hydrilla	Submerged	Invasive
Ludwigia adscendens	Water Primrose	Floating	Invasive
Neptunia plena	Water mimosa	Emergent/floating	Invasive
Nelumbo nucifera	Water lotus	Emergent/floating	Invasive
Polygonum barbatum	Knotweed	Emergent	Exotic/ Non-native
Urochloa mutica	Para Grass	Partially submerged	Invasive
Vesicularia dubyana	Singapore Moss	Partially submerged	Native

In Kranji Reservoir, the reservoir's trophic structure is based on the primary productivity of its vegetation. The extent and distribution of vegetation is an important driver of nutrient cycling and availability and plays a key role in controlling the exchange of nutrients from sediment to water by both active and passive processes. Samples of aquatic vegetation collected from Kranji Reservoir were analysed for water and nutrient content. Water content in each sample was measured using a standard loss-on-ignition approach (Dean, 1974). Up to 98% water content was measured in the samples. Biomass between sites was greatest in zone 5 (33.1 mg/m^2), with *Hydrilla verticillata* in Zone 5 (northwest) contributing the largest biomass (29.5 mg/m^2). While *Hydrilla verticillata* accounts for the largest biomass reported here, it is noted that grab sampling and rake dragging are more likely to capture submerged vegetation, rather than floating plants. Large surface areas of floating plants, such as Eichhornia crassipes, were also observed at the time of sampling. However, the results presented here are successful in identifying *Hydrilla verticillata* and Eichhornia crassipes as two dominant species that were present and account for large amounts of plant biomass in the reservoir at the time of sampling.

Dried samples were further analysed for nutrients total phosphorus (TP), total nitrogen (TN) and total carbon (TC). TP levels were greatest (3,377 mg/kg) in Zone 1 (southwest) where three aquatic species were identified. Relatively high levels of TN (5.2%) and TC (35.3%) were found in Zone 5, where biomass was greatest. A distinct relationship between biomass, TP, TN and TC was also identified at Zone 7 (outside Reservoir Project Site) and Zone 2 (northeast within Reservoir Project Site), which suggests lower biomass results in a reduction of TP and TN levels and increased levels of TC.

3.4.2 WATERBIRDS

Waterbird surveys were carried out by a combination of:

- Boat sampling on the reservoir surface and along the reservoir edges (bird density surveys) from May 2021 – May 2022;
- Vantage point surveys from October 2020 – March 2022 (6 vantage points); and
- Point counts and transect surveys for particular target species i.e. black-crowned night heron (*Nycticorax nycticorax*) from February – April 2022.

Vantage point surveys (VPS) were also performed on Kranji Reservoir to identify focal bird species that use the water edges for foraging. Six vantage points were used to cover the complete extent of the Reservoir Project Site and areas surrounding this to the north and south (Figure 3-9). During the migratory season from September to February, surveys were undertaken twice monthly at each VPS location. This was reduced to once a month during the non-migratory season of March to August. Surveys for VP01–VP03 were conducted over October 2020–October 2021, while surveys for VP04–VP06 were subsequently added and conducted over March 2021–March 2022 (allowing some overlap with the migratory season). The VPs recorded activity of the 16 focal bird species (Table 3-4). The focal species are all piscivorous birds and were targeted for sampling given their reliance on open water for foraging. Some of the focal species are of conservation concern.

A total of 2,282 foraging events across the 16 focal species were observed across all vantage points over a year by the present baseline studies. The relatively highest usage was observed at the SBWR, in front of the BBC radio transmission towers and Kranji Bund, and at the south-eastern part of the reservoir (outside the Reservoir Project Site) where the three rivers converge (Figure 3-4).

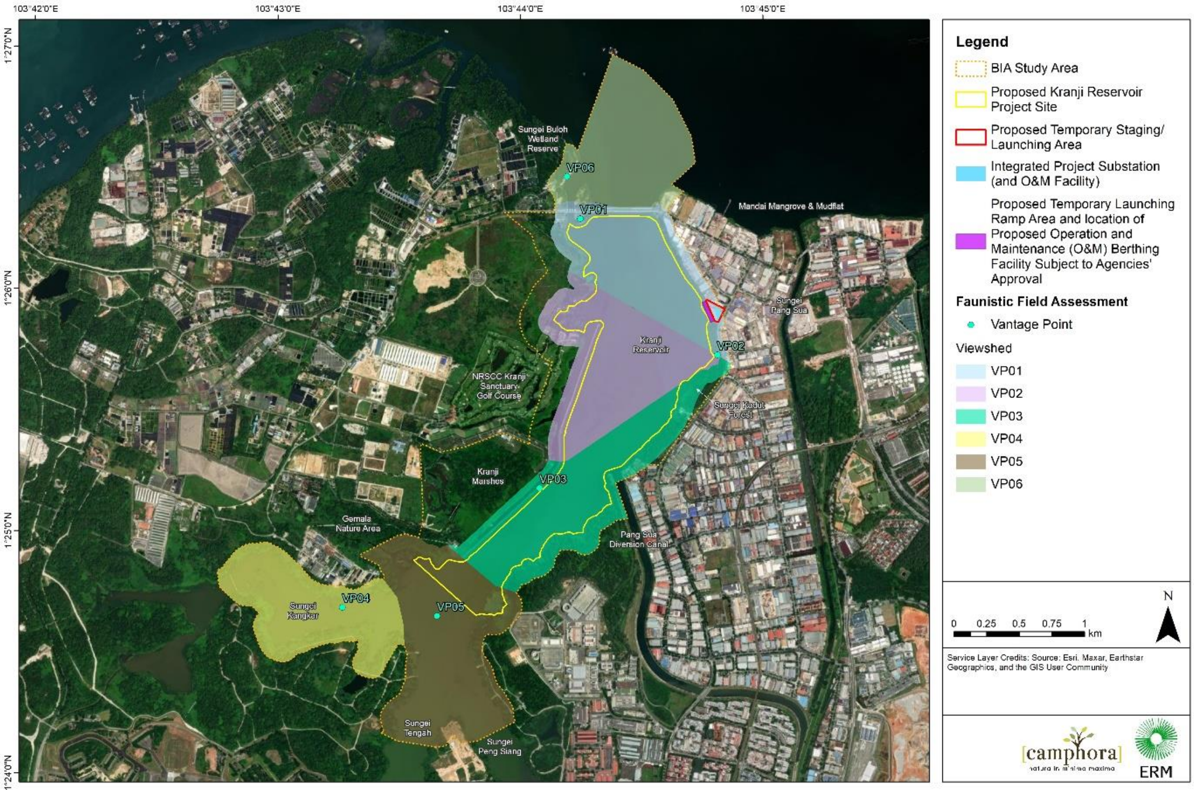


Figure 3-3 Vantage point survey viewsheds

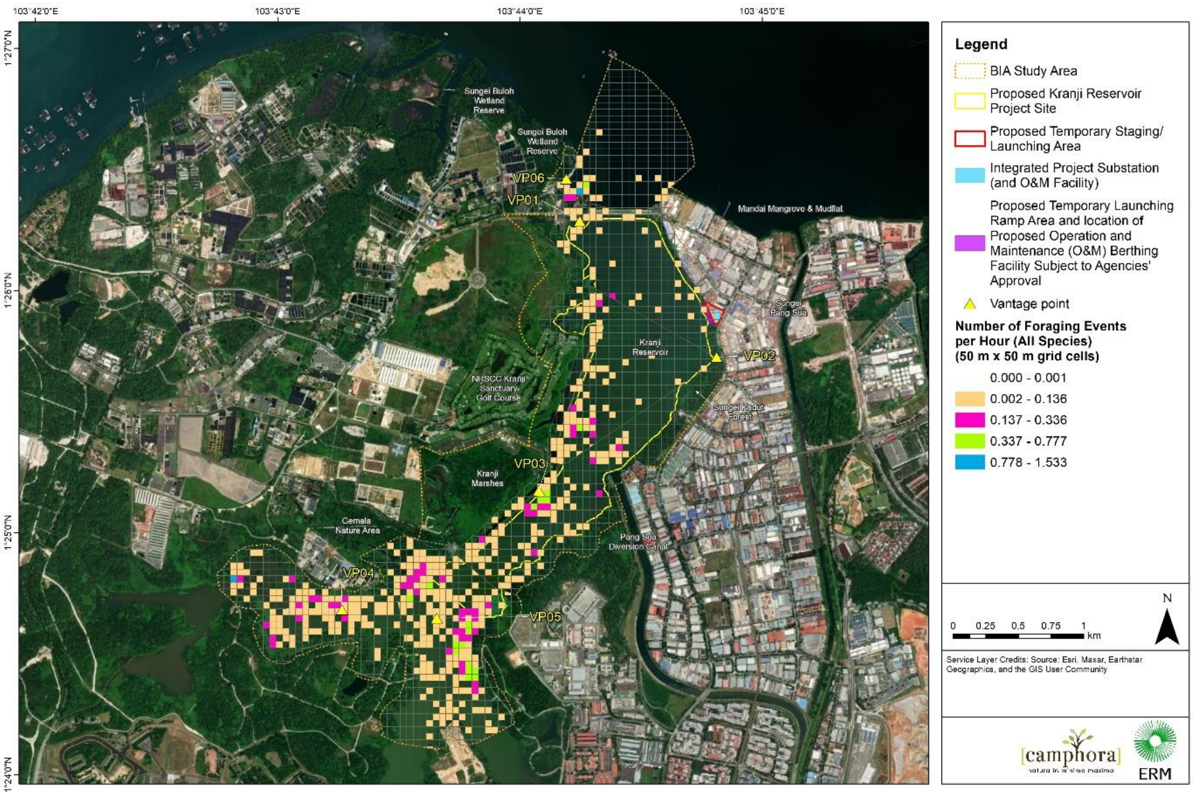


Figure 3-4 The foraging usage of all focal species on Kranji Reservoir.

The map above shows the number of foraging events per hour within each grid. One foraging event constitutes one bird observed foraging at one location.

Table 3-4 Focal species for VPS – birds that were recorded on Kranji Reservoir and its water edges for foraging.

No.	Scientific name	Common name	Global conservation status (IUCN Red List, 2022)	National conservation status (SGP RDB3, 2022 (accessed 28 July 2023))
1	*Haliaeetus leucogaster*	White-bellied sea eagle	Least Concern	Least Concern
2	*Haliaeetus ichthyaetus*	Grey-headed fish eagle	Near-threatened	Vulnerable
3	*Haliastur indus*	Brahminy kite	Least Concern	Least Concern
4	*Pandion haliaetus*	Osprey	Least Concern	Least Concern
5	*Ardea purpurea*	Purple heron	Least Concern	Endangered
6	*Ardea cinerea*	Grey heron	Least Concern	Least Concern
7	*Ardea alba*	Great egret	Least Concern	Vulnerable
8	*Ardea intermedia*	Intermediate egret	Least Concern	Least Concern
9	*Egretta garzetta*	Little egret	Least Concern	Least Concern
10	*Ardeola sp.*	Pond heron	-	-

No.	Scientific name	Common name	Global conservation status (IUCN Red List, 2022)	National conservation status (SGP RDB3, 2022 (accessed 28 July 2023))
11	*Bubulcus coromandus*	Eastern cattle egret	Least Concern	Vulnerable
12	*Butorides striata*	Striated heron	Least Concern	Near Threatened
13	*Ixobrychus sinensis*	Yellow bittern	Least Concern	Vulnerable
14	*Chlidonias hybrida*	Whiskered tern	Least Concern	Least Concern
15	*Chlidonias leucopterus*	White-winged tern	Least Concern	Endangered
16	*Sternula albifrons*	Little tern	Least Concern	Endangered

Table 3-5 Number of foraging events for each species

Species	National conservation status	Global conservation status	Number of foraging events (n) within survey period
Little tern	EN	LC	1,282
Other ardeids (*Ardea alba, Ardea intermedia, Egretta garzetta, Ardeola spp., Butorides striata, Ixobrychus sinensis,* unidentified *Ardeidae*)	See table above	LC	507
Other terns (*Chlidonias* spp. and unidentified *Laridae* spp.)	See table above	LC	301
Purple heron	EN	LC	80
White-bellied sea eagle	LC	LC	52
Brahminy kite	LC	LC	10
Western osprey	LC	LC	11
Grey heron	LC	LC	4
Grey-headed fish eagle	VU	NT	1
		Total	**2,282**

Birds were surveyed along boat sampling transects fringing both the entire length of the Reservoir Project Site and further south into the tributaries. In total, 1,347 birds (those birds that were in contact with the ground, vegetation, or water surface) were counted along the reservoir edge. Figure 3-5 shows the number of birds per month within each grid along the reservoir edge (up to 50m from the boat transect). Higher bird density was observed in the southern reservoir area, outside of the Reservoir Project Site. Bird density along the rest of the reservoir edge is evenly distributed, with the exception of one location found on the eastern edge, which has a higher bird density due to the roost of the black-crowned night heron. Communal roosts of the black-crowned night heron were recorded along northwestern and north eastern edges of the reservoir (Figure 3-6). A number of other nests were recorded around the edge of the reservoir, including a grey-headed fish eagle nest in Sungei Kadut Forest on the east bank.

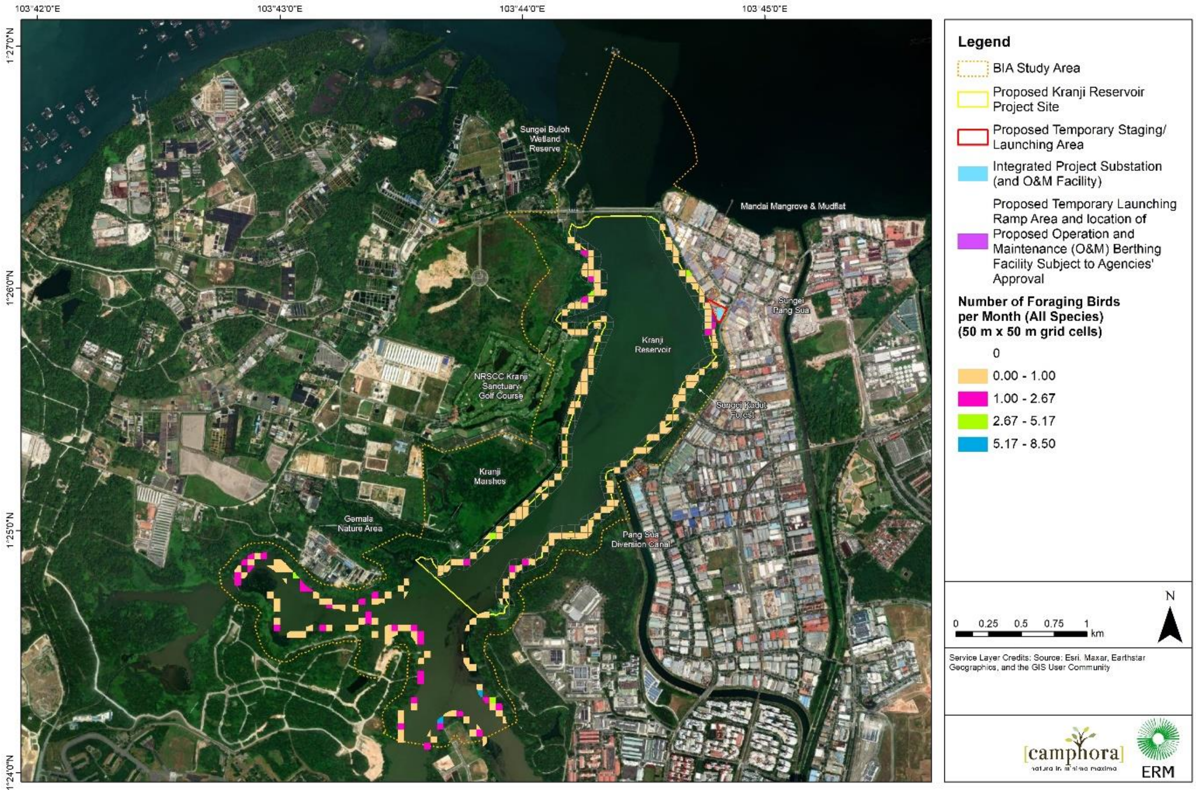


Figure 3-5 All Recorded Bird Density along the Edge of Kranji Reservoir

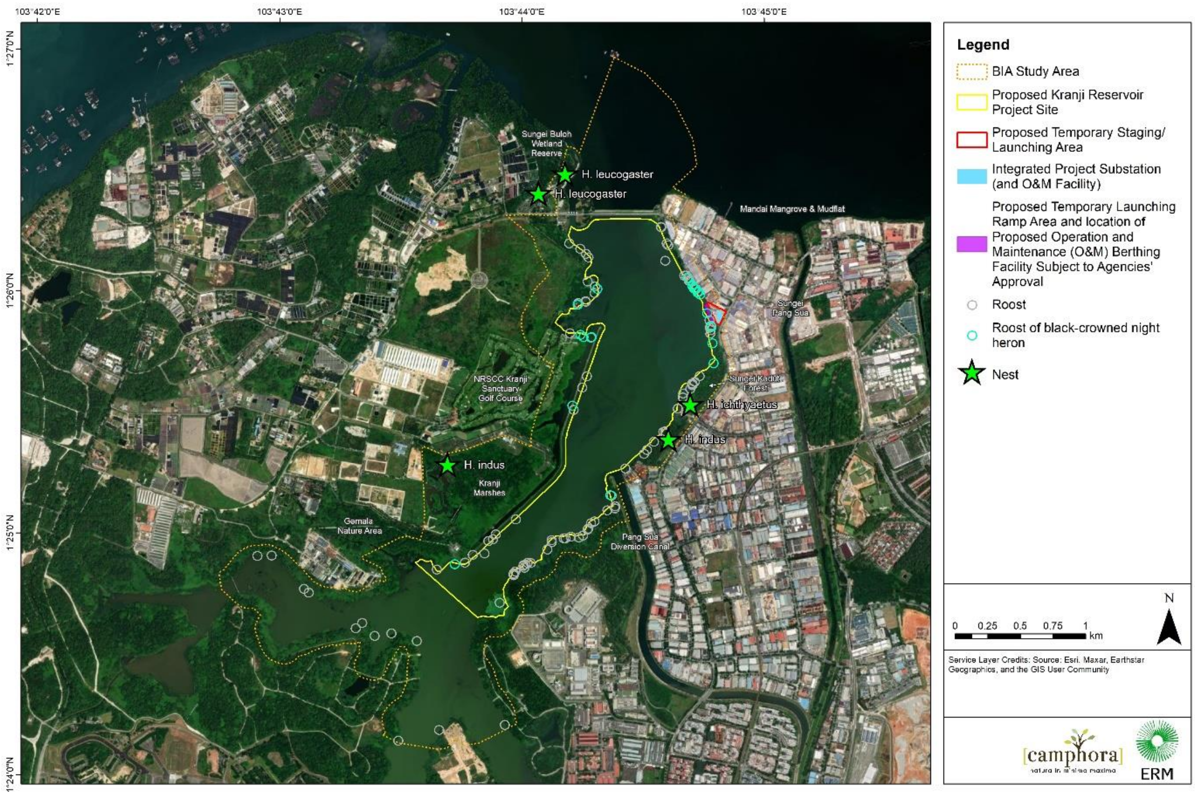


Figure 3-6 Roosts of Black-crowned Night Heron

A summary of the key results is presented below:

- **Little tern** (*Sternula albifrons*) was recorded foraging most frequently on the reservoir (1,282 foraging events). Usually this species was recorded foraging as a single individual but on one occasion 15 individuals were noted. Foraging was concentrated at the western edge, as well as to the area south of the Reservoir Project Site (Figure 3-7). Greater foraging activity was recorded during the little tern's breeding season (May – September, inclusive; Figure 3-7.) as expected given the increased abundance of individuals during this period. Foraging was predominantly recorded in areas with low density in emergent/ floating vegetation and in both, deep and shallow zones of the reservoir. No nesting sites were recorded during the surveys.
- **Other ardeid (heron and egret) species** were recorded foraging in front of the BBC radio transmission towers along Kranji bund, and the southern part of the reservoir outside the Reservoir Project Site (Figure 3-8). Foraging was recorded 507 times within the survey periods. Foraging was also recorded on the mudflat off SBWR and the single sighting of grey heron was recorded near Mandai Mangrove and Mudflats. All heron species observed using the reservoir roost at SWBR, except the black-crowned night heron (*Nycticorax nycticorax*).
- **Other tern species'** foraging mirrored that of the little tern but in lower numbers (Figure 3-9).
- **Purple Heron** (*Ardea purpurea*) (Figure 3-10) was recorded having a total of 80 foraging events, with the majority in the southern part of the reservoir outside the Reservoir Project Site (Figure 3-10). This may be due to their preference for freshwater wetlands, reedbeds and dense marshy vegetation, as they are shyer and prefer concealment in dense vegetation similar to that in the southern part of the reservoir. This species is known to be sensitive to disturbance, and their feeding appears to depend heavily on cover (IUCN-SCC Heron Specialist Group, 2021). While some areas along the Kranji bund is also a suitable habitat, regular grass cutting may have reduced the frequency of the purple herons using this area.
- Raptors foraging on the reservoir was very low and the one raptor of conservation concern, **grey-headed fish eagle** *(Haliaeetus ichthyaetus)*, was observed foraging only once on the reservoir during 313 hours of vantage point surveys (Figure 3-11). Outside the VPS survey a bird was seen carrying fish on three other occasions (Figure 3-11), and the species was observed actively using the area. Most activity by this species was to the south of the Reservoir Project Site. An active nest was recorded on the eastern bank of the reservoir.
- Two pairs of **white-bellied sea eagle** *(Haliaeetus leucogaster)* were recorded nesting in SBWR north of Kranji Way (Figure 3-12). These two pairs at SBWR were not observed to utilise the Reservoir Project Site, nor south of the Reservoir Project Site for foraging. Foraging by other individuals occurred 52 times (over 313 observation hours) in SBWR and the waters in front of the BBC radio transmission towers and Kranj bund, as well as the Gemala Nature Area to the south-west and outside of the Reservoir Project Site. To a much lesser extent, birds were also recorded foraging at the eastern section of the reservoir. Up to five individuals were recorded at any one time. The transmission towers to the west of the Kranji Reservoir are used as a perch.
- **Brahminy kite** *(Haliastur indus)*: Two nests were recorded; one in the south of Sungei Kadut Forest and the other in the western part of Kranji Marshes (Figure 3-13). In total, ten foraging events were observed. A higher density of flight paths was observed in the eastern part (near a nest), and south-western part of the reservoir outside the Reservoir Project Site, suggesting that these two areas are well used by the species.
- **Western Osprey** (*Pandion haliaetus*): At least two individuals were observed from the surveys. 11 foraging events were recorded for the western osprey. Foraging records were scattered across the reservoir, but foraging was observed mostly in the southern part of the

reservoir beyond the Reservoir Project Site (Figure 3-14). Due to its hunting technique, a relatively larger expanse of water surface may be more important for foraging compared to other raptors. Non-breeding individuals are known to travel as far as 10 km between daytime feeding grounds and roosts (Watkins, 2000). This as well as its ability to hunt along seacoast (i.e. outside of the Kranji Reservoir) may explain the low foraging observations.

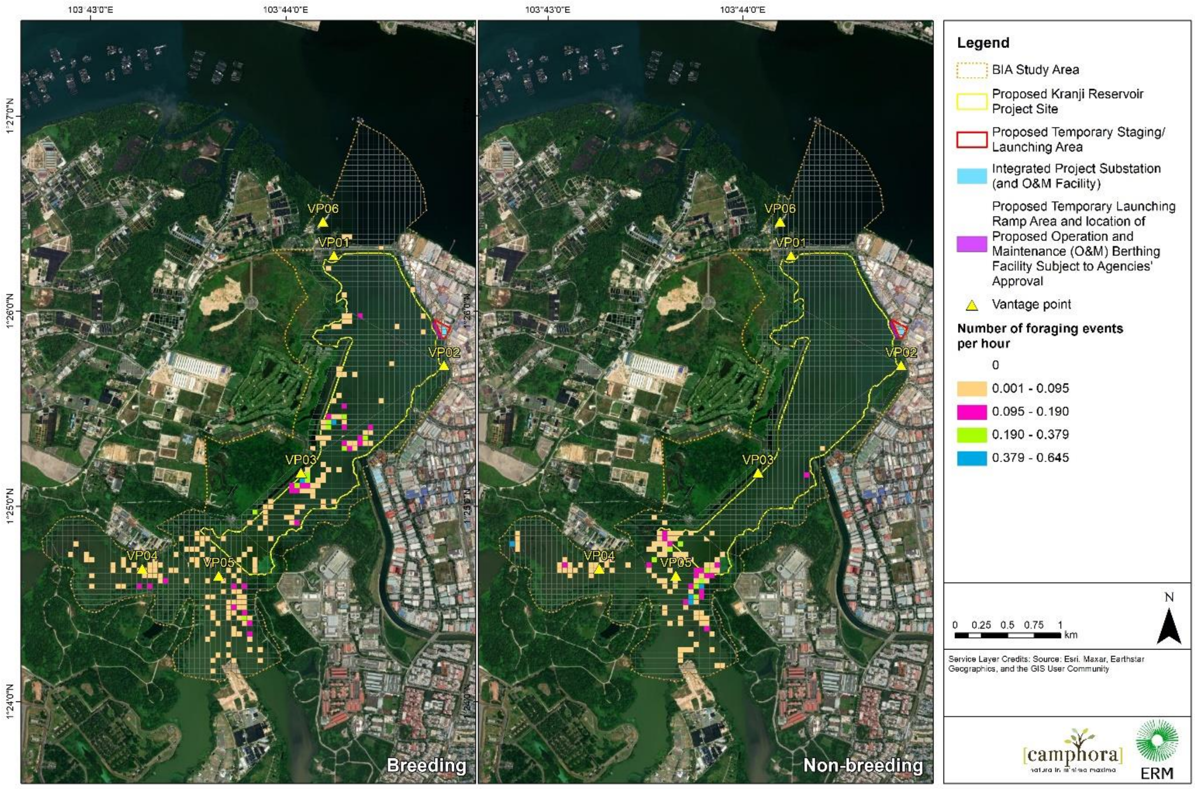


Figure 3-7 Foraging Locations of little tern (*Sternula albifrons*) Between Breeding Season (May-September) and Non-breeding seasons.

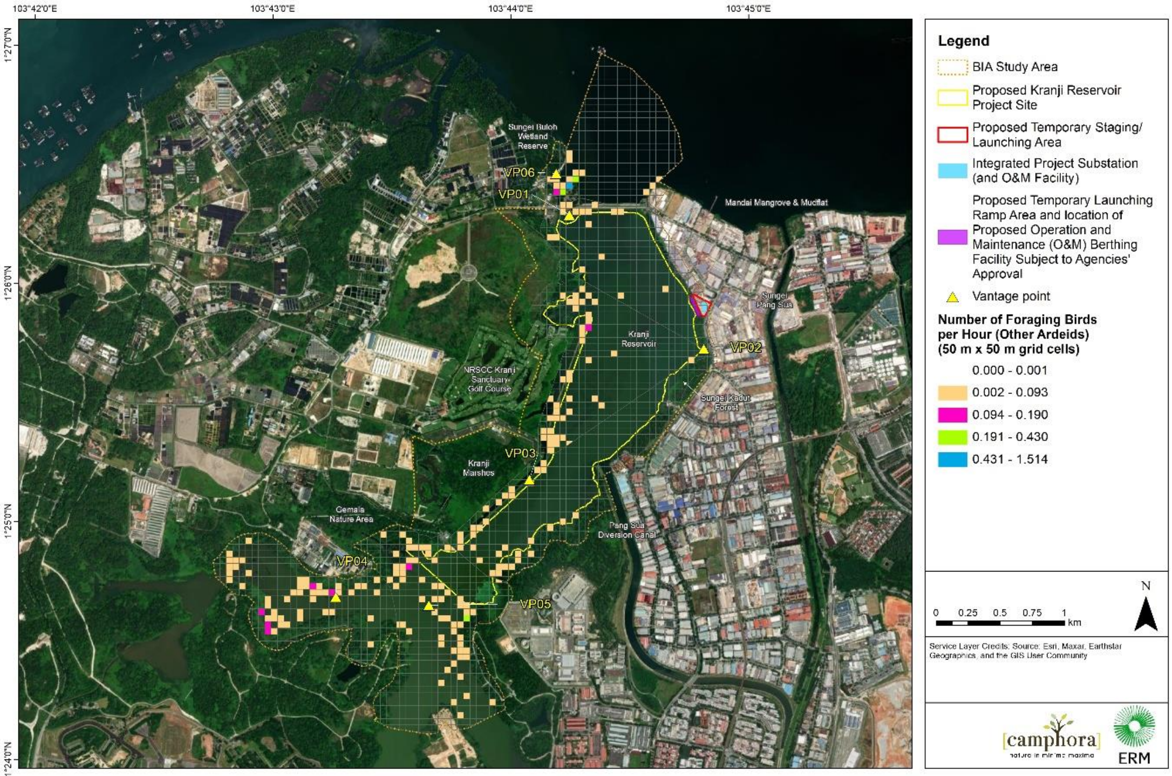


Figure 3-8 Foraging Locations of other ardeid species

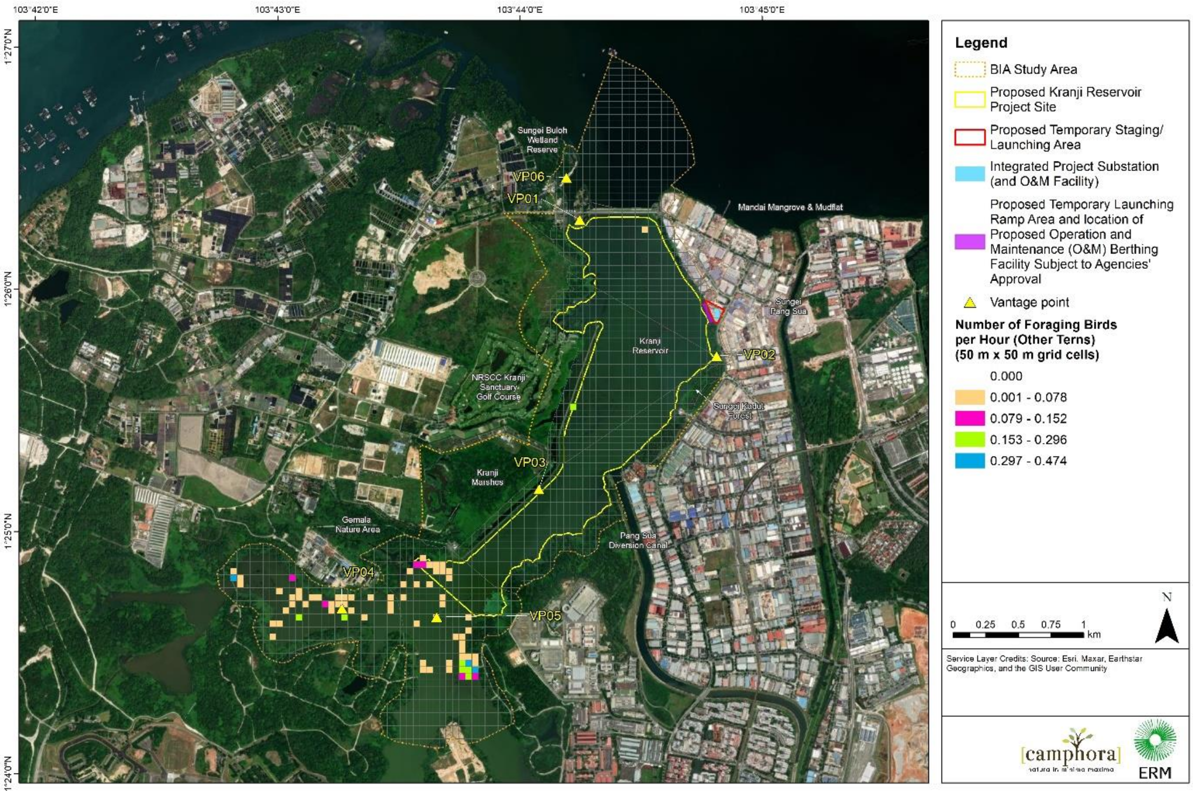


Figure 3-9 Foraging Locations of Other Terns (*Chlidonias* species and Laridae species)

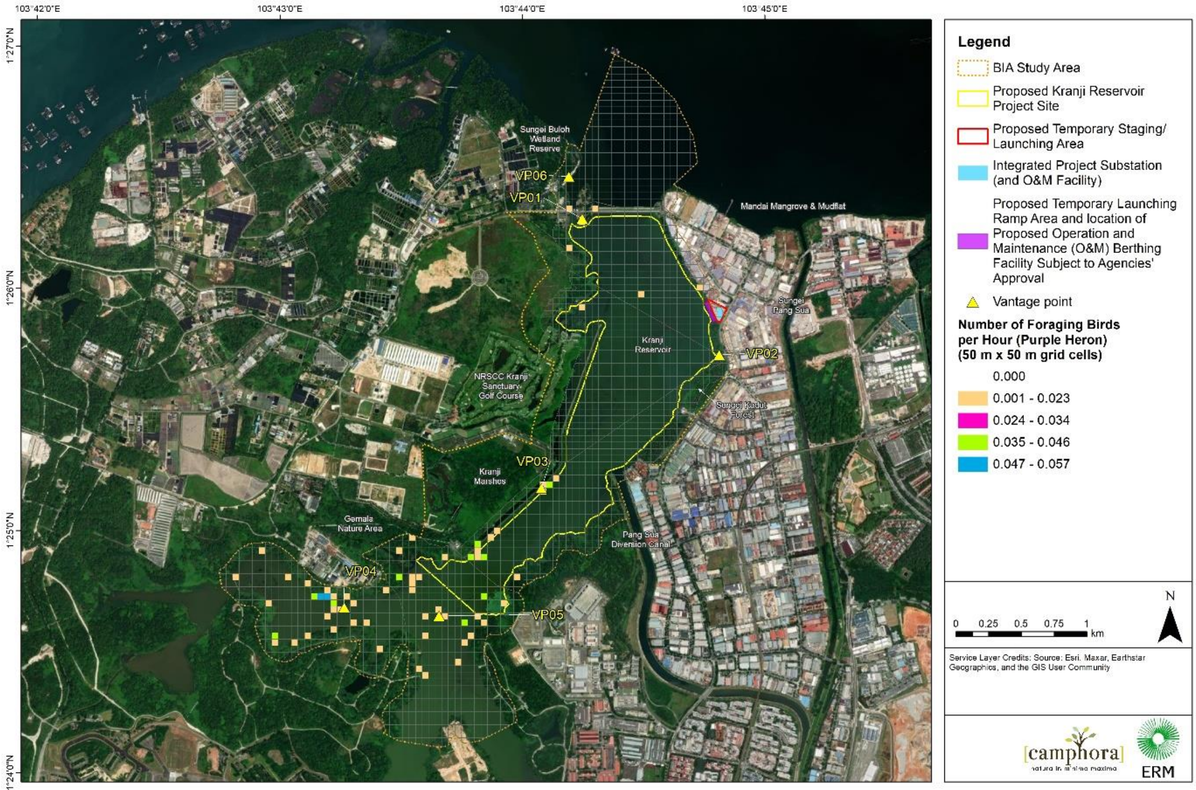


Figure 3-10 Foraging Locations of the Purple Heron (*Ardea purpurea*)

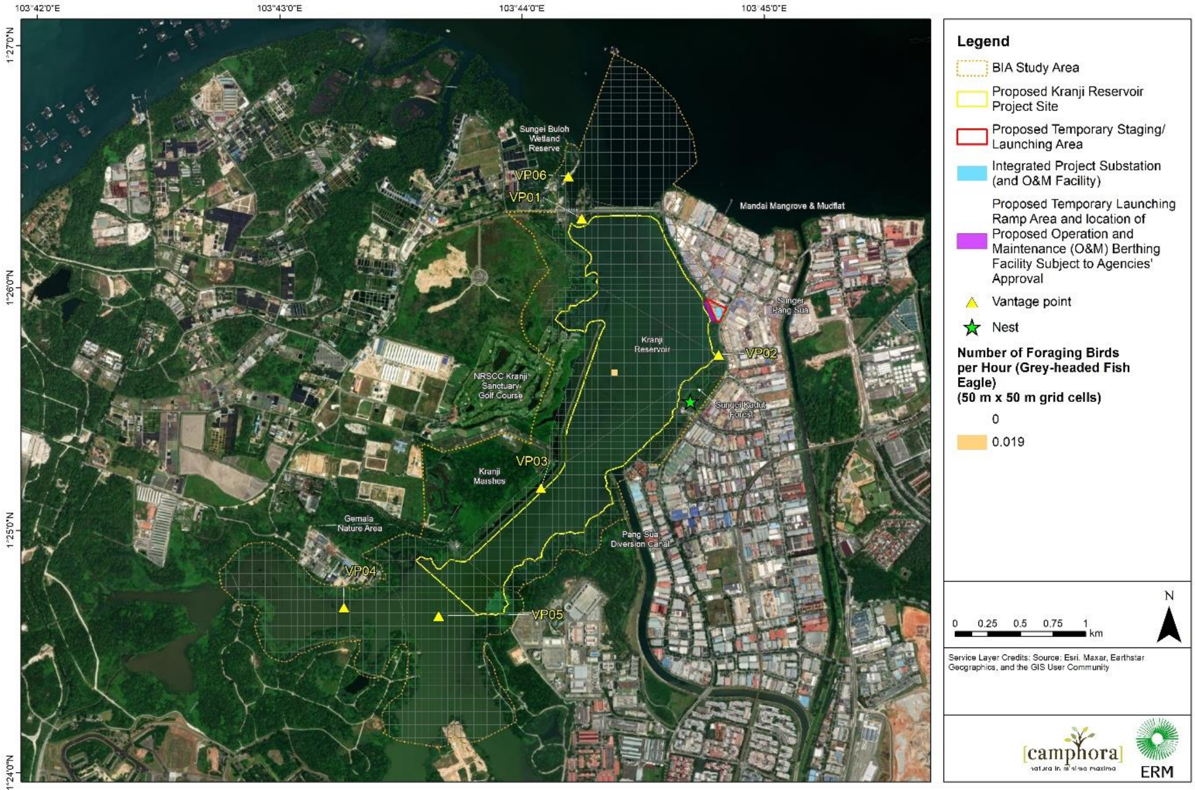


Figure 3-11 Foraging Locations of the Grey-headed Fish Eagle (*Haliaeetus ichthyaetus*)

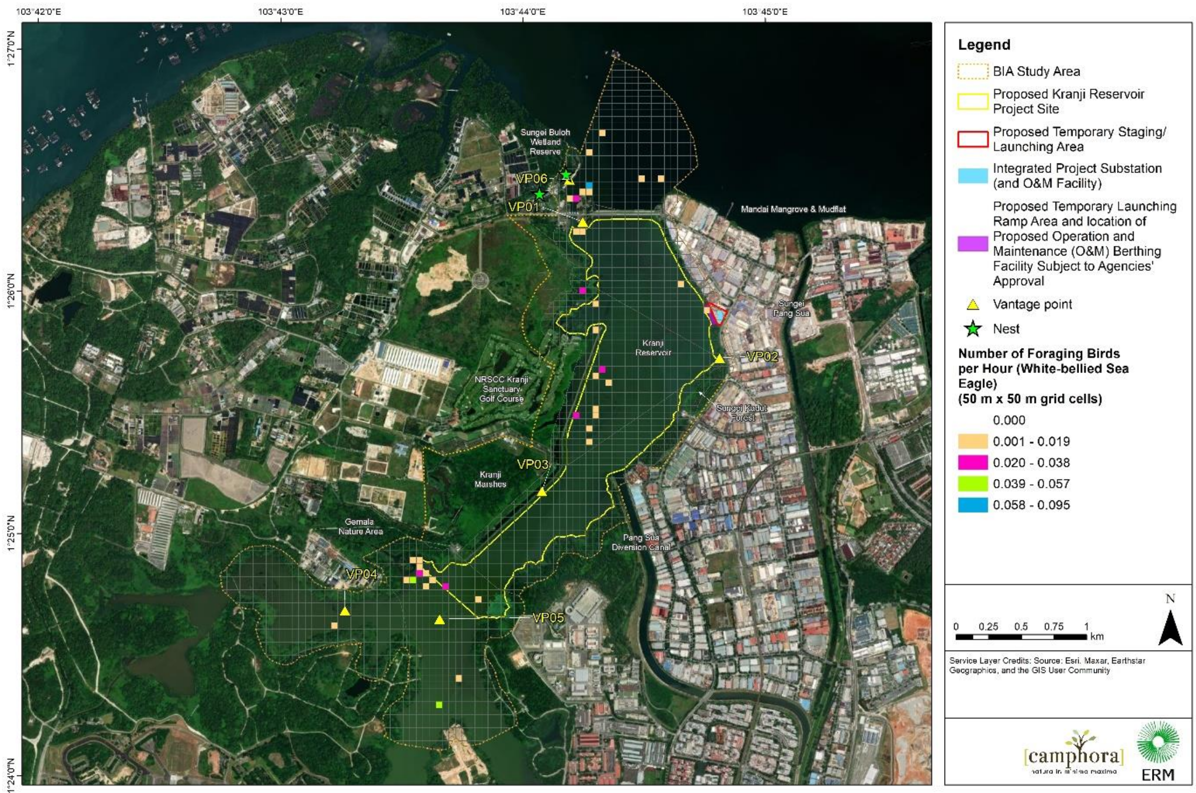


Figure 3-12 Foraging Locations of the White-bellied sea eagle (*Haliaeetus leucogaster*)

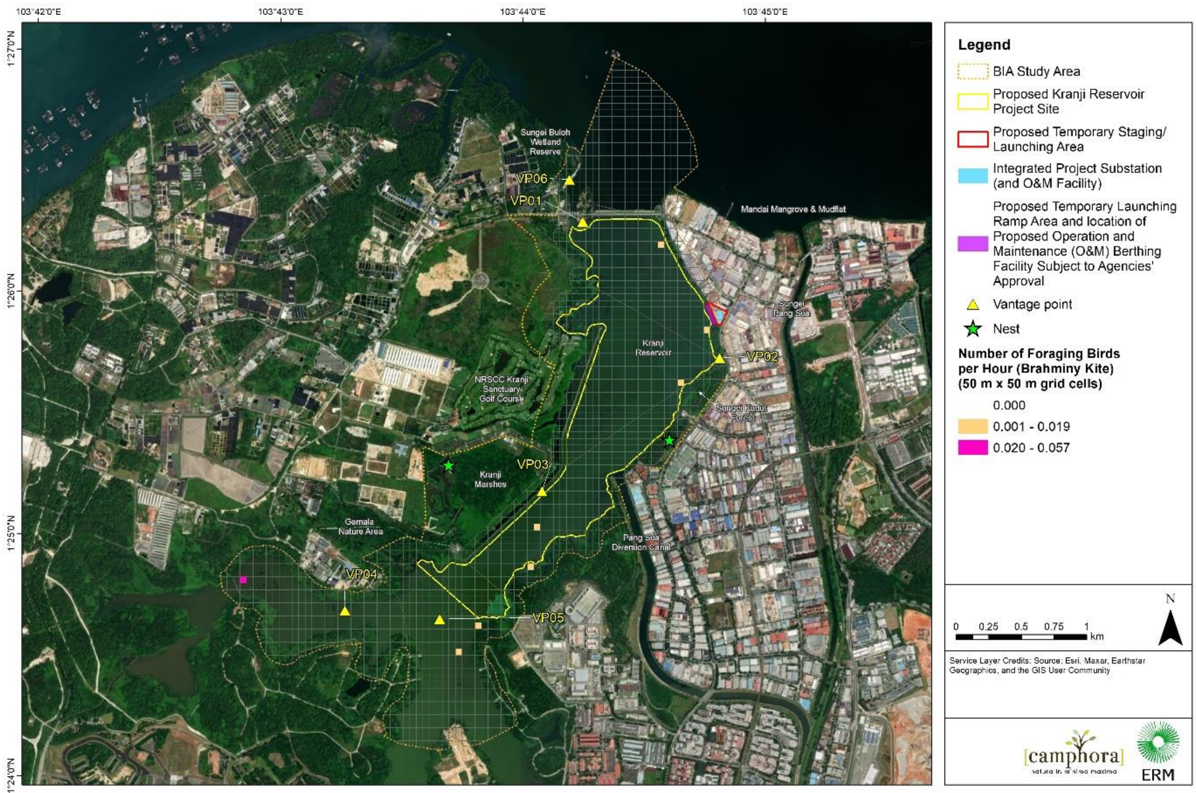


Figure 3-13 Foraging Locations of the Brahminy Kite (*Haliastur indus*)

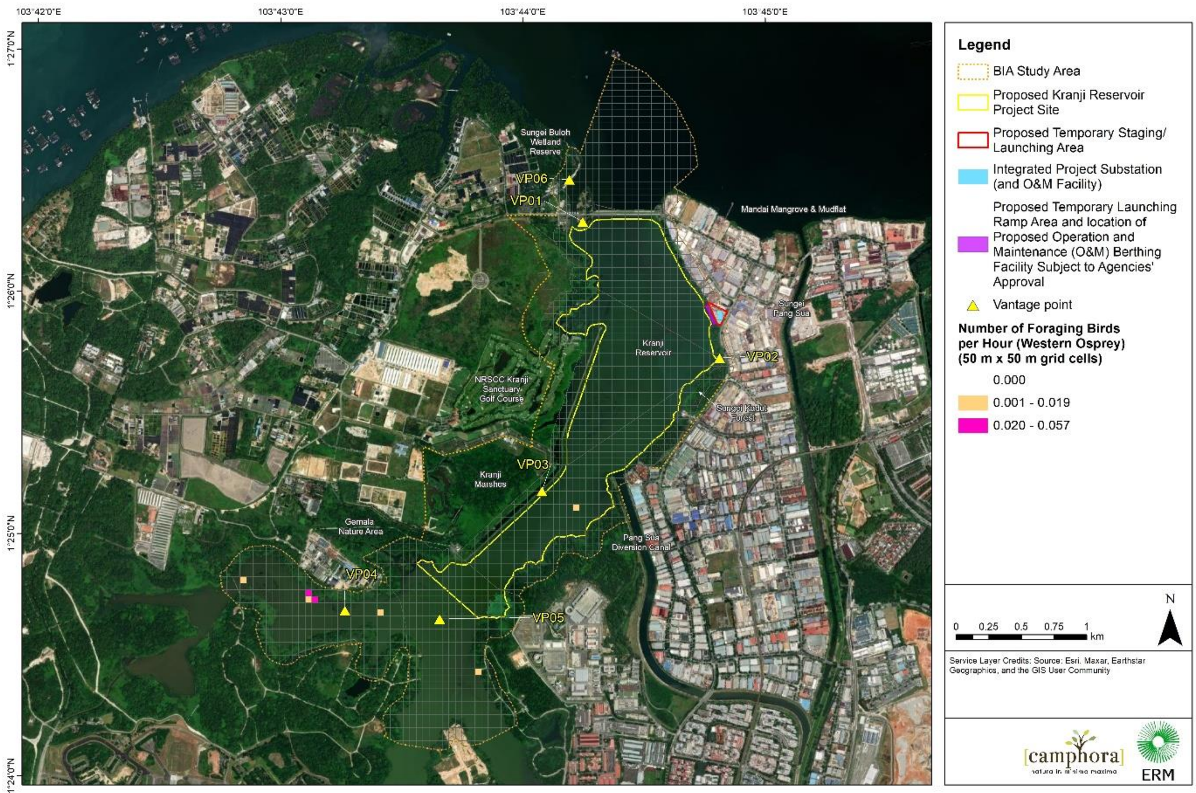


Figure 3-14 Foraging Locations of the Western Osprey (*Pandion haliaetus*)

3.4.3 FISH FAUNA

FISH BIOMASS

Hydroacoustic surveys were conducted across transects on Kranji Reservoir to locate and quantify an estimate of fish biomass present (Figure 3-15). Hydroacoustics is a well-established sampling technique that has been widely adopted by fisheries scientists to determine available fish stocks and are widely used for the monitoring and management in marine and freshwater environments (Pollom and Rose, 2016; Muška et al., 2018). Unlike survey techniques such as trapping, fishing, camera recordings and Underwater Visual Census (UVC), hydroacoustics has the advantage of sampling almost the entire water column, covering a much greater area per unit of time, being non-destructive in nature and not hampered by issues such as water clarity, strong currents or diver depth limits (Egerton et al., 2018).

The limitations of this method include a reduced ability to differentiate between species (the exception being large, characteristic species in some systems) and logistical constraints around shallow waters (noise artefacts make sonar below around 2-3 m depth impractical for this purpose). This creates artefacts within the data such as the absence of vegetation and fish at the reservoir edge. An additional constraint was that some areas could only be partially sampled due to limitations on navigation caused by emergent/ floating and submerged vegetation, in particular close to the end of the Kranji Bund in the west of the reservoir. These constraints have been taken into account during the data analyses.

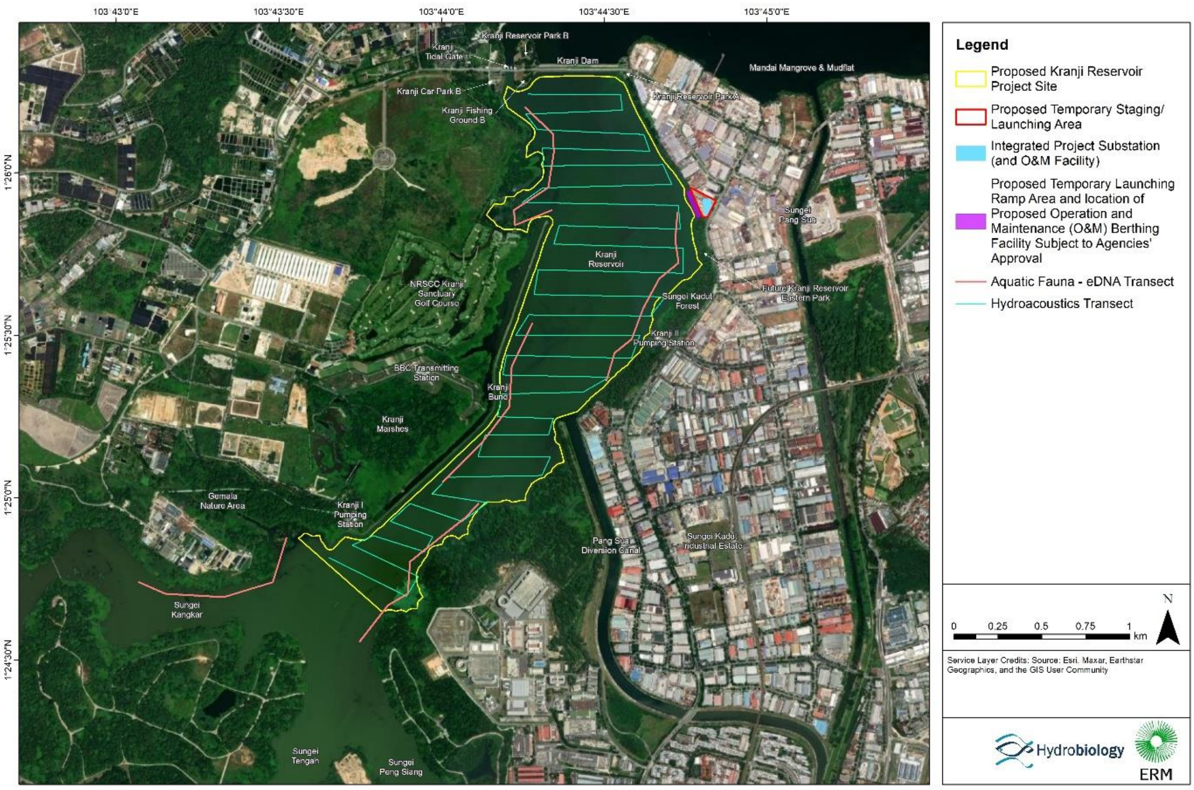


Figure 3-15 Hydroacoustic transects

An extract of the hydroacoustic echograms analysed is presented in Figure 3-16. Most of the transects indicate a layer of plankton at water depths of around approximately 3-4 m. The data shows fish were generally returning stronger echoes in greater numbers in deeper sections of the water column (>3m). The echograms indicated greater diversity in the size and number of fish exists in areas with greater depth.

In total, 25 repeated transects were completed. The echograms presented in Figure 3-16 are ordered from North to South (top to bottom) and illustrate transects number 1, 5, 10, 15, 20 and 25. The red area reflects the bottom of the reservoir, while the area below the reservoir bottom was excluded from the analysis. Note that the depth scale on the right-hand side varies between transects.

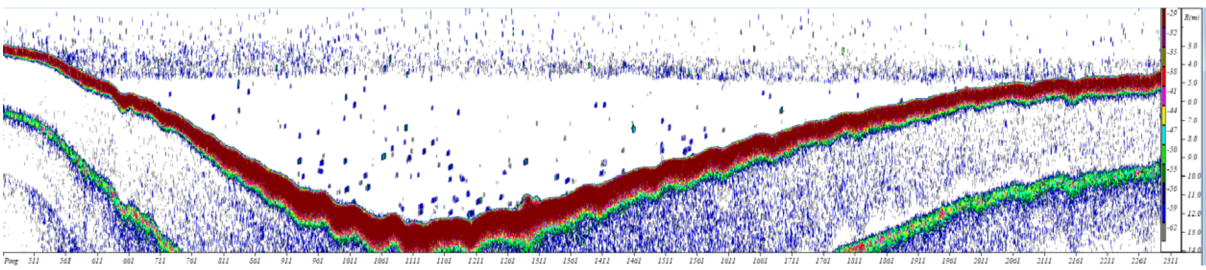


Figure 3-16 Example of hydroacoustic echograms analysed across Kranji Reservoir in June/July 2021

Figure 3-17, complemented with Table 3-6 for corresponding quantitative data, shows the number of fish tracks that were detected during the surveys. The number of tracks detected corresponds to the quantity of individual fish (of any size/ weight) identified by the software on the transects performed. Quantile classification was used to generate different classes. No tracks were detected in approximately 103.98 ha of the reservoir, which generally coincided with areas of <3 m depth (note the limitation above, this does not mean that there are no fish in these shallow margins only that sampling was limited in these areas). There were 1 – 5 tracks detected in about 34.70 ha, 6 – 10 tracks detected in about 11.36 ha, 11 – 20 tracks detected in about 4.96 ha and 21 – 30 tracks detected in about 1.17 ha. The highest range of tracks (31 – 40) covered only about 1.02 ha and was detected in the deepest region of the reservoir. Unscanned areas accounted for about 66.03 ha.

Tracks were detected in parts of the reservoir that were deeper than 3 m, with the greater number of tracks being detected in the deeper parts of the reservoir. This may be associated with both greater fish numbers and reduced noise level at the bottom of the reservoir.

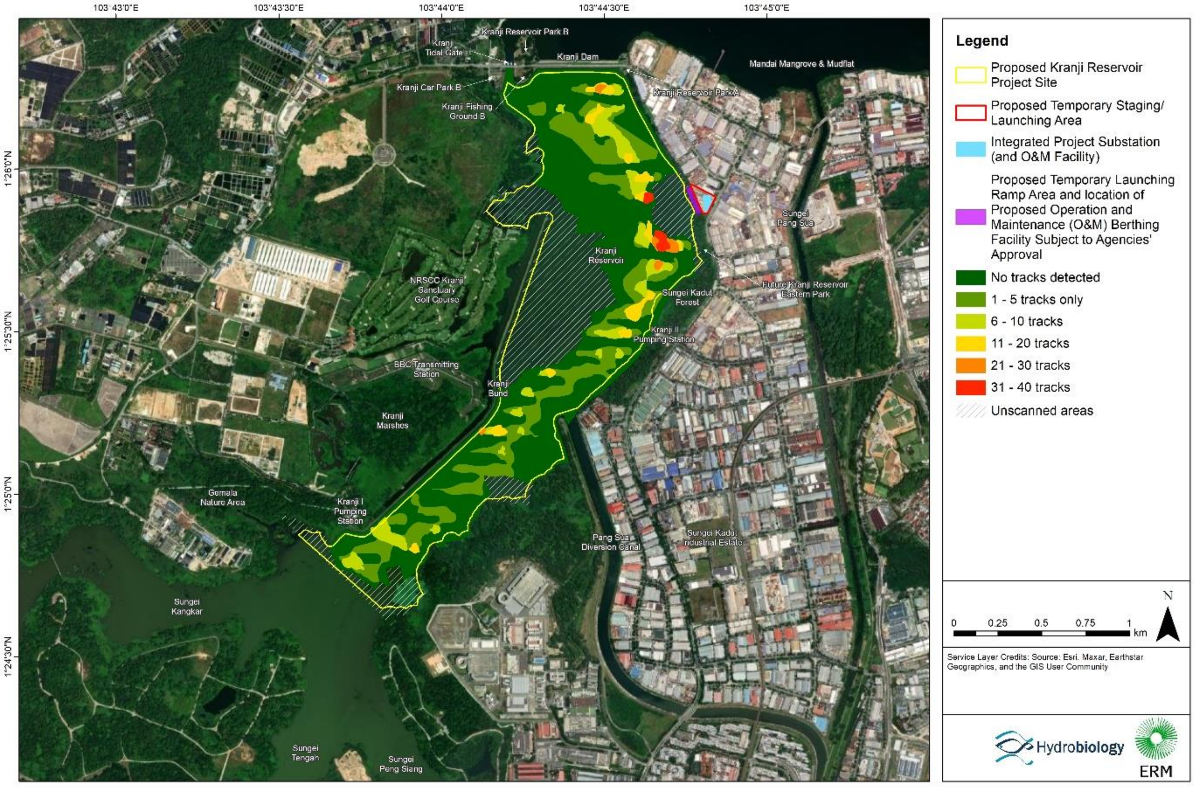


Figure 3-17 Fish tracks in Kranji Reservoir

Table 3-6 Estimated area size corresponding to the fish track categories presented above (calculated based on the interpolated raster dataset).

Total Tracks	Area (ha)
No tracks	~103.98
1 – 5 tracks	~34.70
6 – 10 tracks	~11.36
11 – 20 tracks	~4.96
21 – 30 tracks	~1.17
31 – 40 tracks	~1.02
Unscanned areas	~66.03

Total Tracks	Area (ha)
Total Area Scanned	~223.22

Figure 3-18 and Table 3-7 presents the volumetric biomass (g/m^3) (complemented with Table 3-6 for corresponding quantitative data), which highlights the potential areas of higher fish densities in Kranji Reservoir. Quantile classification was used to categorise volumetric biomass, in order to identify the areas hosting greater biomass in Kranji Reservoir. Fish biomass was estimated to be up to 2.31 g/m^3, based on an algorithm to convert sound data in decibels into fish length and fish biomass. Different species occurring in the reservoir are expected to return different sound signals and therefore, the biomass estimates presented here are relative estimates that can be used for future comparison, but active fish capture methods are required to validate and/or calibrate these biomass estimates with the reality.

Spatial variability in fish biomass across the reservoir was measured. Fish biomass was evenly distributed across the areas where fish were detected and the results suggest fish biomass was highest from the centre to the Southern area of the reservoir. The greatest biomass was measured in the far South and was associated with a small number of tracks (6-10, see Figure 3-17) which suggests that the fish encountered in this hotspot (in red) were few but of substantially larger size compared with other parts of the reservoir. A few other similar but smaller hotspots were also found across the whole reservoir. Patchier biomass was reported in the central to Northern region, with the highest estimates located to the North/ North-West. Relatively low biomass per volume (up to 0.050 g/m^3) was found in the Central-eastern region, where the highest number of tracks were located (31-40). This may suggest smaller fish are present in that area, but it may also be an artefact of the larger volume sampled relative to the shallower regions.

The data indicates the fish distribution in Kranji Reservoir was rather uniform, with higher fish density in the shallower southern half of the reservoir. However, it is likely that different assemblages are occurring in the deeper regions (central to North region).

Table 3-7 Estimate of the surface area surveyed corresponding to the fish biomass categories presented above (calculated based on the interpolated raster dataset)

Total Biomass (g/m^3)	Area (ha)
No biomass detected^	~108.79
>0 – 0.022 g/m^3	~1.28
>0.022 – 0.035 g/m^3	~4.95
>0.035 – 0.042 g/m^3	~2.97
>0.042 – 0.050 g/m^3	~1.98
>0.050 – 0.065 g/m^3	~6.87
>0.065 – 0.092 g/m^3	~6.90
>0.092 – 0.201 g/m^3	~16.04
>0.201 g/m^3	~8.26
Unscanned area	~66.03
Total Area Scanned	~224.07

Note: ^ noise artefacts hamper detection in much of these shallow areas, it does not imply a lack of fish. While hydroacoustic techniques can be used to obtain an estimation of fish habitat distribution and biomass, it is unable to provide species-specific information (Egerton et al., 2018). For this reason, it is necessary to review historical data to determine the species present.

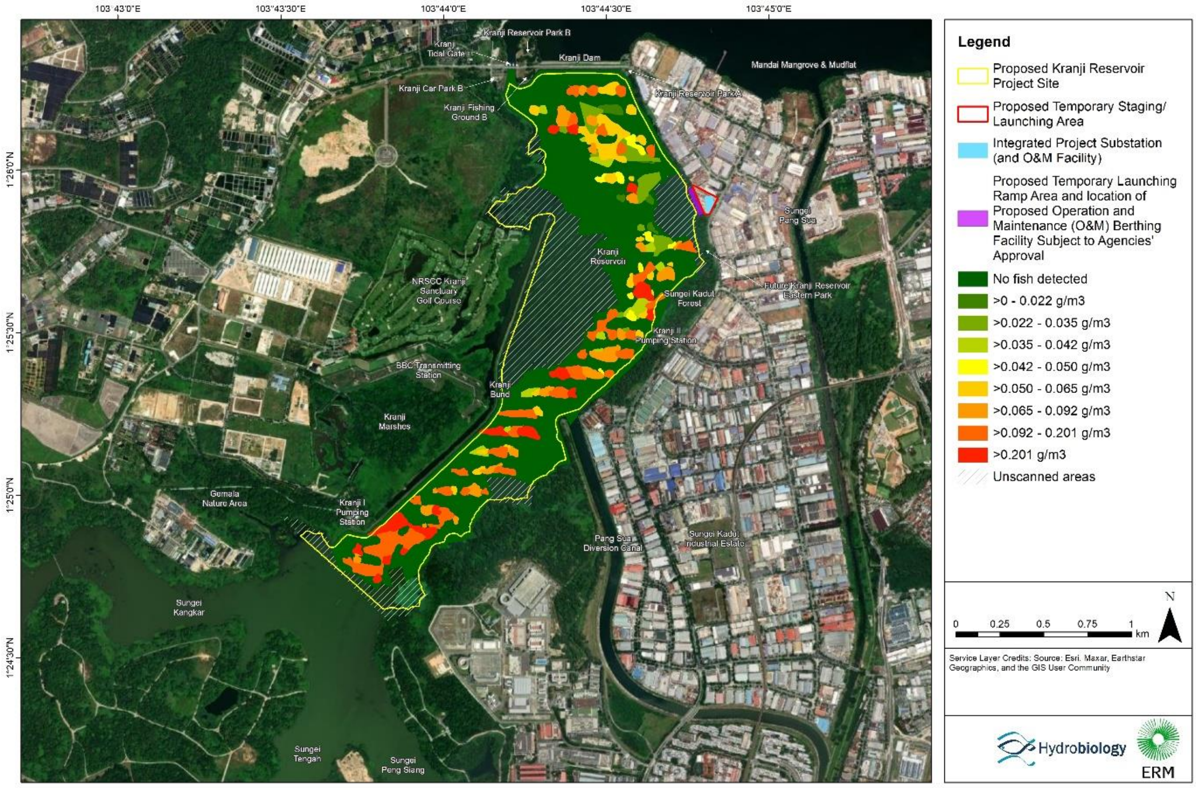


Figure 3-18 Fish bio biomass per volume (g/m^3) in Kranji Reservoir

FISH SPECIES DIVERSITY

Prior to reservoir formation, historical records of fish species present in Sungei Kangkar, Sungei Kranji and Sungei Peng Siang in 1937–1966 were compiled by the Raffles Museum of Biodiversity Research (RMBR) and are presented in Table 3-8. A different assemblage was reported from Sungei Kangkar and Sungei Kranji in 1963 (Table 3-9), presumably with quite different sampling methods given the difference in species recorded. The change in environmental conditions associated with the formation of the reservoir may have changed the habitat niches dramatically, shifting population dynamics. This may have resulted in the local loss of many of these species.

Table 3-8 Historical record of fish species identified from Sungei Kangkar, Sungei Kranji and Sungei Peng Siang in 1937-1966. Adapted from Ng et al. (2010)

S/No.	Common name	Species	Family	Native/Alien
1	Aruan	*Channa striata*	Channidae	**Native**
2	Bangkok halfbeak	*Zenarchopterus pappenheimi*	Hemiramphidae	**Native**
3	Bartail flathead	*Platycephalus indicus*	Platycephalidae	**Native**
4	Brownback trevally	*Carangoides praeustus*	Carangidae	**Native**
5	Bumblebee goby	*Brachygobius kabiliensis*	Gobiidae	**Native**
6	Estuarine dartfish	*Parioglossus palustris*	Microdesmidae	**Native**
7	Humpbacked cardinalfish	*Apogon hyalosoma*	Apogonidae	**Native**
8	Jarbua	*Therapon jarbua*	Terapontidae	**Native**
9	Javan fatnose goby	*Pseudogobius javanicus*	Gobiidae	**Native**
10	Kranji goby	*Drombus kranjiensis*	Gobiidae	**Native**
11	Olive flathead gudgeon	*Butis humeralis*	Eleotridae	**Native**
12	One horned priapusfish	*Neostethus lankesteri*	Phallostethidae	**Native**
13	Orangefin ponyfish	*Photopectoralis bindus*	Leiognathidae	**Native**
14	Oriental sole	*Brachirus orientalis*	Soleidae	**Native**
15	Robust mangrove goby	*Acentrogobius janthinopterus*	Gobiidae	**Native**
16	Rough golden toadfish	*Lagocephalus lunaris*	Tetraodontidae	**Native**
17	Silver sand whiting	*Sillago sihama*	Sillaginidae	**Native**
18	Snakeskin goramy	*Trichopodus pectoralis*	Osphronemidae	**Native**
19	Spangled gudgeon	*Ophiocara porocephala*	Eleotridae	**Native**
20	Speckled tongue sole	*Cynoglossus puncticeps*	Cynoglossidae	**Native**
21	Two horned priapusfish	*Neostethus bicornis*	Phallostethidae	**Native**

Table 3-9 Fish species recorded from Sungei Kangkar and Sungei Kranji in 1963 (after Alfred, 1966) (adapted from Ng et al., 2010)

S/No.	Common name	Species	Family	Native/Alien
1	Common walking catfish	*Clarias batrachus*	Clariidae	**Native**
2	Croaking goramy	*Trichopsis vittatta*	Osphronemidae	**Native**
3	Forest fighting fish	*Betta pugnax*	Osphronemidae	**Native**
4	Javanese ricefish	*Oryzias javanicus*	Adrianichthyidae	**Native**
5	Malayan pygmy halfbeak	*Dermogenys collettei*	Hemiramphidae	**Native**
6	Mozambique tilapia	*Oreochrmis mossambicus*	Cichlidae	**Alien**
7	Saddle barb	*Systomus banksi*	Cyprinidae	**Native**
8	Swamp eel	*Monopterus albus*	Monopteridae	**Native**
9	Three-spot goramy	*Trichopodus trichopterus*	Osphronemidae	**Native**
10	Whitespot	*Aplocheilus panchax*	Aplocheilidae	**Native**

A survey of aquatic fauna conducted at Kranji Reservoir in January 2016 found at least 37 different species living at the site (Yeo et al., 2016). An additional 19 fish species were identified and documented in a biodiversity report for Kranji Reservoir by Kwik et al. (2020). All of these species are listed in Table 3-10. Due to the site being modified by humans, the species present largely consist of alien species that were introduced to the reservoir following the damming of the river mouth. For example, the South American cichlid fish, *Acarichthys heckelii*, is one of many exotic/non-native species introduced to freshwater systems in Singapore, making it the only recorded population outside its native distribution (Liew et al., 2014). The majority of all species are of least concern in terms of conservation value, although fish species such as *Amblypharyngodon chulabhornae* (Princess carplet) and *Trichopodus pectoralis* (Snakeskin gourami) are experiencing a decline in global population.

Table 3-10 A list of aquatic species identified at Kranji Reservoir in 2016 and 2020.

Scientific Name	Common Name	Organism	Native / Alien / Cryptogenic	Status in Singapore (IUCN Red List, 2022)	Habitat	Current population trend (IUCN Red List, 2022)
Notopterus notopterus*	Bronze knifefish	Fish	Alien	LC	F, M	Stable
Amblypharyngodon chulabhornae*	Princess carplet	Fish	Alien	LC	F	Decreasing
Puntius sophore*	Spotfin swamp barb	Fish	Alien	LC	F	Unknown
Rasbora borapetensis*	Red-tailed rasbora	Fish	Alien	LC	F	Stable
Clarias gariepinus*	African sharptooth catfish	Fish	Alien	LC	F	Unknown
Gambusia affinis*	Western mosquito fish	Fish	Alien	LC	F	Stable
Dermogenys colletteі*	Pygmy halfbeak	Fish	Alien	LC	F, M	Unknown
Monopterus javanensis*	Swamp eel	Fish	Native	LC	F	Unknown
Macrognathus zebrinus*	Zebra spiny eel	Fish	Alien	LC	F	Unknown
Oreochromis niloticus*^	Nile tilapia	Fish	Alien	LC	F	Unknown
Oxyeleotris marmorata*^	Marbled goby	Fish	Alien	LC	F	Unknown
Brachygobius sabanus*	Lesser bumblebee goby	Fish	Alien	LC	F	Unknown
Anabas testudineus*	Climbing perch	Fish	Native	LC	F	Stable
Betta imbellis*	Crescent fighting fish	Fish	Native	LC	F	Unknown

Scientific Name	Common Name	Organism	Native / Alien / Cryptogenic	Status in Singapore (IUCN Red List, 2022)	Habitat	Current population trend (IUCN Red List, 2022)
Trichopodus pectoralis*	Snakeskin gourami	Fish	Alien	LC	F	Decreasing
Trichopodus trichopterus*	Three-spot gourami	Fish	Native	LC	F	Unknown
Trichopsis vittate*	Croaking gourami	Fish	Native	LC	F	Unknown
Channa striata*	Common snakehead	Fish	Native	LC	F	Stable
Acarichthys heckelii^	Threadfin acara	Fish	Alien	Not listed	F	Not listed
Geophagus altifrons^	Eartheater cichlid	Fish	Alien	LC	F	Not listed
Hemigrammus rodwayi^	Golden tetra	Fish	Alien	Not listed	F	Not listed
Channa micropeltes^	Giant snakehead	Fish	Alien	LC	F	Stable
Parambassis siamensis^	Indochinese glass-perchlet	Fish	Alien	LC	F	Stable
Cichla temensis^	Speckled peacock bass	Fish	Alien	Not listed	F	Not listed
Cichla kelberi^	Kelberi peacock bass	Fish	Alien	Not listed	F	Not listed
Cichla orinocensis^	Orinoco peacock bass	Fish	Alien	Not listed	F	Not listed
Notopterus notopterus^	Bronze featherback	Fish	Alien	LC	F, M	Stable
Cichla spp.^	Peacock bass	Fish	Alien	Not listed	F	Not listed
Osphronemus goramy^	Giant gourami	Fish	Alien	LC	F	Not listed
Etroplus suratensis^	Green chromide	Fish	Alien	LC	F	Decreasing

Scientific Name	Common Name	Organism	Native / Alien / Cryptogenic	Status in Singapore (IUCN Red List, 2022)	Habitat	Current population trend (IUCN Red List, 2022)
Glossogobius aureus^	Golden tank goby	Fish	Native	LC	F, M	Stable
Chitala ornata^	Clown knifefish	Fish	Alien	LC	F	Stable
Dermogenys colletteі^	Pygmy halfbeak	Fish	Native	LC	F	Not listed
Scleropages formosus^	Asian arowana	Fish	Alien	Introduced to Singapore but globally EN	F	Decreasing
Macrognathus zebrinus^	Zebra spiny eel	Fish	Alien	LC	F	Not listed
Clarias gariepinus^	African walking catfish	Fish	Alien	LC	F	Not listed
Xiphophorus maculatus^	Southern platyfish	Fish	Alien	LC	F	Not listed

Notes:
LC: Least concern; VU: Vulnerable; F: Freshwater; Not listed; Unknown
M: Marine; T: Terrestrial
* Identified in 2016 survey; ^ Identified in 2020 survey

In order to obtain a better understanding and more detailed representation of the fish species currently present in Kranji Reservoir, environmental (e)DNA was obtained from water samples collected from five (5) locations on the reservoir to complement the hydroacoustics and historical data. The use of eDNA was to increase the likelihood of detecting cryptic species, which are of particular importance for this study.

The eDNA analysis identified 15 fish taxa across the five locations on Kranji Reservoir (Table 3-11). The number of taxa detected were averaged for each site, with the largest average number of taxa detected at location 1. While 7-13 taxa were detected at location 1, only 2-7 taxa were found at locations 2-5, which suggests location 1 is a hotspot for fish diversity. Out of the 15 fish taxa detected by eDNA analysis, only 12 of these species were identified in previous reports (Table 3-12).

The eDNA results detected less species than either the 2016 or 2020 surveys carried out in the Reservoir. This may be the result that some of the eDNA results were to genus level only rather than species. Three additional species that had not been recorded before in the Reservoir were detected, including the alien *Cyprinus carpio* which was probably introduced for angling. The record of *Barbatula* sp. is a first for any reservoir in Singapore. *Actinopteri* sp. had also not been recorded in the Reservoir before. Together these suggest the fish community in the Reservoir is relatively dynamic perhaps although no long term monitoring data is available to inform whether newly introduced species are surviving and establishing as part of the community.

Table 3-11 Fish taxa in Kranji Reservoir that were detected using eDNA technology

Scientific names	Location 1			Location 2			Location 3			Location 4			Location 5		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3
_c:Actinopteri	+	+	+	+	+	+	+	+	+					+	
_f:Cichlidae	+		+	+	+			+				+	+	+	+
***Barbatula* sp.**											+				
Chitala ornate				+					+						
Cyprinus carpio	+		+	+						+			+		
***Eugnathogobius* sp. (1)**	+	+	+		+						+				
***Geophagus* sp.**	+	+	+	+	+		+				+	+			+
Notopterus notopterus	+										+	+			
***Oreochromis* sp. (2)**	+		+						+				+		

Scientific names	Location 1			Location 2			Location 3			Location 4			Location 5		
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1	5.2	5.3
Oxyeleotris marmorata	+			+											+
***Parambassis* sp.**	+	+	+	+	+	+	+	+	+	+		+	+		
***Rhinogobius* sp.**	+	+	+							+					+
Trichopodus pectoralis	+		+												
Trichopodus trichopterus	+	+													
Trichopsis vittata	+	+	+				+								
Number of taxa detected	13	7	10	7	5	2	4	3	4	3	4	4	4	2	4
Average number of taxa per site	10			5			4			4			3		

Notes:
Taxa prefixed with an underscore cannot be classified further. Abbreviations: p-phylum, c-class, o-order, f-family
1) Synonym or possible species complex with *Pseudogobiopsis sp*.
2) *Oreochromis niloticus* and *O. aureus* cannot be distinguished due to shared haplotypes and/or hybridisation.

Table 3-12 Comparison between eDNA results and historical data for Kranji Reservoir

Scientific names	Present in historical data?	Level of certainty in species identification	Native/ alien/Cryptogenic	Reference
_c:Actinopteri	No	Less certain. Reported in Singapore waters.	Crytogenic	Fishbase (2022)
_f:Cichlidae	Yes	High certainty. Cichlidae species reported in Singapore Reservoirs.	Crytogenic	Heok Hui et al. (2020)
***Barbatula* sp.**	No	Uncertain. No reports of *Barbatula* in Singapore Reservoirs.	Crytogenic	Chen et al. (2019)
Chitala ornata	Yes	High certainty, exact match.	Alien	Heok Hui et al. (2020)
Cyprinus carpio	No	Possible, as it has been reported in other Singapore reservoirs. See Ng and Tan (2010)	Alien	Ng and Hui Tan (2010)
***Eugnathogobius* sp. (1)**	Yes	Possible (*Eugnathogobius* species found in Singapore) – Larson et al. (2016)	Crytogenic	Larson et al. (2016)
***Geophagus* sp.**	Yes	Possible (*Geophagus altifrons* found here).	Crytogenic	Heok et al. (2020)
Notopterus notopterus	Yes	High certainty, exact match	Alien	Heok et al. (2020)
***Oreochromis* sp. (2)**	Yes	*Oreochromis niloticus* found here	Crytogenic	Heok et al. (2020)
Oxyeleotris marmorata	Yes	High certainty, exact match	Alien	Heok et al. (2020)
***Parambassis* sp.**	Yes	*Parambassis siamensis* reported in Kranji Reservoir	Crytogenic	Heok et al. (2020)
***Rhinogobius* sp.**	Yes	Possible, as *Rhinogobius similis* reported at Kranji Marsh	Crytogenic	Heok et al. (2020)

Scientific names	Present in historical data?	Level of certainty in species identification	Native/ alien/Cryptogenic	Reference
Trichopodus pectoralis	Yes	High certainty, exact match	Alien	Heok et al. (2020)
Trichopodus trichopterus	Yes	High certainty, exact match	Native	Heok et al. (2020)
Trichopsis vittata	Yes	High certainty, exact match (Reported for Kranji Marsh) – in Singapore Biodiversity Records (2016)	Native	Heok et al. (2020)

Notes:

Taxa prefixed with an underscore cannot be classified further. Abbreviations: p-phylum, c-class, o-order, f-family

1) Synonym or possible species complex with *Pseudogobiopsis sp*.

2) *Oreochromis niloticus* and *O. aureus* cannot be distinguished due to shared haplotypes and/or hybridisation.

3.4.4 OTHER FAUNA

BATS OVER THE RESERVOIR

Four species of insectivorous bat were recorded foraging over the reservoir (Figure 3-19). Feeding rates were low/ negligible. None are of conservation concern, i.e.

- Horsfield's bat (*Myotis horsfieldii*),
- Pouch-bearing bat (*Saccolaimus saccolaimus*)
- Asiatic lesser yellow house bat (*Scotophilus kuhlii*)
- Black bearded tomb bat (*Taphozous melanopogon*)

Asiatic lesser yellow house bat was the most common bat within the BIA Study Area (terrestrial and aquatic habitats).

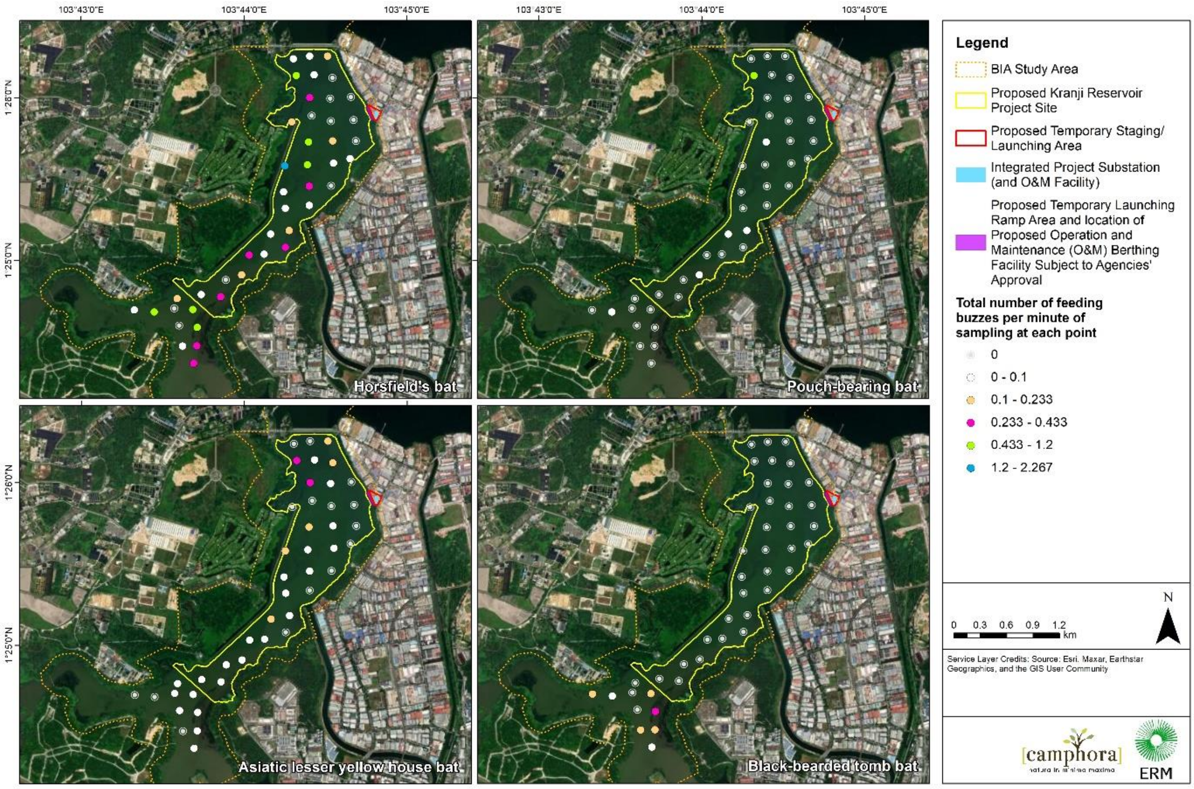


Figure 3-19 Total Number of Feeding Buzzes of Bat Species Observed in Kranji Reservoir

AMPHIBIAN AND REPTILES (HERPETOFAUNA)

Historical surveys and the recent surveys carried out for this Project's EIA identified amphibians and reptile species present at Kranji Reservoir. In a study from November 2009 to June 2010 (Ng et al. 2010), amphibian and reptile (Herpetofauna) surveys were conducted during both daytime and night-time in 2010 along the water edges of Kranji Reservoir.

- Eight amphibian species were identified in total, including six native species and two alien species. All of the native amphibian species recorded at Kranji Reservoir are widespread and common species. The native species include Asian toad (*Duttaphrynus melanostictus*), common greenback (*Hylarana erythraea*), crab-eating frog (*Fejervarya cancrivorus*), dark-sided chorus frog (*Microhyla heymonsi*), field frog (*Fejervarya limnocharis*) and four-lined tree frog (*Polypedates leucomystax*). The alien species present were the American bullfrog (*Lithobates catesbeianus*) and the banded Bull frog (*Kaloula pulchra*).

- Five reptile species were found in total, consisting of four native species and one alien species. All of the four native species were widespread and common. These native species were the common house gecko (*Hemidactylus frenatus*), common sun skink (*Eutropis multifasciata*), Malayan water monitor (*Varanus salvator*), and the spotted house gecko (*Gekko monarchus*). The alien species was identified as the changeable lizard (*Calotes versicolor*).
- No snakes were recorded at this time. Species that are likely to be found around the reservoir include the reticulated python (*Broghammerus reticulatus*). No turtles were recorded. However, anglers caught an alligator snapping turtle (*Macrochelys temminckii*) from this reservoir in July 2008 (Shin Min Daily News, 3 July 2008), which was speculated to be an abandoned pet.

Surveys performed in 2016 found a few amphibians and reptiles and crustaceans present in Kranji Reservoir (Yeo et al., 2016) (Table 3-13). The reservoir provides refuge for *Siebenrockiella crassicollis* (Black marsh terrapin), a vulnerable and globally threatened species that is not native to Singapore and is often released into the wild as religious offerings. However, it was not identified in the subsequent 2020 survey and it was not present in the surveys carried out for this Project's EIA.

During the baseline surveys for this Project’s EIA, three reptiles of conservation significance were found at Kranji Reservoir (Figure 3-20). These include the asian softshell turtle (*Amyda cartilaginea*), an endangered and globally vulnerable species; the Malayan box terrapin (*Cuora amboinensis*), a vulnerable species; and the red-tailed pipe snake (*Cylindrophis ruffus*), a vulnerable species.

Table 3-13 Amphibians, reptiles and crustaceans identified in Kranji Reservoir (from Yeo et al. 2016)

Species	Common name	Group	Native/Alien/ Crytogenic	Global status (IUCN, 2022)	Habitat	Global population trend
Fejervarya limnocharis*	Field frog	Amphibian	Native	LC	F, T	Stable
Hylarana erythraea tadpole*	Pond frog	Amphibian	Native	LC	F, T	Stable
Siebenrockiella crassicollis*	Black marsh terrapin	Reptile	Alien	VU	F, T	Vulnerable
Trachemys scripta elegans*	(Red-eared terrapin	Reptile	Alien	LC	F, T	Stable
Caridina sp.*	Unknown	Crustacean	Cryptogenic	Unknown	F	Unknown
Macrobrachium lanchesteri*	Riceland shrimp	Crustacean	Alien	LC	F	Unknown

Notes:

LC: Least concern; VU: Vulnerable; F: Freshwater;
M: Marine; T: Terrestrial

* Identified in 2016 survey; ^ Identified in 2020 survey

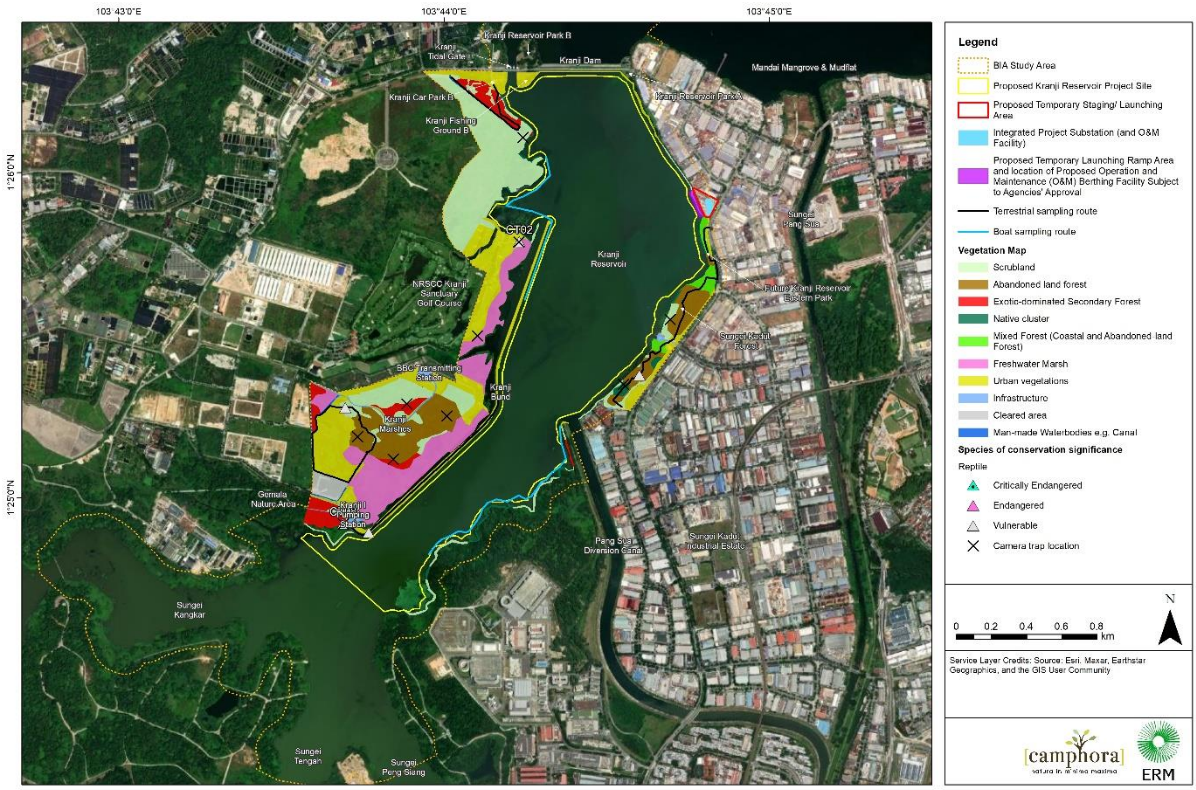


Figure 3-20 Location of Reptilian Species of Conservation Significance at Kranji Reservoir

MAMMALS

Two mammals of conservation significance were identified during this Project's baseline surveys (Figure 3-21). One such mammal includes the nationally Endangered smooth-coated otter (*Lutrogale perspicillata*). The Reservoir is used by at least one family of otters. A group of 7-8 individuals were sighted once on the western bank. A group of 6 individuals were also seen on the eastern bank on a separate occasion. One otter was seen on camera trap CT04 near Kranji Marshes. Two families of otters are known in the environs of the BIA Study Area. This finding is therefore considered expected. Although no holt sites have been observed, the reservoir provides a foraging ground for them. They are likely using the entire reservoir.

In addition to the smooth-coated otter, long-tailed macaque (*Macaca fascicularis*), a globally vulnerable species, was identified during this Project's baseline surveys.

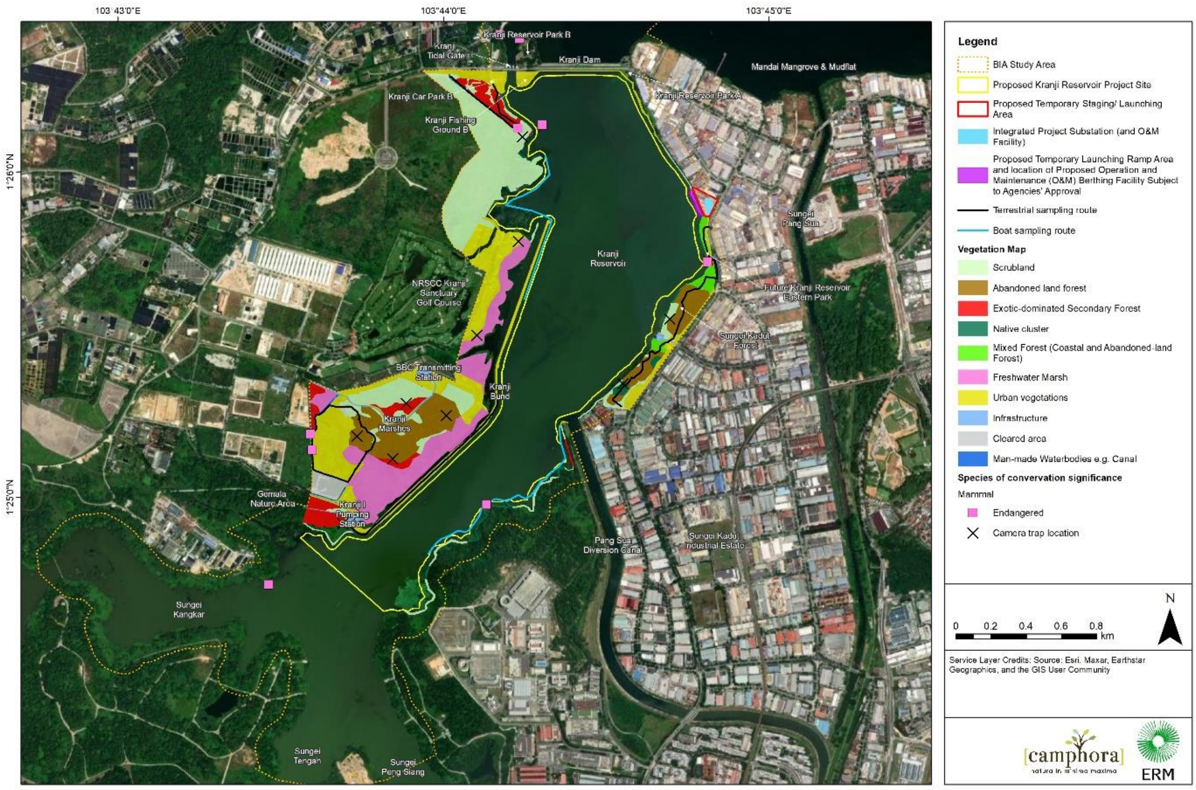


Figure 3-21 Location of Mammalian Species of Conservation Significance

3.4.5 AQUATIC INVERTEBRATES

Inventories of aquatic, benthic invertebrates are frequently used to assess the pollution level of freshwater environments because these organisms are highly sensitive and respond rapidly to changes in water quality parameters and habitat disturbance (Rosa et al., 2014). Few studies of Kranji Reservoir have researched the composition of invertebrate fauna at this site.

To access macroinvertebrate assemblages present at Kranji Reservoir, a study by Clews et al. (2014) used five replicate colonisation-type invertebrate samplers placed within rocky littoral habitats at Kranji Reservoir for a period of four weeks in October 2008. The study found 17 invertebrate types present across the five colonisation samplers retrieved from Kranji (Table 3-14).

A survey done in 2016 by Yeo et al. (2016) identified the presence of numerous molluscs in Kranji Reservoir (Table 3-15).

Table 3-14 Invertebrate types identified in five coloniser samplers deployed in Kranji Reservoir in October 2008

Macroinvertebrate identification	Mean (and range of) abundance
Hirudinea	1 (0–4)
Oligochaeta	116 (11–409)
Palaemonidae	9 (0–25)
Parastacidae	2 (0–4)
Gyrinidae	0 (0–1)
Chironomidae	278 (143–404)
Diptera pupae	4 (0–13)
Caenidae	2 (0–3)
Polymitarcyidae	319 (132–526)
Micronectidae	10 (5–13)
Libellulidae	1 (0–4)
Coenagrionidae	1 (0–3)
Ecnomidae	0 (0–1)
Ancylidae	0 (0–2)
Planorbidae	84 (8–153)
Thiaridae	25 (4–73)
Viviparidae	443 (167–776)

Table 3-15 Molluscs identified in Kranji Reservoir during the 2016 survey (Yeo et al.,2016)

Species identification	Common name	Native/Alien/ Cryptogenic	Conservation status (IUCN, 2022) LC: Least concern; VU: Vulnerable;	F: Freshwater; M: Marine; T: Terrestrial	Global status
Pila scutata*	Apple snail	Native	LC	F	Unknown
Pomacea canaliculata*	Golden apple snail	Alien	LC	F	Increasing
Bithynia sp.*	Bithyniid snail	Cryptogenic	Unknown	Unknown	Unknown
Radix rubiginosa*	Pond snail	Cryptogenic	Not listed	F/T	Unknown
Physella acuta*	Bladder snail	Alien	LC	F	Increasing
Amerianna carinata*	Keeled ramshorn	Alien	Not listed	F	Not listed
Gyraulus convexiusculus*	Little ramshorn	Cryptogenic	LC	F	Increasing
Indoplanorbis exustus*	Ramshorn snail	Cryptogenic	LC	F	Unknown
Indosuccinea sp.*	Amber snail	Cryptogenic	LC	F	Unknown
Melanoides tuberculata*	Malayan trumpet snail	Native	LC	F	Increasing

Species identification	Common name	Native/Alien/ Cryptogenic	Conservation status (IUCN, 2022) LC: Least concern; VU: Vulnerable;	F: Freshwater; M: Marine; T: Terrestrial	Global status
Filopaludina martensi*	Marten's mystery snail	Alien	LC	F	Unknown
Filopaludina sumatrensis polygramma*	Banded mystery snail	Alien	LC	F	Unknown
Sinotaia guangdungensis*	Many-zoned mystery snail	Alien	Not listed	F	Unknown

* Identified in 2016 survey

In order to characterise the different primary habitat niches occupied by macroinvertebrates, three methods were used to sample macroinvertebrates for this Project's baseline surveys:

1. Colonisers, repeating the survey approach of Clews et al. (2014) described above
2. Benthic grab samples, representing the bare and vegetated reservoir bed which is the bulk of the study area
3. Sweep samples along the reservoir edge.

COLONISER SURVEYS

Colonisers were constructed in the manner described in (Loke et al. 2010), namely stainless steel cages (ø 20 cm; height 10 cm, 1.2 cm^2 mesh size) filled with coconut brushes and palm fronds as artificial substrate. As per Clews et al. (2014), five colonisers were deployed at an approximate 1 m water depth, each at 2 m intervals along a 10 m transect, which is roughly 5 m away from the shoreline. Colonisers were deployed at the same location used in the Clews et al. (2014) study as advised by PUB. This area composed of a rocky rip-rap protecting the bund at the mouth of the intake. Colonisers were retrieved after four weeks of deployment.

A total of 13 phyla and 25 families were identified during the sampling period in May 2022, with 794 individuals recorded. Taxon richness of each sampling site ranged from 11 – 17, while abundance ranged from 62 – 284. A standard error value of 1.08 was measured for taxon richness. A standard error value of 38.2 was measured for abundance between sampling sites. Colonisers 2 and 5 demonstrated abundance and richness values greater than the mean, whereas abundance and taxon richness values fell below the mean for Colonisers 1 and 4. However, this trend was not found at Coloniser 3, where abundance was lower than the overall mean but taxon richness exceeded the mean value. The lowest taxon richness was found at Coloniser 1, while the highest taxon richness was found at Coloniser 2. The lowest abundance was measured at Coloniser 4, while the highest abundance was recorded at Coloniser 2. These results suggest Coloniser 2 has a relatively high biodiversity, whereas both Colonisers 1 and 4 may have a relatively lower biodiversity.

Individuals collected from coloniser sampling were generally smaller in size compared to specimens obtained via sweep net sampling. Mean abundance (38) of coloniser samples is significantly less than the mean abundance for sweep net samples (325). However, the mean taxon richness (14) of coloniser samples was slightly higher than that of sweep net samples (11). Both sweep net and coloniser sampling produced greater abundance and taxon richness values than sediment grab sampling. The mean taxon richness values obtained from the coloniser sampling in the current works (7 – 17) were similar to the findings of Clews et al. (2014) (11 – 17). However, values of abundance in the current works were less (62 – 284) compared to Clew et al.'s (2014) results (470 – 2414). Note that differences in size, richness and abundance often relate to habitat niches as well as condition. The different methods all target different habitat niches.

BENTHIC SURVEYS

A total of 11 families from the phyla Arthropoda, Annelida and Mollusca were identified across all 5 sampling sites and over the three sampling events. A total of 629 individuals were identified and was dominated by Oligochaeta, followed by Chironominae, Chaoboridae and Tanypodinae.

Oligochaeta are highly diverse and distributed widely across all terrestrial and aquatic habitats. They play an important role in the food web of aquatic organisms at Kranji Reservoir as a food source for chironomid larvae and other invertebrates, but also for fish that feed on benthos. In addition to this, Oligochaeta serve a vital function in the decomposition and uptake of nutrients in aquatic ecosystems and increase the availability of nutrients for higher level consumers.

The relatively high abundance of Chironominae suggests that the abundance, distribution and extent of lakebed aquatic vegetation is an important controlling driver of Chironominae assemblages at Kranji Reservoir. An increase in turbidity and reduced light availability at the site may cause change in lakebed vegetation cover and these changes have potential implications for habitat availability of Chironominae and other aquatic invertebrates at Kranji Reservoir.

Camphora also identified three odonate species of conservation significance. These were nighthawker (*Heliaeschna* sp.) (conservatively assumed to possibly be the nationally critically endangered *Heliaeschna crassa*), the lesser nighthawker (*Heliaeschna uninervulata*) (nationally vulnerable), and the small duskhawker (*Gynacantha bayadera*) (nationally vulnerable).

EDGE SURVEYS

Triplicate samples were collected from seven locations (Edges 1 to Edge 7). These locations include five sites that may be located close to shore-based infrastructure for the FPV (Edges 1 to 5); and two reference sites (Edges 6 and 7). Edges 1 and 2 are in close proximity to the designated fishing areas at Kranji Reservoir. Active sweep and kicknet style sampling occurred along a composite 10 m reach using a D-shaped kicknet with 250 µm mesh, using the methods outlined by Blakely et al (2014) and Ho et al. (2018).

A total of 17 phyla and 41 families were identified over the sweep sampling events conducted in May 2022, with a total of 6828 individuals recorded. Mean taxon richness of each sampling site ranged from 5 to 16.3 while mean abundance of each sampling site ranged from 25.3 to 1018. Highest mean abundance and richness was found at Edge 5 and the lowest at Edge 2. For mean richness, Edges 3, 5, 6 and 7 were higher than the overall mean but only Edges 3, 5 and 7 had higher mean abundance than the overall mean.

The most represented functional feeding group (FFG) across all locations is filtering collectors, which composed of micro-crustaceans such as Conchostraca, Copepoda and Ostracoda. Their percentage proportion ranged from 29.4 – 82.8%. Scrapers were also consistently found in all sites and were mainly composed of snails and the micro-crustacea Cladocera. Their percentage FFG ranged from 5.24 – 42.3%. This was followed by shrimps (Family: Atyidae) with the FFG of predators, filtering and gathering collectors, with proportions ranging from 1.01 – 29.9% across all sweep sampling sites. Shredder-scrapers, composed of the family Ampullariidae, made up a proportion ranging from 0.13 – 18.3%.

Filtering collectors were most abundant across all sites, which suggests fine particulate organic matter (FPOM) is abundant. However some gatherers were also present at Edges 2 and 3, which indicate that FPOM is not abundant everywhere at Kranji Reservoir. However, as the food source for the upper trophic levels. Given their widespread distribution and abundance across the reservoir, the FFG scrapers may be used as an indication of sites experiencing acidification. Their proportion is expected to decrease at impacted sites as they are sensitive to organic pollution (Rawer-Jost et al., 2000).

Predators, consisting of taxa like spiders, leeches, damselfly and dragonfly nymphs, beetles and water bugs, were found in Edges 3-7 but not in Edges 1 and 2. A similar trend observed at these sites was the amount of vegetation in the area, hence it is possible that the presence of predators are linked to the presence of moss (Heino, 2000). With an abundance of moss, scrapers are attracted to these areas which in turn act as prey for the predators. It has also been suggested that moss flora introduces an intermediate amount of environmental disturbance that encourages species richness (Vuori et al., 1999), subsequently attracting more prey for the predators.

The presence of FFG shredders in this set of surveys, as compared to its complete absence throughout the grab sampling surveys, could be due to the different variety of habitats found at the different sampling sites. Sampling sites for this round of survey were at the edge-surface water interface while those of the first survey were at least 1m underwater. The edge-surface interface is favoured by shredders since a higher concentration of its food source – dead leaves and FPOM – would be found there.

3.4.6 PHYTOPLANKTON AND ZOOPLANKTON

Phytoplankton and zooplankton provide food for macroinvertebrates and fish in Kranji Reservoir, while phytoplankton are the primary food source for zooplankton. For example, diatoms are consumed by zooplankton and other copepods, which in turn, are eaten by small fish. Importantly, phytoplankton are also responsible for primary production and nutrient cycling at Kranji Reservoir. There is a positive correlation between *Aulacoseira* sp. and *Daphnia* sp. (R^2 = 0.47), which suggests a relationship exists between diatoms and *Daphnia* at this site, although other factors besides diatom abundance likely act as direct or indirect drivers of changes in *Daphnia* assemblages.

PHYTOPLANKTON

During a study survey undertaken between November 2009 to June 2010, a total of 39 genera/ species of phytoplankton was recorded from Kranji Reservoir during the monsoon and non-monsoon seasons (Ng et al., 2010). The phytoplankton identified in this survey are presented in Table 3-16.

Phytoplankton (water column algae) and zooplankton were assessed by Hydrobiology (2021) under this Project's EIA baseline surveys. Samples were collected monthly between December 2020 and May 2021 by a phytoplankton tow net pulled vertically through the water column.

A total of five phytoplankton Phyla were identified at the five survey sites. The results show 1-2 species belonging to the phyla Bacillariophyceae (Diatoms); 1-2 species were Euglenophyceae; 1 species was identified as Cryptophyta; 3 species were Chlorophyceae; one Ciliata species; and one species belonging to Dinophyceae (Dinoflagellates). At least two of the species from the five sites were potentially toxic. The relatively high abundance of *Aulacoseira* sp. suggests the reservoir is characterised by warm, well-mixed nutrient-rich waters with relatively high P-availability, in pH conditions of 7.3 or higher (Tibby et al., 2020; Vázquez-Loureiro et al., 2019; Yang et al., 2019).

Table 3-16 Phytoplankton identified at Kranji Reservoir by Ng et al. (2010)

No.	Species/Genera	Benthic/ planktonic	Monsoon		Non-Monsoon	
			Open water	Littoral	Open water	Littoral
Cyanobacteria						
1	*Anabaena aphanizomenoides*	Planktonic	X	X		X
2	*Anabaena circinalis*	Planktonic	X	X	X	X

No.	Species/Genera	Benthic/ planktonic	Monsoon		Non-Monsoon	
			Open water	Littoral	Open water	Littoral
3	*Anabaena spiroides*	Planktonic	X			
4	*Anabaena* (other species)	Planktonic/ benthic	X			
5	*Aphanizomenon*	Planktonic			X	X
6	*Aphanocapsa*	Benthic	X	X	X	X
7	*Chroococcus*	Planktonic	X			
8	*Cylindrospermopsis raciborskii*	Planktonic			X	X
9	*Geitlerinema*	Benthic				X
10	*Leptolyngbya*	Benthic			X	X
11	*Lyngbya*	Benthic			X	X
12	*Merismopedia* (small)	Planktonic/ benthic			X	
13	*Microcystis aeruginosa*	Planktonic	X	X	X	X
14	*Microcystis flos-aquae*	Planktonic	X	X	X	X
15	*Microcystis wesenbergii*	Planktonic	X	X	X	X
16	*Planktolyngbya*	Benthic	X	X	X	X
17	*Planktothrix*	Planktonic	X	X	X	X
18	*Pseudanabaena*	Planktonic			X	X
Chlorophyceae						

No.	Species/Genera	Benthic/ planktonic	Monsoon		Non-Monsoon	
			Open water	Littoral	Open water	Littoral
19	*Ankistrodesmus*	Benthic	X		X	X
20	*Closterium*	Planktonic			X	
21	*Oocystis*	Planktonic	X	X		
22	*Scenedesmus*	Benthic			X	X
23	*Staurastrum*	Planktonic/ benthic			X	X
24	*Tetraedron*	Benthic			X	X
Euglenophyceae						
25	*Euglena*	Benthic	X	X		
26	*Trachelomonas*	Benthic		X	X	X
Cryptophyceae						
27	*Chroomonas*	Benthic	X	X		
28	*Cryptomonas*	Benthic	X	X	X	X
Dinophyceae						
29	*Ceratium*	Benthic				X
30	*Peridinium*	Planktonic	X	X		
Bacillariophyceae						
31	*Aulacoseira*	Planktonic	X	X	X	X

No.	Species/Genera	Benthic/ planktonic	Monsoon		Non-Monsoon	
			Open water	Littoral	Open water	Littoral
32	*Cyclotella*	Planktonic	X	X	X	X
33	*Navicula*	Benthic			X	
34	*Nitzschia*	Benthic	X	X	X	
Other algae						
35	*Centritactus*	Planktonic			X	
36	*Coelastrum*	Planktonic				X
37	*Mallomonas*	Planktonic	X	X		
38	*Phacus*	Planktonic	X	X		
39	*Schroederia*	Planktonic			X	

ZOOPLANKTON

A 2010 survey performed by Ng et al. (2010) identified a total of 11 zooplankton species in Kranji Reservoir (Table 3-17).

The baseline survey for this Project found a total of twelve (12) zooplankton species present at the five sites sampled between December 2020 and May 2021. Zooplankton were identified to genus level, when possible, and values were expressed as a percentage abundance of the total sum of zookplankton present in each sample. Three phyla were identified and zooplankton were assigned to either Arthropoda, Rotifera or Platyhelminthes. Previous research on Kranji Reservoir also found high abundances of rotifers and copepod nauplii (Haberman and Haldna, 2014; Kwik et al., 2020), which supports the assertion that the waters in Kranji Reservoir are eutrophic (Jindal et al., 2014). Monthly variability in abundance of zooplankton types was observed, with small changes observed in species diversity. Variability in species abundances were also observed between sampling locations. For each month, species diversity ranged from eight to ten different species.

The most abundant components of all samples collected under this EIA study combined were the *Keratella* sp. and the *Daphnia* sp. The monthly average percentage abundance for *Keratella* sp. abundance across all five sampling locations range from 20 to 45%, with the lowest value observed in February 2021 (20.1%) and the highest value measured in March 2021 (44.2%).

Keratella are commonly found in eutrophic waters and are mostly associated with phosphates (e.g. Krupa et al., 2020). Monthly averages of *Daphnia* sp. range from 5 to 45%, with the lowest value identified in December 2020 and the highest value found in February 2021. *Daphnia* sp. were not present in any of the water samples collected in March 2021. Daphnia are sensitive to pollutants and are used as bioindicators for water pollution. There is a very strong negative correlation between monthly average abundances of *Keratella* sp. and *Daphnia* sp. (R2 = 0.95), with the peak abundance of *Keratella* sp. coinciding with the complete absence of *Daphnia* sp. in March 2021, which may suggest increased pollution pressures during that month.

Table 3-17 Zooplankton of Kranji Reservoir in 2010. Table adapted from Ng et al. (2010).

Taxon	Open	Littoral
F. Sididae		
Diaphanosoma sarsi	X	X
F. Bosminidae		
Bosminopsis deitersi	X	
F. Chydoridae		
Chydorus barroisi		X
Chydorus eurynotus	X	
Chydorus parvus	X	X
Chydorus ventricosus	X	X
Indialona sp.		X
F. Daphniidae		
Ceriodaphnia cornuta	X	X
Copepoda		
Calanoida		
F. Diaptomidae		
Neodiaptomus botulifer	X	X
Cyclopoida		
F. Cyclopidae		
Mesocyclops thermocyclopoides		X
Thermocyclops sp.	X	X

3.5 KEY PROCESSES

Three key processes were identified: "water quality", "fish spawning" and "waterbird support".

Six other processes were identified, reviewed and considered: climate, geology, soils, bathymetry, hydrology and water quality (discussed above), and sediment quality.

The other processes are important for aquatic health and biodiversity, but it is not possible to directly manage many of these processes (e.g. climate) and some of the processes are directly or indirectly influenced by changes in water quality (e.g. fish spawning, waterbird support, sediment quality). These other processes were therefore included as supporting processes.

3.5.1 REASONS FOR SELECTION AS 'KEY'

Maintaining **water quality** within an acceptable range is essential for conserving the key component "water reservoir" and ensuring that the reservoir can continue to provide water for human consumption. Water quality is a key process for ensuring the health and survival of flora and fauna that depend on the natural resources available at Kranji Reservoir and any detrimental changes in water quality can potentially result in a loss of life and an undesirable shift in reservoir processes and services.

Fish spawning was chosen as one of the key processes, since Kranji Reservoir supports several fish species that provide important sources of food for waterbirds as well as providing recreational fishing for public recreation.

Another key process is predation in particular of fish by **waterbirds** (as well other fauna given the bird species recorded are generalist feeders). This predation process maintains the value of Kranji Reservoir as a local feeding ground for a high diversity of waterbirds. For example, 60 species were recorded at the reservoir edge. This waterbird community also includes 13 species of conservation concern.

All three of these key processes play an important role in characterising the site's ecological character.

3.5.2 DESCRIPTIONS

Water quality frames the conditions for which aquatic biota are present within the reservoir. In order for the reservoir to provide important ecosystem services and benefits, which includes food and water provision, recreational amenity (e.g. being aesthetically pleasing), and maintenance of local biodiversity, water quality must be monitored and maintained within an acceptable range that supports local biodiversity and ecosystem processes at Kranji Reservoir.

Breeding is key for all organisms and is essential for the long-term survival and persistence of populations that contribute towards a site's ecological character. Any disruption to these stages is expected to pose a threat to the long-term conservation of species present at Kranji Reservoir. In this ECD, the areas where juvenile fish are found are termed nursery grounds. Higher densities of juveniles, reduced rates of predation and faster growth rates are expected at nursery grounds. Such areas are key for **fish spawning** and thus, a priority for habitat management and conservation.

There are at least 37 different fish species in Kranji Reservoir. Most of the fish are alien introduced species. The baseline data indicates the fish distribution in Kranji Reservoir was rather uniform, with higher fish density in the shallower southern half of the reservoir. However, it is likely that different assemblages are occurring the deeper regions (Central to North region). It is also expected that aquatic vegetation is an important component for nursery and feeding grounds.

However, it is unlikely that these areas are equal in terms of reproductive success. Fish are likely to favour certain areas of the reservoir which may exhibit greater habitat complexity, protection/ shelter and appropriate biogenic substrates. Taken together, these two factors (water quality and fish) are key to supporting the prey items on which **waterbirds** feed.

3.5.3 PATTERNS IN VARIABILITY

WATER QUALITY

Recent biological studies have reported Kranji Reservoir to be hyper-eutrophic with high productivity (Low et al. 2010; Ng et al. 2010; Gin et al. 2011; and Clews et. al 2014). Ng et al (2010) further reported that much of Kranji Reservoir had moderate to low biodiversity, contained high levels of invasive species, and supported no areas of high native biodiversity. Such low species richness is generally known to be a function of eutrophic lakes (e.g. Dodson et al. 2000). Water quality in Kranji Reservoir has been noted as being eutrophic for over a decade (Ng et al. 2010). This suggests variability over recent timescale is generally limited.

Variability on a shorter timescale occurs monthly due to weather conditions i.e. impulses of run off during rain/ storm events, following releases across Kranji Dam, and diurnally as the waterbody is heated and cooled during day and night-times respectively (Xing et. al 2014).

Results from the baseline studies carried out at the locations shown in Figure 3-2 above indicate the site is still classed as a eutrophic freshwater body. Xing et al (2014) showed that the diurnal pattern of development of thermal stratification of waters into a warmer less-dense epilimnion and a cooler, denser hypolimnion (lower layer of water) due to daytime heating and overnight cooling leads to well mixed conditions. Thermal stratification, pH stratification and dissolved oxygen (DO) stratification are presented in Figure 3-22, Figure 3-23 and Figure 3-24 respectively for the monitoring period December 2020 to May 2021 inclusive. Key takeaways from these figures are:

- Most of the reservoir area is relatively shallow (3-4 m deep) and because of this, the daytime heating of the surface is generally mixed each night.
- Between December and February, when temperatures are relatively cooler, the water column is generally well mixed.
- Thermal stratification was observed between the months of March 2021 to May 2021 inclusive, with some spatial variability in thermal stability between sampling locations.
- In terms of pH, the reservoir showed pH stratification occurring between the months of January and May 2021, with stratification being greatest during the warmer months of April and May 2021.
- There is evidence of DO stratification occurring as early as March 2021, which shows a decline in DO that coincides with the rising temperatures and increasing acidity observed at lower water depths.
- These changes are expected to have a detrimental effect(s) on key habitats and fish spawning processes that take place at these sampling locations.

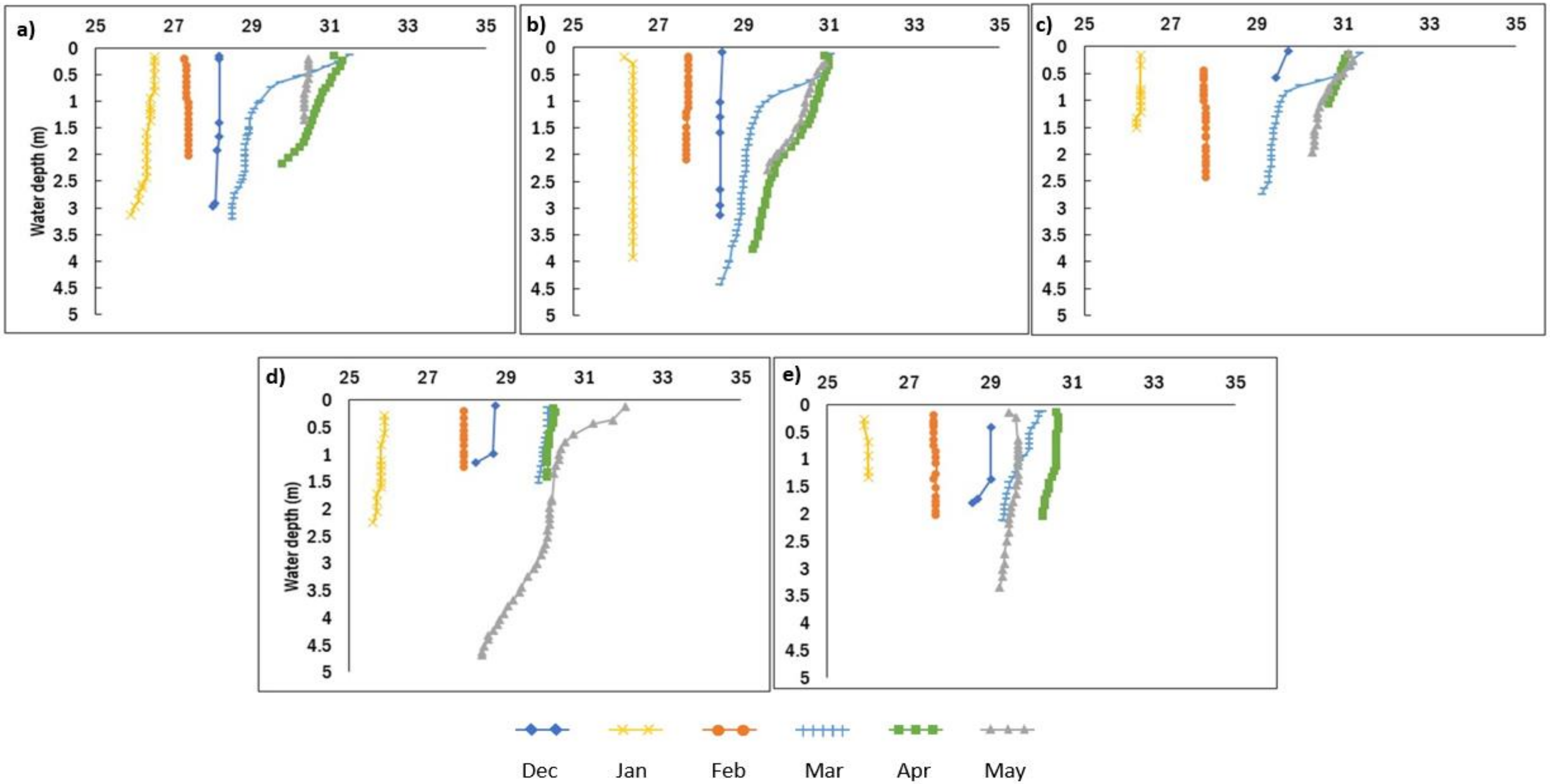


Figure 3-22 Monthly vertical temperature-depth water column profiles at a) WQ01, b) WQ02, c) WQ03, d) WQ04 and e) WQ05 between December 2020 and May 2021.

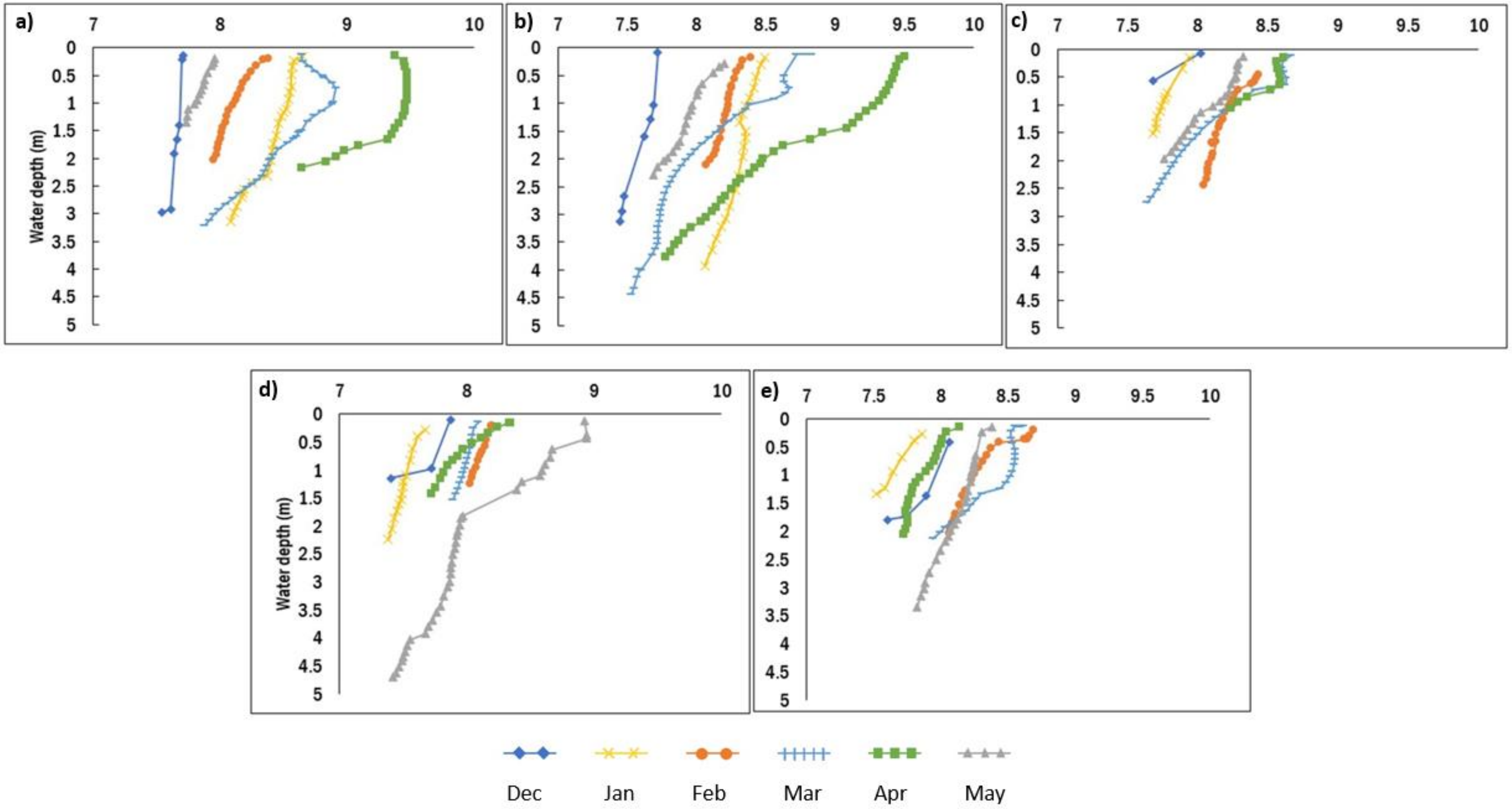


Figure 3-23 Monthly vertical pH-depth water column profiles at a) WQ01, b) WQ02, c) WQ03, d) WQ04 and e) WQ05 between December 2020 and May 2021.

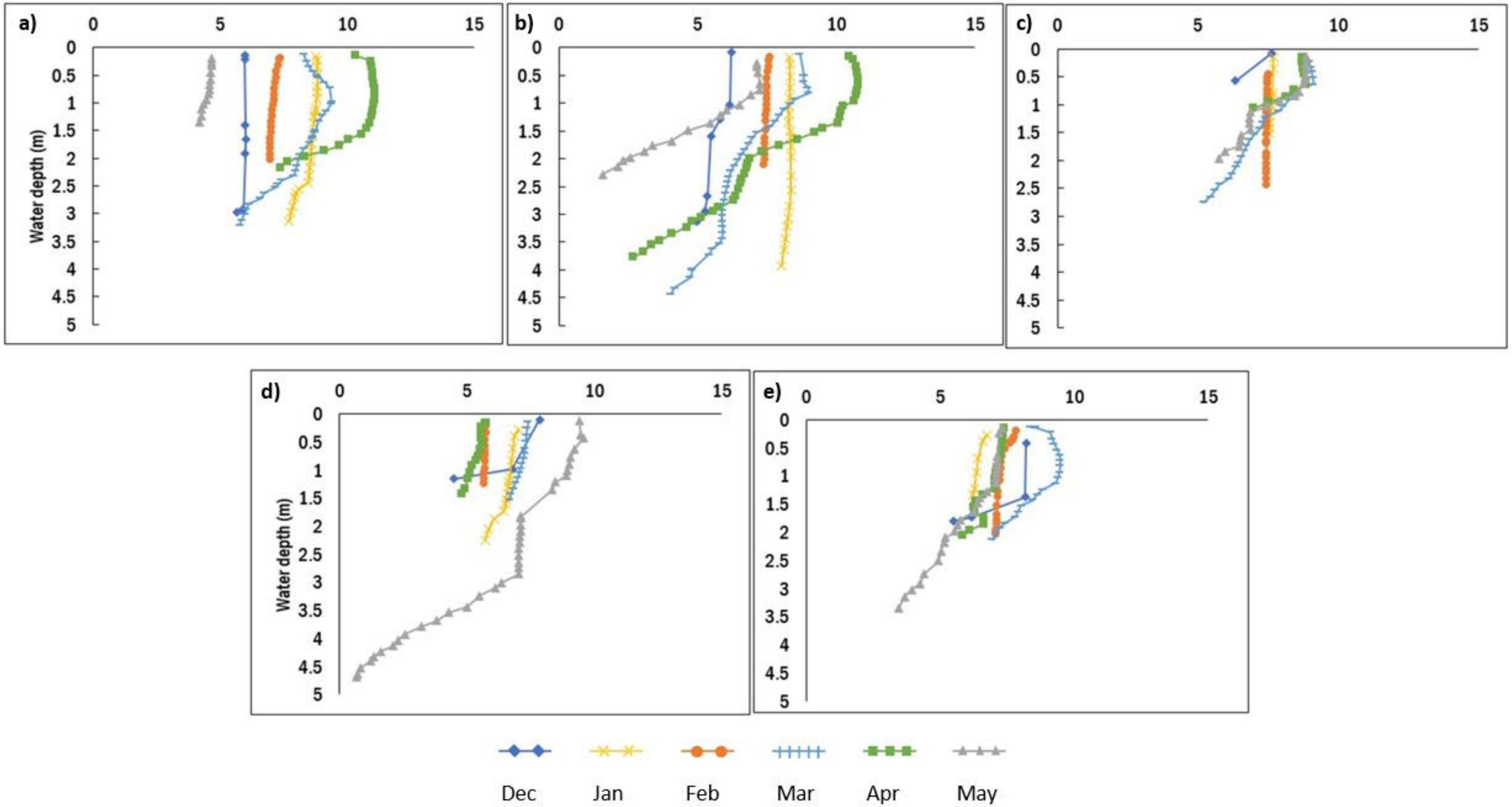


Figure 3-24 Monthly vertical DO-depth water column profiles at a) WQ01, b) WQ02, c) WQ03, d) WQ04 and e) WQ05 between December 2020 and May 2021

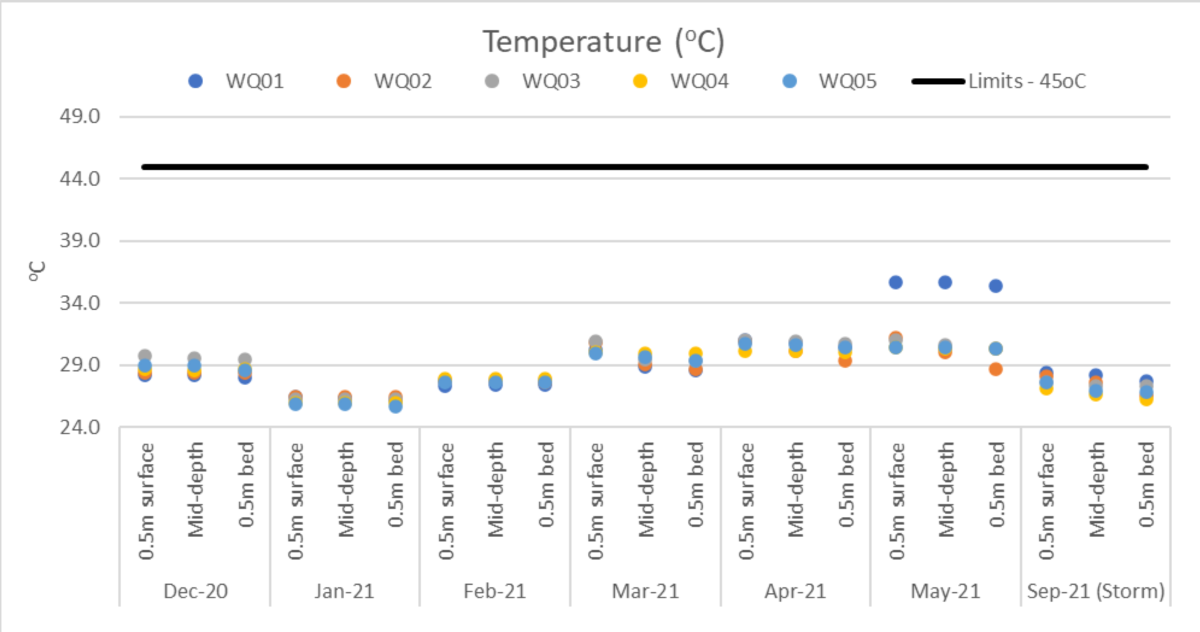
Table 3-18 presents average monthly values for water quality parameters measured from water samples that were collected in December 2020, January 2021, February 2021, March 2021, April 2021, May 2021 and September 2021.

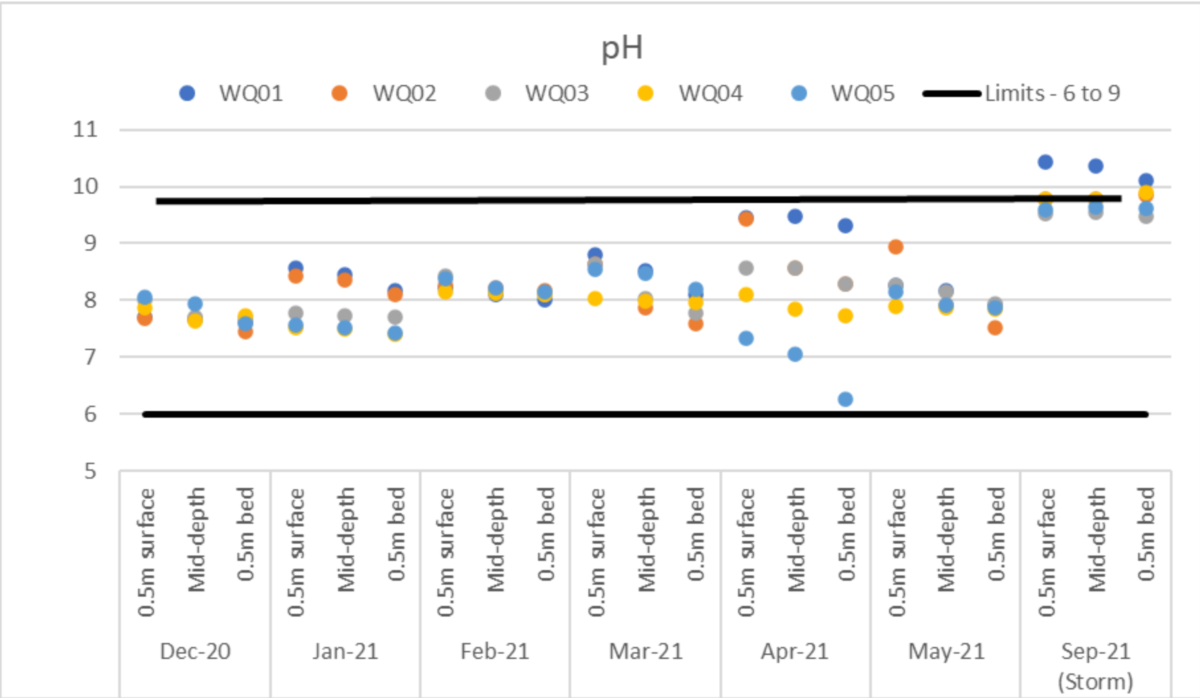
Water grab samples collected from the five locations between December 2020 and May 2021, with additional samples collected in the reservoir following a storm event in September 2021, also demonstrate monthly variability in water parameters such as temperature (°C), pH and DO (Figure 3-25). From February onwards, pH values greater than 8 were observed, with the highest pH values measured in September 2021 following a storm event.

Table 3-18 Water quality parameters measured from water samples collected at Kranji Reservoir at monthly intervals.

Test Parameter	Unit	Test Method	Average (Dec 2020 – Sept 2021)
Total Organic Carbon, TOC	mg/L	APHA 5310B / C	7.31
Dissolved Organic Carbon, DOC	mg/L	APHA 5310B	5.58
Ammonia as NH_3-N	mg/L	APHA 4500-NH_3 (H)	0.04
Nitrate as NO_3	mg/L	APHA 4500-NO_3 (I)	0.39
Total Nitrogen,TN	mg/L	APHA 4500-P (J)	0.87
Total Phosphorous,TP	mg/L	APHA 4500-P (J)	0.05
Dissolved Phosphorous	mg/L	APHA 4500-P (J)	0.04
Phosphate as PO_4	mg/L	APHA 4500-P (G)	0.08
Sulphide	mg/L	APHA 4500-S^{2-} (D)	0.10
Iron as Fe	mg/L	APHA 3120B	0.47
Aluminium as Al	mg/L	APHA 3120B	0.34
pH	-	APHA 4500-H^+ (B)	7.63
Conductivity	µS/cm	APHA 2510B	178.10
Turbidity	NTU	APHA 2130B	36.13
Microcystin-LR	µg/L	LCMS-MS	0.42
Geosmin	ng/L	APHA 6040D	6.32
2-Methylisoborneol (MIB)	ng/L	APHA 6040D	10.58
Chlorophyll-a	mg/L	APHA 10200H (2) (Spectrophotometric)	37.31
Antimony as Sb	mg/L	APHA 3120B	0.02

Test Parameter	Unit	Test Method	Average (Dec 2020 – Sept 2021)
Molybdenum as Mo	mg/L	APHA 3120B	0.0046
Total Microcystins	µg/L	LCMS-MS	0.80
Cylindrospermopsin	µg/L	LCMS-MS	0.10





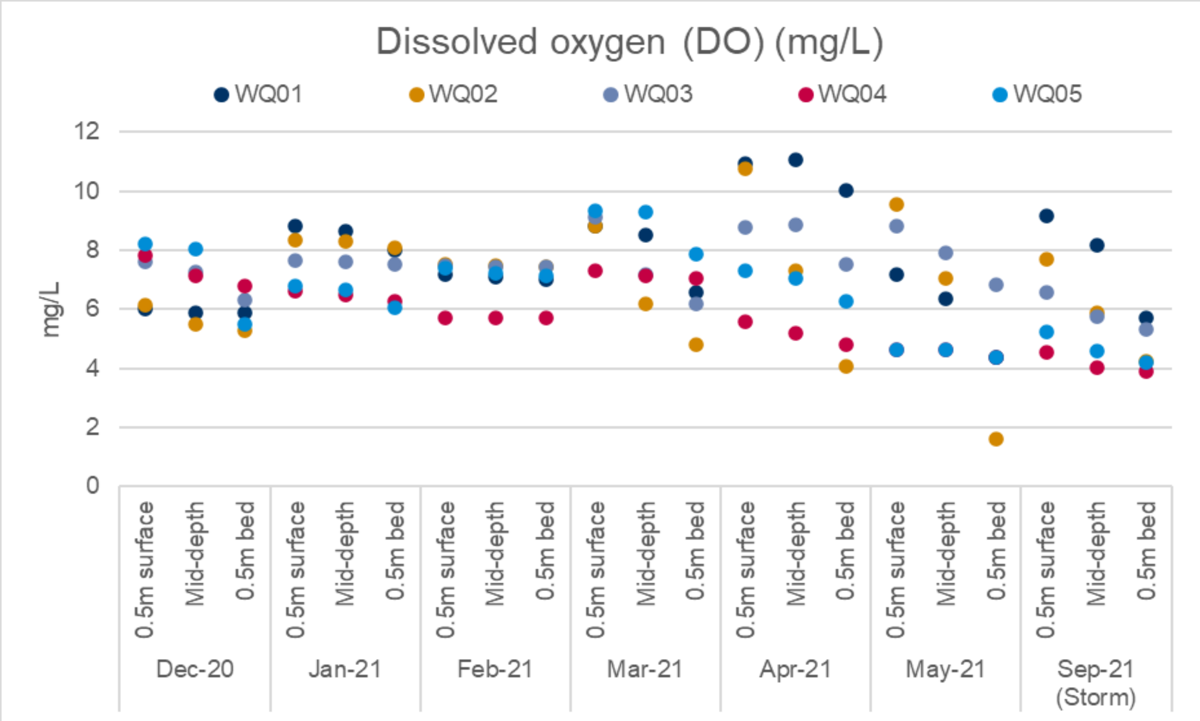


Figure 3-25 Water quality measurements of a) temperature (°C); b) pH; and c) DO (mg/L) for water grab samples collected from the surface, mid-depth and bed of five locations on Kranji Reservoir.

FISH

There are no data to describe historic reproductive success of fishes at Kranji Reservoir. The only data collected on fish variability both historically (Ng et al., 2010) and more recently (Kwik et al., 2020; and surveys for this Project) is an inventory of fish species present at the site. Comparison of surveys conducted by Ng et al. (2010) and Kwik et al. (2020) may suggest a change in fish assemblages at Kranji Reservoir during the past decade. Since the Kwik et al. 2016 survey the biodiversity of fish fauna at Kranji Reservoir may have changed, as previously absent fish species were identified in the 2020 Ng et al. survey. However, this could rather reflect differences in fish sampling methods and the effort applied to fish sampling. Fish were sampled by Ng et al. (2010) using an array of methods depending on the habitat. For example, a combination of gill nets, long lines, and baited fish traps were used to collect the larger fishes, while shallow areas with abundant, submerged vegetation were sampled using a combination of seine nets, push nets, and scoop nets. On the other hand, Kwik et al. (2020) used an array of different fish sampling methods between August and October 2018 that included electrofishing and cast netting. A total of 12 occasions of electrofishing were performed at Kranji Reservoir, with each sampling occasion consisting of 10-20 electrofishing bursts carried out over one to two days. Cast netting (3.5 m height, 1 cm mesh size) was performed also fortnightly at Kranji Reservoir. For each sampling occasion, 80 casts were performed across all eight sampling zones. Because of these differences, the differences in fish assemblages recorded could reflect the different fish methods and sampling efforts, rather than changes in fish assemblages over time.

Hydroacoustic survey work completed at Kranji Reservoir as part of this Project's baseline surveys indicates that the fish distribution is relatively uniform, with higher fish density in the shallower southern half of the reservoir. Fewer tracks but higher biomass in the southern area may indicate relatively few, but larger fish species present in the southern area and could reflect different nursery and feeding grounds for different fish species in the reservoir.

WATERBIRDS

A high-level comparison of waterbird data collected during the last decade shows some differences in the presence/ absence of certain species, although this may simply be due to chance rather than any particular cause. It is notable that many of the focal species which are also of conservation interest have been recorded previously at the site during the past decade (e.g. grey-headed sea eagle and grey heron). It is likely that the habitats available to waterbirds have remained relatively static over the last decade allowing for these species, which are adapted to using modified waterbodies, to persist.

3.6 SUPPORTING PROCESSES

3.6.1 CLIMATE

Kranji Reservoir has a mean annual temperature of 27°C with mean monthly temperatures ranging between 26.2°C in January and 27.8°C in May (Figure 3-26). The mean of total annual rainfall (mm) is approximately 2,250 mm with monthly mean rainfall values ranging between 134 mm in July and 268 mm in December (Figure 3-26). Long term climate records between 1901 and 2019 indicate annual variability in temperature (Figure 3-27) and precipitation (Figure 3-28) (Climate Research Unit [CRU], University of East Anglia, 2021).

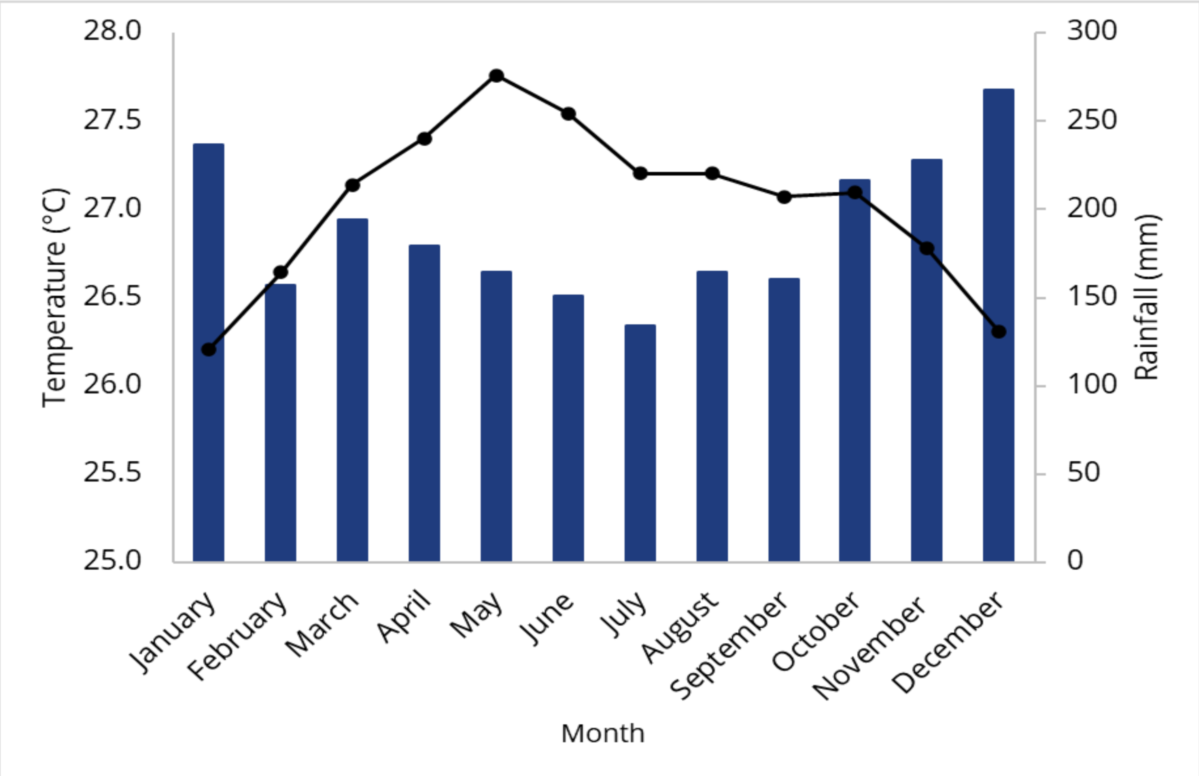


Figure 3-26 Monthly air temperature (°C) and rainfall (mm) at Kranji Reservoir for the monitoring period 1901 – 2019. Values are expressed as mean values. Data extracted from the website of the Climate Research Unit [CRU], University of East Anglia (CRU, 2021).

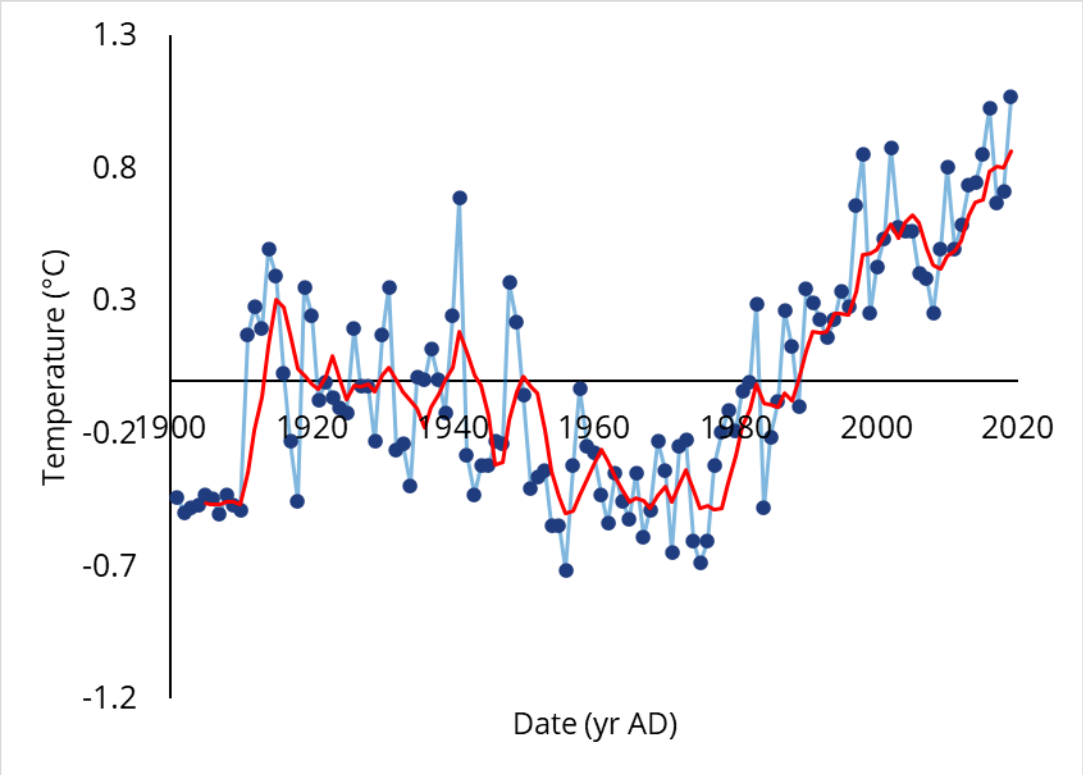


Figure 3-27 Annual variability in mean air temperature (°C) at Kranji Reservoir during the monitoring period 1901 – 2019. The red 5-year smoother line indicates the deviation from the mean value. Data extracted from the website of the Climate Research Unit [CRU], University of East Anglia (CRU, 2021).

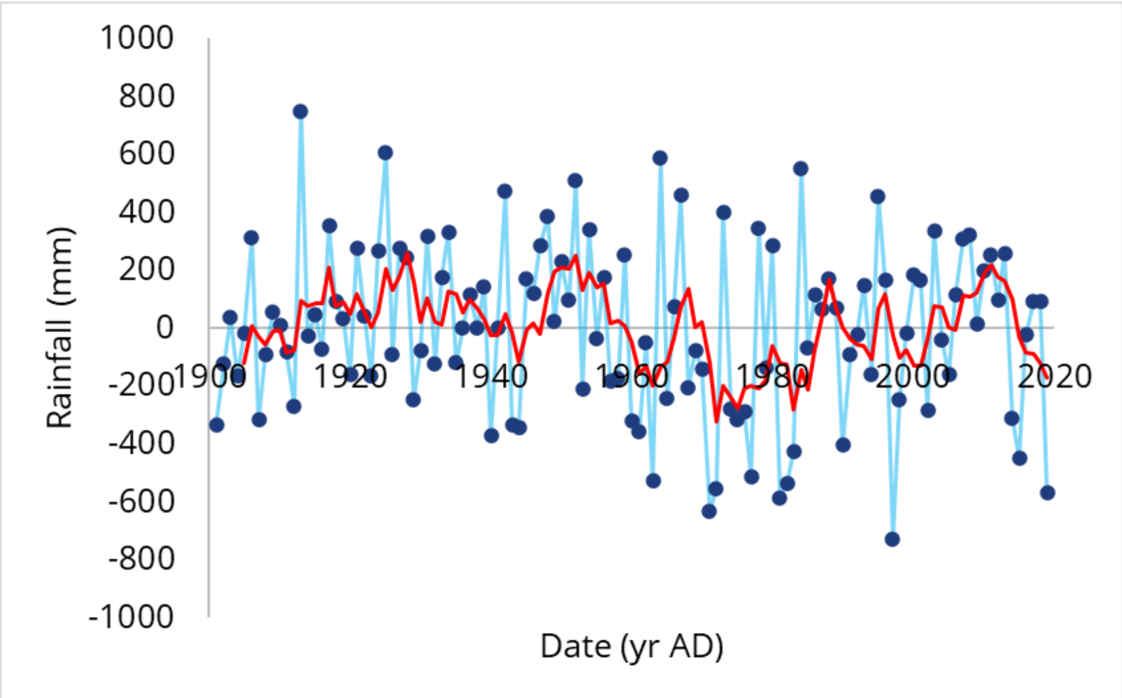


Figure 3-28 Annual variability in total precipitation (mm) at Kranji Reservoir during the monitoring period 1901 – 2019. The red 5-year smoother line indicates the deviation from the mean value. Data extracted from the website of the Climate Research Unit [CRU], University of East Anglia (CRU, 2021).

Long-term climate measurements collected between 1901 and 2019 suggest climate warming has occurred at the site since the 1980s. From 1990 onwards, mean annual air temperature is above the mean value for the monitoring period and continues to demonstrate an increasing trend. The trend in annual rainfall is less clear, however, and cycles between periods of increasing and decreasing rainfall.

3.6.2 GEOLOGY

Kranji Reservoir is a man-made freshwater reservoir that was formed in 1972 when a dam was built across the Kranji River. The geology of the area is characterised by three geological formations: a large portion of the site is classified as the Bukit Timah Granite, with parts of the catchment also belonging to the Kallang Formation and Old Alluvium. The Bukit Timah Granite is made up of granite and is the oldest of the three geological formations, dating back to the early to middle Triassic period (250 – 235 million years ago). The Kallang Formation is composed of soft marine clay, loose alluvial muddy sand, loose beach sand, soft peaty, organic mud, and coral. It is the youngest geological formation, dating from the late Pleistocene to present (0.14 million years ago until present). The Old Alluvium is formed of dense to cemented muddy sand and or gravel with beds of silt and or clay, formed between the late Tertiary to middle Pleistocene (5 – 0.5 million years ago).

3.6.3 SOILS

Singapore is characterised by different soil types deposited on igneous rocks, sedimentary rocks, alluvial deposits, alluvium, recent marine sediments and organic soils. The Kranji Reservoir catchment is largely characterised by recent marine alluvium, transported as sediment and deposited by the sea, which has been classified by geographers as the “Kranji series” (a sandy loam). The surrounding area is also composed of soils that form on sedimentary rocks, which belong to the Ayer Terjun series. A small area of soils formed on alluvium is also present in the southern portion of Kranji Reservoir and is identified as being part of the Jurong series.

The majority of the benthos comprises muddy substrate. Coarser particles are found close to the dam, most likely where shear stresses remove fines during releases.

3.6.4 BATHYMETRY

Overall the bathymetry of the reservoir is shallow and mirrors the historic geomorphology of the Kranji River prior to it being dammed. Deeper sections follow what was once a meander in the river along the eastern shoreline. The deepest area is approximately 20 m deep. The majority of the reservoir is 3-4 m deep.

3.6.5 SEDIMENT QUALITY

Sediment samples were collected at five locations within the Reservoir in January 2021, March 2021 and May 2021. Sediments were sent to SINGLAS accredited laboratory with a completed Chain of Custody (COC) form for analysis of heavy metal toxicity and nutrient availability. Sediment samples were processed and analysed using the APHA 3120B test method. The reports are presented below in the Table 3-18.

The sediment toxicity reports identified current baseline conditions for several heavy metals associated with human activity in 2021. The heavy metal elements are redox-sensitive, except Arsenic (As), Cadmium (Cd), Mercury (Hg), Lead (Pb) and Zinc (Zn), which are redox-inactive (Garza et al., 2018; Mesquita et al., 2016; Valko et al., 2016) and thus, unlikely to have accumulated in the sediments by process of water chemistry changes and or remobilisation of surface sediments.

Zn concentrations in sediments at this site are substantially high compared to freshwater lakes that have been impacted by human activities such as intensive aquaculture (e.g. Alvarado et al., 2020) and suggest large contributions of Zn may be transported and delivered via surface runoff and atmospheric deposition from nearby military, industrial and recreational zones. Fertilisers from the nearby golf course are likely to be an important source of Zn delivered to the sampling locations at Kranji Reservoir.

Sediment Hg concentrations for samples collected from Kranji Reservoir (ranging between 0.08 mg/kg and 0.36 mg/kg across all sampling locations) are comparable with Hg concentrations in soil and sediment samples collected from a reservoir in Singapore's Central Catchment Nature Reserve (0.02 and 0.23 mg/kg) (Fong et al., 2020). The Hg concentrations measured in the sediments from Kranji Reservoir are, however, lower than surface sediment concentrations measured at lakes located in industrial areas in the UK, which showed lake sediment concentrations reaching 400-1600 ng g-1 before the mid-19th century (Yang et al., 2016). The Sungei Kadut industrial estate and the nearby military zone are likely sources of atmospherically deposited Hg contamination in Kranji Reservoir, with additional contributions of Hg transported via atmospheric deposition from regional and global Hg sources.

It is also worth noting that sediments are a source of P and can contribute additional P to the reservoir via internal loading from the sediments. Internal loading of P from sediments can proliferate eutrophication in water bodies, despite reductions in external loadings of P (Ibelings et al., 2007; Dakos et al., 2015). The breakdown of thermal stability in the reservoir during the cooler months are expected to result in the release of nutrients from sediments via redox processes and oxygenation of the hypolimnion, followed by upwelling and delivery of input nutrients from anoxic bottom waters to the epilimnion. However, the data in the current works show thermal stratification is persists for only short periods throughout the year. Because of this, nutrients stored in the lake sediments are likely available in the epilimnion for the majority of the year. Internal loading of nutrients from lake sediments combined with the catchment inflow loads are likely to sustain eutrophication and annual algal blooms in the reservoir.

Table 3-18 Sediment quality reports for sediment samples collected from Kranji Reservoir in Jan 21, Mar 21 and May 21. Units in mg/kg, unless stated otherwise.

Test Parameter	Reservoir Bed														
	SS01			SS02			SS03			SS04			SS05		
	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May
Aluminium, Al	12,765	17,318	33,796	17,472	25,914	32,668	15,495	18,983	6,324	15,003	22,299	35,287	17,510	21,550	30,542
Antimony, Sb	<0.5	<0.5	2.5	<0.5	<0.5	6.9	1.1	<0.5	3.5	1.7	<0.5	1.2	1.3	<0.5	3.2
Arsenic, As	48.1	57.0	47.5	50.2	51.2	50.0	32.8	64.4	36.4	21.2	21.3	25.1	26.3	27.2	24.4
Barium, Ba	45.3	56.9	67.6	43.0	51.7	52.6	46.9	62.3	34.0	42.4	50.2	80.2	46.3	52.5	53.8
Boron, B	38.3	45.2	46.3	30.9	34.7	32.5	36.6	42.4	18.8	32.9	32.2	34.9	35.9	34.0	33.9
Cadmium, Cd	0.9	1.0	0.9	0.9	1.7	1.2	1.0	1.1	0.4	0.9	0.9	0.9	0.9	1.0	1.0
Chromium, Cr	27.8	31.7	35.2	30.0	43.1	4.0	31.0	38.8	12.7	26.9	30.9	33.0	40.9	43.3	47.3
Copper, Cu	33.3	32.9	36.7	70.9	97.6	105.0	53.7	38.9	12.5	44.1	40.4	40.7	51.5	48.4	50.6
Iron, Fe	38,967	47,052	51,993	33,078	41,357	50,357	41,363	58,282	20,745	37,702	42,109	44,272	40,319	44,272	54,896
Lead, Pb	29.3	31.7	31.3	39.3	54.5	54.8	30.3	35.3	12.0	26.8	27.2	28.1	30.2	30.1	30.8
Manganese, Mn	235.0	331.0	228.0	264.0	207.0	201.0	243.0	418.0	212.0	139.0	135.0	139.0	219.0	223.0	204.0

Test Parameter	Reservoir Bed														
	SS01			SS02			SS03			SS04			SS05		
	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May
Mercury, Hg	0.3	0.1	0.1	0.2	0.2	0.3	0.2	0.1	0.1	0.2	0.4	0.3	0.3	0.3	0.3
Molybdenum, Mo	4.4	6.3	6.3	3.2	0.8	1.7	1.4	5.4	5.5	1.6	0.9	2.7	0.9	0.7	1.2
Nickel, Ni	13.6	16.0	16.8	12.5	15.8	15.6	11.4	17.1	5.9	10.4	11.0	13.1	12.0	13.3	1.4
Selenium, Se	1.0	<0.3	<0.3	0.6	<0.3	<0.3	<0.1	1.2	1.1	<0.1	<0.3	<0.3	<0.1	<0.3	<0.3
Zinc, Zn	157.0	166.0	173.0	440.0	560.0	654.0	236.0	216.0	82.5	211.0	207.0	203.0	297.0	271.0	294.0
Total Nitrogen, TN	5,705.3	1,704.1	6867.6	5,086.2	4,504.2	6,045.0	4,941.4	5,865.9	2,559.0	5,978.8	4,778.4	6,185.2	3,940.1	5,017.5	5,057.1
Total phosphorus, P	1,285.3	1,507.0	1,416.0	1,176.2	1,539.0	1,484.0	1,950.0	1,838.0	1,176.0	1,747.0	1,733.0	1,506.0	1,956.0	2,022.0	1,934.0
Loosely-bound P	16.3	3.2	4.1	10.1	3.6	3.5	92.3	2.8	5.4	61.0	3.7	3.7	42.3	4.6	3.9
Fe/Al bound P	788.5	844.0	885.0	671.9	508.0	115.0	1,250.0	972.0	38.0	912.0	948.0	418.0	832.0	1,147.0	79.0
Ca bound P	196.5	149.0	94.0	223.0	93.0	491.0	194.0	149.0	535.0	292.0	204.0	512.0	424.0	183.0	673.0

Test Parameter	Reservoir Bed														
	SS01			SS02			SS03			SS04			SS05		
	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May	Jan	Mar	May
Organic bound P	284.8	511.0	433.0	271.0	934.0	874.0	413.0	715.0	598.0	483.0	577.0	571.0	658.0	688.0	1,178.0
Organic Matter as LOI*	-	-	24.8	-	-	10.3	-	-	19.9	-	-	13.5	-	-	8.1
Total Organic Carbon*	-	-	13.5	-	-	8.4	-	-	4.4	-	-	7.1	-	-	5.0

*Units in %

3.7 KEY SERVICES

Six services were identified as key services:

- "Water reservoir",
- "Flood control",
- "Climate and water regulation",
- "Public recreation and spiritual enrichment",
- "Education and aesthetics" and
- "Maintenance of local biodiversity".

These services were selected as key services since Kranji Reservoir's primary purpose is to provide important services that are beneficial to humans, which include water provision, education and public recreation. In addition to this, the tidal gates at Kranji Reservoir are used for flood control, while the reservoir also provides habitat for wetland birds of which some species are important nationally for conservation.

Two other supporting services were identified:

- Water and nutrient cycling, and
- Habitat for biota.

3.7.1 REASONS FOR SELECTION AS 'KEY'

The "**water reservoir**" was chosen as a key service since the primary function of Kranji Reservoir is water provision.

"**Flood control**" was identified as a key service because of the role Kranji Reservoir serves for flood management. During periods of heavy rainfall, the tidal gates are opened to control water flow and prevent flooding of the area surrounding Kranji Reservoir.

"**Climate and water regulation**" were selected as key services due to the interactions between the reservoir and the local climate, particularly the reservoir's role in the cooling of microclimates. Management of water regulation is also essential, as changes in climate can contribute towards undesirable water losses from the reservoir.

Since the reservoir's formation, "**public recreation and spiritual enrichment**" is a key service provided at Kranji Reservoir. The reservoir hosts recreational fishing activities at two points along the northern shore and is adjacent to SBWR. A golf course is located in the western area of Kranji Reservoir, as are the Kranji Marshes which are partly accessible to the public (noting there is a core conservation zone which is not accessible to the public). It forms part of the Sungei Buloh Nature Park Network and constitutes a large green space for the public to experience in north-western Singapore.

"**Education and aesthetics**" are an important service at Kranji Reservoir. Increasing work has been done on the reservoirs in Singapore (e.g. Chen et al., 2016; Fong et al., 2020; Kutty et al., 2022; Wilkinson et al., 2022) and during the last few decades, Kranji Reservoir has been subject to numerous scientific research and interest, particular in terms of its biodiversity. Of particular note is the research conducted during the past decade by the national water agency PUB in collaboration with researchers from the National University of Singapore's Freshwater and Invasion Biology Laboratory at the Department of Biological Sciences. Findings from this research have been reported in Ng et al. (2010) and Kwik et al. (2020). In addition to this, books on Singapore's freshwater biodiversity have been published by Davison et al. (2008) and Yeo et al. (2010) and an online biodiversity database has been made publicly available by NParks (2021).

Some work has been done on sediment nutrient dynamics in Kranji Reservoir (e.g. Appan et al., 2000) but literature on nutrient dynamics at this site is generally limited.

The semi-natural terrestrial habitats adjacent to the reservoir host a relatively high diversity of flora and fauna, and some of these contribute to ecological processes at Kranji Reservoir. For example, the littoral zone adjacent to Sungei Kadut Forest was relatively richer in macroinvertebrates than else where, most likely due to the input of organic material (e.g. foliage, invertebrate prey, etc) from the forest into the reservoir at that location.

The reservoir aesthetics play an important role in creating a tranquil and desirable environment for visitors visiting the site. The reservoir provides a scenic nature site for visitors to enjoy, which includes visitors that use the reservoir for recreational fishing. The Kranji Reservoir Park and the Kranji Marshes provide scenic nature sites for locals to enjoy. Ecotourism is also promoted in the area surrounding Kranji Reservoir, with the adjacent SBWR hosting a number of nature walks and bird watching activities at SBWR and Kranji Marshes.

Kranji Reservoir provides a role in "**maintaining local biodiversity**" by providing habitat for wetland species. It also provides some foraging habitat for certain bird species of conservation concern, although no one species of conservation concern is wholly dependent on the reservoir for its foraging needs.

Kranji Reservoir supports fisheries resources in the form of nursery habitats. This service is dependent on the availability of suitable habitats and the abundance of fish and the components are expected to change over time.

3.7.2 DESCRIPTION

Kranji Reservoir is a permanent, man-made freshwater reservoir that is continuously extracted as a water supply (after treatment) and provide services and benefits to humans, flora and fauna. It is important for flood control and management and contributes towards microclimate conditions (e.g. cooling). The site also provides numerous educational and aesthetic amenities that are beneficial for ecotourism and supports a locally important wetland bird community.

3.8 SUPPORTING SERVICES/BENEFITS

3.8.1 WATER AND NUTRIENT CYCLING

Water and nutrient cycling directly and indirectly influence the key components, processes and services at Kranji Reservoir. Kranji Reservoir stores water to providing important water resources for human consumption, and supports local fauna and flora.

Nutrient cycling acts as a supporting service at Kranji Reservoir, as baseline survey results have demonstrated an increase in algal blooms and hyacinth proliferation following heavy rainfall events, as a result of increased surface runoff of nutrient. An improved understanding of the internal loading of nutrients from shoreline runoff, atmospheric deposition and human activities on the reservoir itself, together with external loading and recycling of nutrients from sediments, would be needed for predicting and informing any future reservoir response and management for activities that may affect these cycles.

3.8.2 HABITAT FOR BIOTA

This ECD study and Project surveys have identified "habitat for biota" as one of the supporting services at Kranji Reservoir. The reservoir is utilised by terrestrial and aquatic flora and fauna, and facilitates their growth and reproduction by providing a broad range of different habitat types and environmental conditions that are favourable for supporting these species.

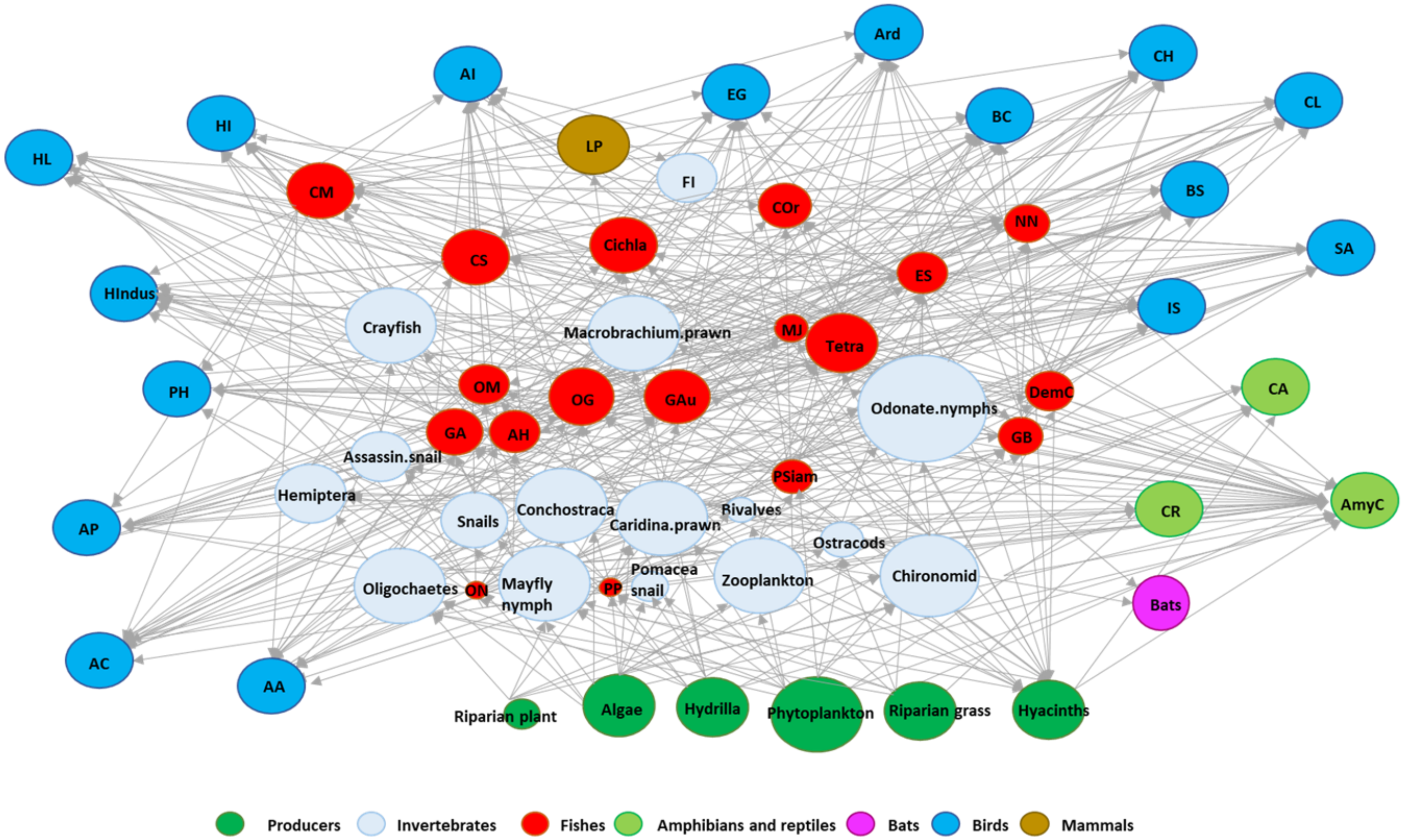
3.9 CONCEPTUAL MODELS

Several conceptual models have been prepared to support this ECD, in particular to illustrate the interaction of key components and processes to produce ecosystem services/benefits.

No conceptual mapping has previously been carried out at Kranji Reservoir, except for Kwik et al. (2020) who mapped the food web and which is shown here for reference (Figure 3-29).

In seeking to logically characterise the broad range of ecosystem characteristics present at Kranji Reservoir, four conceptual models were developed as part of this ECD:

- Figure 3-30 depicts the key and supporting components that are characteristic of Kranji Reservoir and the areas along the shoreline. The water reservoir itself is recognised as a key component that is crucial for the functioning and survival of other components, processes and services.
- Figure 3-31 depicts the key and supporting processes identified for Kranji Reservoir. These processes are characteristic of many tropical freshwater lakes and reservoirs.
- Figure 3-32 depicts the key and supporting services provided by Kranji Reservoir.
- Figure 3-33 depicts the current and future threats that pose a risk to water quality and both terrestrial and aquatic biodiversity present at Kranji Reservoir



Legend

Amphibians and reptiles

AmyC = *Amyda cartilaginea*

CA = *Cuora amboinensis*

CR = *Cylindrophis ruffus*

Bats

Birds

HL = *Haliaeetus leucogaster*

HI = *Haliaeetus ichthyaetus*

Hindus = *Haliastur indus*

PH = *Pandion haliaetus*

AP = *Ardea purpurea*

AC = *Ardea cinérea*

AA = *Ardea alba*

AI = *Ardea intermedia*

EG = *Egretta garzetta*

Ard = *Ardeola* sp.

BC = *Bubulcus coromandus*

BS = *Butorides striata*

IS = *Ixobrychus sinensis*

CH = *Chlidonias hybrida*

CL = *Chlidonias leucopterus*

SA = *Sternula albifrons*

Fish species

AH = *Acarichthys heckelii*

Cichla = *Cichla orinocensis Cichla kelberi*, and *Cichla temensis*, combined due to their similar isotopic signatures

CM = *Channa micropeletes*

COr = *Chitala ornata*

CS = *Channa striata*

DemC = *Dermogenys colletti*

ES = *Etroplus suratensis*

GA = *Geophagus altifrons*

GAu = *Glossogobius aureus*

GB = *Gobiopterus brachypterus*

MJ = *Monopterus javanensis*

NN = *Notopterus notopterus*

OG = *Osphronemus goramy*

OM = *Oxyeleotris marmorata*

ON = *Oreochromis niloticus*

PSiam = *Parambassis siamensis*

PP = *Pterygoplichthys paradalis*

Tetra = Unknown tetra sp.

Mammals

LP = *Lutrogale perspicillata*

Prawns

FI = *Fenneropenaeus indicus*

Macrobrachium prawn

Caridina prawn

Figure 3-29 Conceptual food web for Kranji Reservoir, adapted from Kwik et al. (2020).

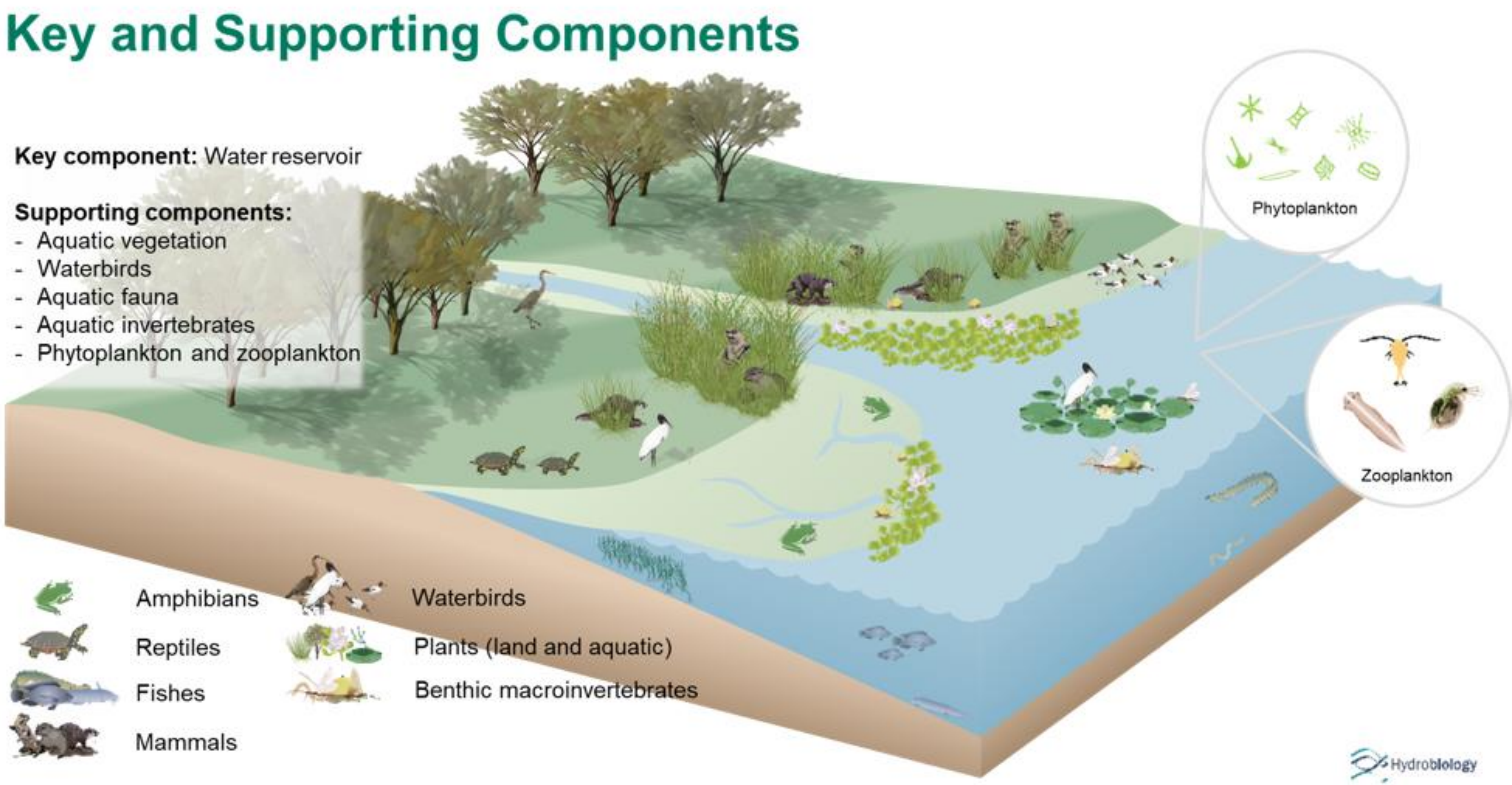


Figure 3-30 Key and supporting components at Kranji Reservoir

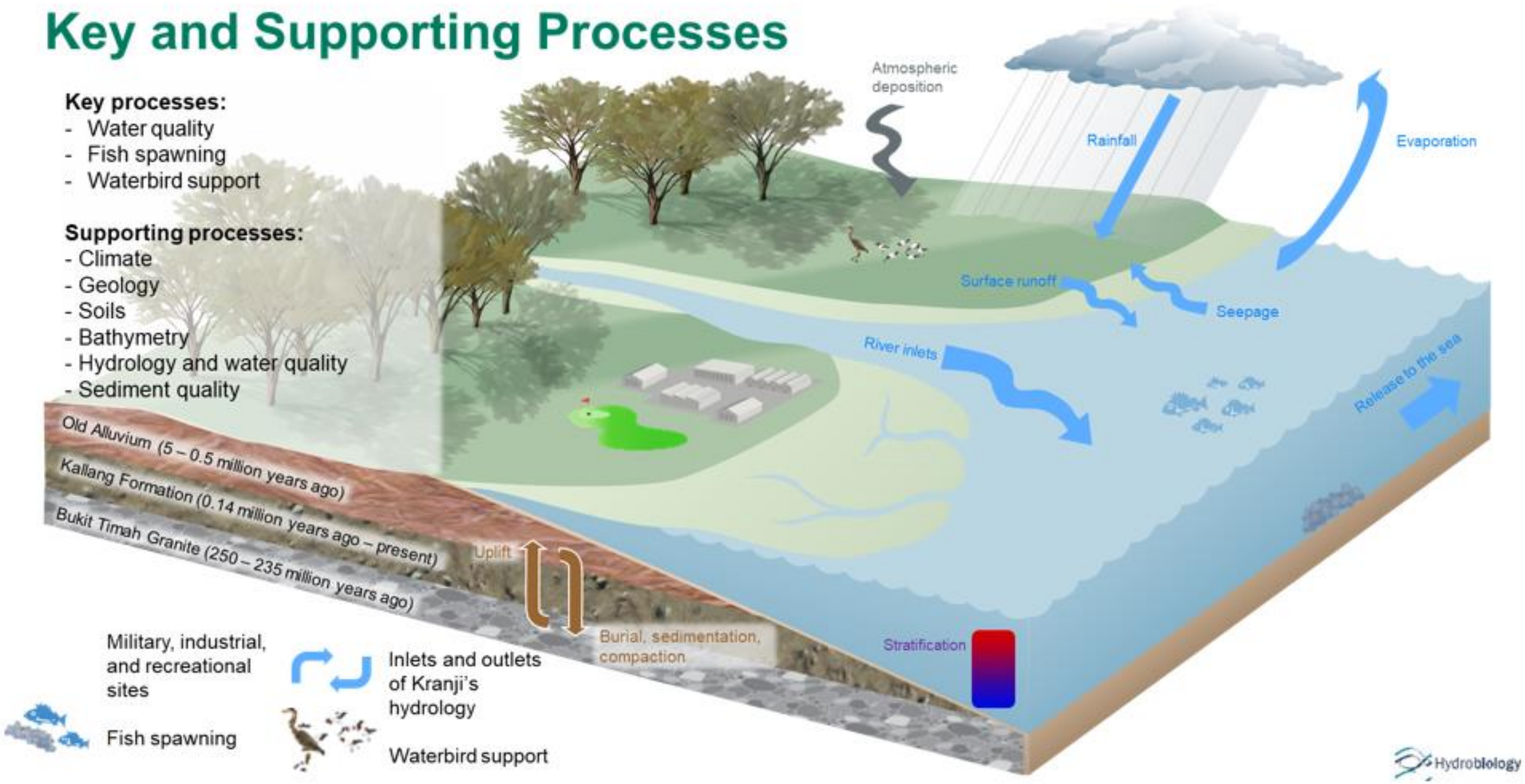


Figure 3-31 Key and supporting processes at Kranji Reservoir

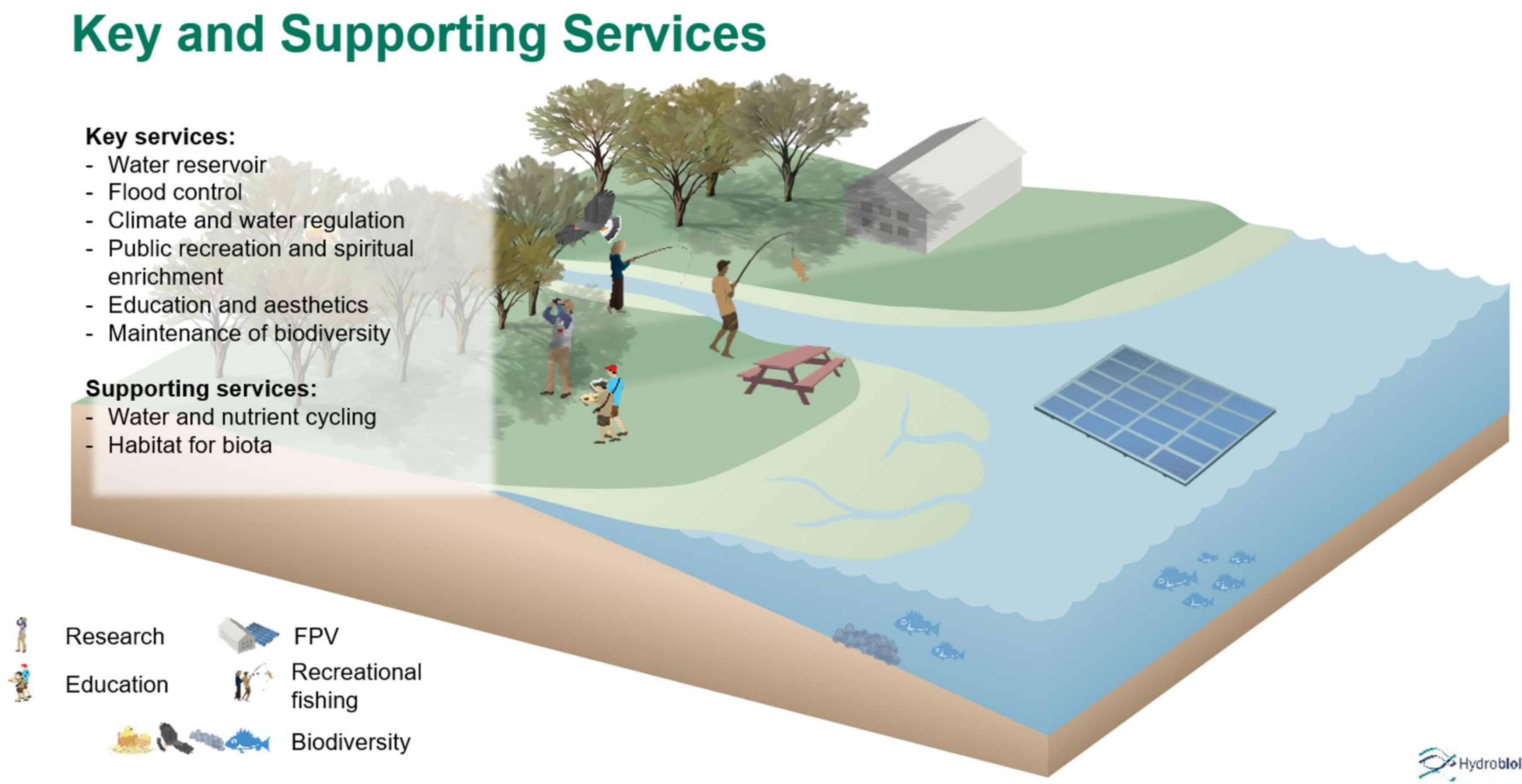


Figure 3-32 Key and supporting services at Kranji Reservoir

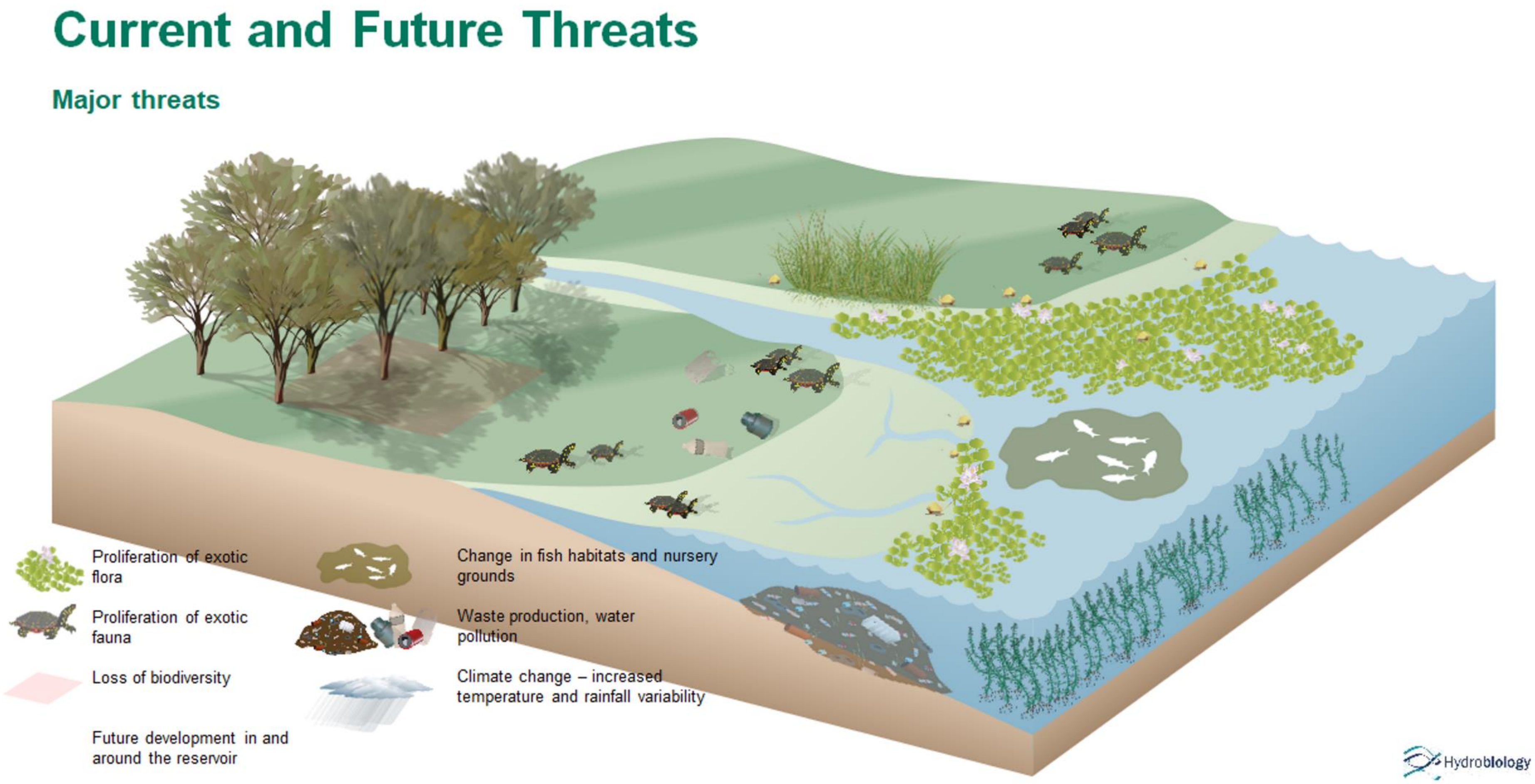


Figure 3-33 Current and future threats that may threaten water quality, terrestrial and aquatic ecology at Kranji Reservoir

4. OVERVIEW OF CURRENT AND FUTURE THREATS

The current and future threats to the ecological character of Kranji Reservoir vary substantially across multiple spatial and temporal scales and in terms of their potential severity. The threats discussed here exclude those relating to the Project but rather focusses on threats which could occur regardless of the Project proceeding or not.

4.1 INTRODUCTION

Current and future threats are summarised in Table 4-1 and are discussed below. When characterising the threats, the consequence of individual threats are assessed based on the categories presented in Table 4-2.

Table 4-1 Current and future threats in and around the Kranji Reservoir

Current and future threats	Potential impacts to ecosystem	Consequence (without mitigation)	Timing
Proliferation/ introduction of exotic/ non-native flora	• Continuing impacts from historical introduction and proliferation of key weed species such as water hyacinth and hydrilla. • Future negative impacts may yet occur with the introduction of further species or as a result of climate change proliferation of alien species already in the reservoir.	Medium	Short-to long-term
Proliferation/ introduction of exotic/ non-native fauna	• Continuing impact of historical introduction of introduction of alien and invasive species, particularly fish, into the reservoir. These effects are probably stabilised at present. • Future negative impacts may yet occur with the introduction of further species or as a result of climate change proliferation of alien species already in the reservoir.	Medium	Short-to long-term
Loss of biodiversity	• Changes in species assemblages and impact to food web. • Reduction in, or loss of, population of species of conservation concern.	Medium-to high	Medium-to long-term
Change in fish habitats and nursery grounds	• Impact on fish populations.	Medium	Medium-to long-term
Waste production and water pollution	• Disturbance to flora and fauna, litter and waste production, water pollution, impacts to habitats.	Medium-to high	Short-to long-term
Climate change – increased temperature in particular	• Increased stratification. • Accelerated nutrient and element cycling and production. • Chemical effects. • Biological effects. • Increased nutrient delivery and productivity. • Increased depth or stability in maximum depths.	Medium-to high	Medium-to long-term
Future development in and around reservoir	Construction and operation of: • Round Island Route along Kranji Way • Sungei Buloh Nature Park Network. • Sungei Kadut Eco-District. • Lim Chu Kang High-tech Agri-Food Cluster.	Low	Short-, medium- and long-term

Table 4-2 Threat consequence categories

Consequence	Interpretation
High	Permanent and irreversible impacts of any or all of the components, processes and services identified in the ECD.
Medium	Significant, possibly irreversible impacts of any or all of the components, processes and services identified in the ECD.
Low	Short term/temporary and reversible impacts of any or all of the components, processes and services identified in the ECD.

4.2 PROLIFERATION OF EXOTIC/ NON-NATIVE FLORA

Two aquatic plants found in Kranji Reservoir, hydrilla (*H. verticillata*) and water hyacinth (*E. crassipes*), are recognised as having pest potential. Both species restrict waterflow, modify aquatic vegetation habitats by replacing species and causing a loss of biodiversity, and reduce water quality amongst others. These species also interfere with reservoir maintenance operations by PUB and potentially fishing activities.

Water hyacinth is a significant problem at Kranji Reservoir, particularly after periods of high rainfall and nutrient delivery to the reservoir. Globally, water hyacinth is a highly invasive aquatic plant and is responsible for substantial ecological and socio-economic effects. It alters water clarity, phytoplankton productivity, DO, N and P concentrations. However, there is a non-linear relationship between water hyacinths and ecological communities. For example:

- Water hyacinths can provide increased habitat heterogeneity and structural complexity that increases the abundance and diversity of aquatic invertebrates, but the abundance and diversity of these species can decline when phytoplankton (food) availability is low.
- The ecological impact of water hyacinth on fish is dependent on the original community composition and food-web structure. Fish biomass and diversity may increase in response to increased diversity and abundance of epiphytic invertebrate community, but decreasing phytoplankton may reduce DO concentrations and planktivorous fish biomass, which has implications for higher trophic levels; and
- Water hyacinth has socio-economic effects, but these effects are dependent on the extent of the invasion, the use of the impacted waterbody, management and control methods, and the response of the hyacinth to control methods.

Between March and June 2021, rapid expansion of the distribution and extent of Hyacinths was observed at the site. The reproductive rate of hyacinth is influenced by two major conditions: climate and water quality conditions (Gaikwad and Gavande, 2017). The invasive plant can double itself within 5-15 days (Dersseh et al., 2019). Hyacinths favour still water, shallow water depth (<6 m), and lakebed sediments rich in organic matters and availability of nutrients N and P (Makhanu, 1997) (Table 4-3). Annual climatic warming has been observed since the 1980s at Kranji Reservoir and the reservoir is characterised by shallow, eutrophic waters that favour extensive hyacinth growth. The expansion of hyacinth mats has significant negative impacts on reservoir hydrology by enhancing the evapotranspiration of reservoir water. It can also create more favourable conditions for the breeding of snails and mosquito that carry diseases such as Bilharzia and malaria. Ecosystem services at the site are also at risk, as the hyacinth growth can be detrimental towards water quality, the aesthetic amenities of the reservoir, and fishing and poses a threat to the Project itself.

Table 4-3 Summary for optimum conditions for water hyacinth growth. Table adapted from Dersseh et al. (2019).

Parameter	Optimum value	Authors
Waterbody depth	<6 m	Makhanu (1997)
Temperature	28-30°C	Gaikwad and Gavande (2017)
Salinity	<2%	Gaikwad and Gavande (2017)
Nitrate (N)	5.5-20 mg/L	Gaikwad and Gavande (2017), Khan and Ansari (2005)
Phosphate (P)	1.66-3 mg/L	Gaikwad and Gavande (2017)
Potassium (K)	Up to 53 mg/L	Gaikwad and Gavande (2017)
pH	6.5-8.5	Gaikwad and Gavande (2017)

Rapid changes occurring over much shorter, seasonal timescales have also been observed. For example, a change in the extent of water hyacinths was observed over very short timescales (ranging from weeks to months, refer to EIA Appendix 7.4 for time series mapping of emergent/ floating vegetation). These patterns may change further in response to shifts in climate and increasing human disturbance (e.g. changes in nutrient availability).

4.3 PROLIFERATION OF EXOTIC/ NON-NATIVE FAUNA

Kranji Reservoir is a man-made freshwater system and thus, its fauna largely consists of exotic/ non-native, non-native species that were introduced to the reservoir. While the site hosts a diverse range of aquatic species, fish are important due to their role in supporting species of conservation concern, particularly waterbirds. Threats to fish community include:

- Decline and localised extinction of fish species through habitat destruction and/ or predation;
- Habitat damage/ destruction through human activity, including increased water turbidity, loss of aquatic plants, increased erosion and decreased bank stability; and
- Destruction of spawning habitat of fish species.

4.4 CLIMATE CHANGE

Singapore has no distinct wet or dry season, yet there is a trend of month-to-month rainfall variation embedded within the NE monsoon, with approximately 50% more rainfall received in December compared to February (Hassim and Timbal, 2018). Less variability is observed during the SW monsoon. A significant increase in annual total rainfall has been identified in Singapore over the 1981-2014 period from station gauge data (Hassim and Timbal, 2018), with the trend being consistent with that obtained from a 2.5◦ 82 grid 83 box centered on Singapore from the Climate Prediction Center Merged Analysis of Precipitation (CMAP) 2.5◦ × 2.5◦ 84 pentad product (Xie and Arkin, 1997).

Two large uncertainties are apparent in making climate projections for Singapore and for Southeast Asia (CCRS, 2022):

- A limited understanding of tropical convection and limited ability to realistically simulate tropical convection in global climate models.

Uncertainty and lack of understanding of the drivers of inter-annual rainfall variability and drought in the region, including the role of ENSO, and the factors responsible during other times of the year (NE monsoon) when ENSO has little influence.

Changes in air temperature and precipitation directly drive changes in the physical, chemical and biological characteristics of freshwater systems, and they can also indirectly drive changes in the waterbody via modifications in the surrounding watershed, e.g., through changes to hydrological flow pathways, weathering, catchment erosion, soil properties and vegetation. Long-term monitoring data for the period 1901 to 2019 show increasing air temperatures are occurring at Kranji Reservoir since the 1980s. However, the effect of climate change on precipitation is less clear. The below provides a discussion of potential impacts that are likely if climate change projections are realised.

4.4.1 WATER BALANCE

Tropical convection is the primary source of rainfall in Singapore (CCRS, 2022). The latent heat of condensation released in these convective complexes is also an important factor for the large scale wind circulation of the region, including the monsoon (CCRS, 2022).

Increasing intensity and duration of storms may result in changes in water level and increased flooding at Kranji Reservoir as well as increased hydraulic flushing and storm-induced mixing of the water column. An increase in the water depths of Kranji Reservoir are expected if intense storm events become more frequent, whereas periodic reductions in water depth and greater depth fluctuation are likely should climate change result in reduced annual precipitation.

4.4.2 TEMPERATURE AND STRATIFICATION

Kranji Reservoir currently experiences diurnal variability in water temperatures, with daytime heating of the water surface and overnight cooling that facilitates the mixing of shallow (<5 m deep) waters. However, increasing air temperatures may reduce the difference between daytime and overnight temperatures, resulting in reduced mixing of the water column and prolonged duration of thermal stratification. This is expected to be most prominent in locations where water depth is >5 m in Kranji Reservoir. Warming of the surface waters by heat transfer (conduction) can cause changes in the density structure of freshwater systems, with a layer of warmer, lighter water forming at the water surface. This warmer layer prevents the transport of heat via turbulent mixing to deeper parts of the reservoir and acts as a positive feedback mechanism, with increases in temperature strengthening the thermal stratification and increasing resistance to wind-induced mixing. As a result, heat becomes trapped in the surface mixed layer and deeper waters can become cooler due to the increased thermal stability of the water column caused by climate warming.

Enhanced thermal stratification can have a strong impact on the structure of phytoplankton communities. For example, a decline in benthic diatoms and an increase in small, planktonic diatoms is expected when thermal stratification takes place. The absence of well mixed waters via climate warming can also cause enhanced anoxia in the deeper, hypolimnetic waters. When stratification breaks down, upwelling of anoxic waters from the bottom layer can occur, leading to abrupt and substantial fish kills. Further to this, the sudden breakdown of stratification and the mixing of oxygen to the deeper, hypolimnetic layer promotes the internal loading and release of nutrients and heavy metals sequestrated in the sediments, which have major implications for algal blooms and poses a potential threat to both aquatic and human health, respectively.

4.4.3 CHEMICAL EFFECTS OF CLIMATE CHANGE

The residence time of water at Kranji Reservoir (the time required to completely replace all water by its groundwater and rainfall inputs) has implications for the chemical composition of reservoir waters by influencing the time available for biogeochemical and photochemical processes to operate, the accumulation extent and loss of dissolved and particulate matter, and the duration of biogeochemical interactions with the reservoir sediments and littoral zone. As Kranji Reservoir experiences enhanced anoxia in its bottom layer and internal loading of nutrients from its sediments, a prolonged residence time caused by reduced precipitation and inflows can result in increased internal loading and accumulation of P and eutrophication. Alternatively, an increase in precipitation and water inflow and the subsequent increase in flushing of nutrients and phytoplankton may lead to reductions in algal production. However, this effect can be offset by increases in external loading of nutrients from increased catchment erosion, when storm events become more frequent and severe.

4.4.4 BIOLOGICAL EFFECTS OF CLIMATE CHANGE

The responses of species to climate-induced changes in physical and chemical parameters at Kranji Reservoir involve multiple interactions, feedbacks and complex non-linear responses that cannot be fully predicted based on the current knowledge available. However, likely impact pathways of ongoing climate change (both direct and indirect) can be identified. These impact pathways occur at multiple scales, ranging from changes in structure and function at the ecosystem level, down to changes in individual species that in turn feed back into overall ecosystem dynamics.

ECOSYSTEM INTEGRITY

Climate change has the potential to drastically alter the physical structure of reservoir ecosystems, and thereby cause the extinction or alteration of vulnerable aquatic biota. Climate warming has the potential to drive a reduction in water level that may result in aquatic habitat loss, and even deep reservoir areas may lose important ecological features as a consequence of relatively small fluctuations in water level. Small changes in water level are enough to make freshwater wetland systems vulnerable to climate change. Changes in water level at Kranji Reservoir may impact the connectivity between aquatic habitats, which will also influence the species composition of aquatic biota, especially fish assemblages. For example, a loss of habitat connectivity may have a detrimental impact on the spawning and nursery grounds that are essential for fish species in Kranji Reservoir as they rely on these environments for reproduction.

VERTICAL HABITAT STRUCTURE

Changes in thermal stratification and reservoir mixing regimes can alter the vertical gradients in reservoir properties and is expected to have far reaching effects on pelagic communities and production. These changes include shifts in light and nutrient availability, which affects phytoplankton production and therefore the availability of food to high trophic levels. As a consequence of climate change, increased thermal stratification at Kranji Reservoir may allow for increased irradiance supply and rates of primary production.

However contrary to expectations, there is some evidence that thermal stratification via climate warming can result in gradual re-oligotrophication (i.e. a reduction in nutrient contents back to levels that existed previously) of tropical lake systems (e.g. Nöges et al., 2018; Salmaso et al., 2017), due to the stratified, anoxic hypolimnion preventing internal recycling and mixing of limiting nutrients to the upper epilimnetic layer of the water column (Domis et al., 2013; Neil et al., 2018). This could potentially increase nutrient limitation of algal growth and is particularly relevant for Kranji Reservoir where sedimentary TP values are relatively high compared to those measured in other freshwater lake studies (e.g. Guo et al., 2017; Thin et al., 2020; Wang and Liang, 2015) and greater than 1,000 mg/kg.

PHOTOSYNTHETIC COMMUNITIES

Climate change may drive changes in light and nutrient availability at Kranji Reservoir, which in turn, will also have an effect on species composition and diversity at the primary producer level and may impact on higher trophic levels. Shifts in diatom assemblages may occur, with warmer stratified waters favouring small centric diatoms such as *Cyclotella* and *Discostella* that are able to remain suspended in the water column. Increasing precipitation due to climate change can also have an impact on diatom assemblages. Enhanced soil erosion and runoff from the shoreline due to increasing frequency and duration of heavy rainfall events may lead to increased turbidity in the water column, leading to a decline in light-demanding benthic diatoms and a relatively higher abundance of planktonic diatoms. Runoff associated with increased rainfall may also increase the external loadings of nutrients N and P from the shoreline to the reservoir. External loading of P may increase at Kranji Reservoir and high runoff of P derived from fertilisers applied to the NSRCC Kranji Sanctuary Golf Course is highly likely. The consequence of this is enhanced eutrophication of Kranji Reservoir and a shift towards diatom species tolerant of eutrophic conditions, such as *Aulacoseira granulata* (Ehrenberg) Simonsen. *A. granulata* is typically found in warm, well-mixed eutrophic waters, in pH conditions of 7.3 or higher (Tibby et al., 2020; Vázquez-Loureiro et al., 2019; Yang et al., 2019). The species is P-limited and is used as an ecological indicator of changes in P-availability (Tibby et al., 2020) and its current presence in Kranji Reservoir suggests that the reservoir is currently experiencing eutrophic conditions.

Increasing nutrient availability as a consequence of climate change may also result in diatoms (which are highly abundant within the reservoir) being replaced by faster growing, non-diatom species, including picophytoplankton and possibly even species of cyanobacteria that form noxious blooms. The latter is a major concern, as bloom-forming cyanobacteria are likely to be dominant in a warming climate by several mechanisms. First, warmer temperatures are optimum for growth and will favour their rapid accumulation and dominance. Second, these species can maintain their position in the water columns when waters are stratified by way of gas vacuoles that allow them to sink or rise to the optimal depths for photosynthesis or nutrient uptake. Third, increasing P enrichment linked to increased anoxia and internal P loading (and possibly external P loading) is likely to occur with a warmer climate, creating conditions more favourable for bloom-forming cyanobacteria.

FISH COMMUNITIES

Many fish species are sensitive to small changes in temperature, and it is predicted that climate warming is likely to cause changes in the geographical distribution and abundance of many taxa. Fish kills in Kranji Reservoir may be exacerbated as a consequence of rising air temperatures, due to the effect of heat stress on fish physiology and thereby on populations and fisheries (Chrétien and Chapman, 2016). This is especially true for fish assemblages found in tropical wetland systems, since tropical fish species are often living close to their thermal maxima (Tewksbury et al., 2008) and demonstrate a limited ability to change their key thermal maxima (Huey and Hertz, 1984; Vinagre et al., 2016). Because of this, fish species and populations in Kranji Reservoir may become more vulnerable to climate warming than previously. However, the exact response of fish communities to rising temperatures at Kranji Reservoir remains unclear based on the current data, since no long-term records of fish kills are available for this site.

Climate change can also have an indirect impact on fish mortality via reservoir stratification, and the subsequent breakdown and upwelling of toxic heavy metals and anoxic waters from the hypolimnion (Alvarado et al., 2020; Cohen et al., 2016; Fukushima et al., 2017). Under anoxic conditions, the biological oxygen demand (BOD) will increase, which in turn, is likely to increase the uptake of heavy metal contaminants by fish species. The increased uptake of heavy metals by farmed fish can also lead to bioaccumulation of toxic heavy metals that poses a substantial threat to human health (Rajeshkumar and Li, 2018). This may present risk to human health if, for example, anglers were to eat contaminated fish from Kranji Reservoir.

There is potential for interactions between natural (climate) and human pressures to drive shifts in nutrient availability, enhance eutrophication and heavy metal contamination, and amplify the impact responses of reservoir stratification. Studies of freshwater systems have demonstrated complex interactions between climate warming, land cover change and water pollution that are causing a substantial decline in water quality and may be having a negative impact on the health of animals and humans that utilise these wetlands and their resources (Callisto et al., 2014). A common example is tropical freshwater lakes where algal blooms and fish kills are already occurring as a result of climate change, but exacerbated further by eutrophication and increasing human pressures (e.g. Bannister et al., 2019).

5. CRITICAL COMPONENTS & PROCESSES

Building on the above ECD, this section scopes which key components, processes and services could be affected by development of the Project at Kranji reservoir. It also assesses how these aspects may change following development. The outputs from this section are used to inform limits of acceptable change and related monitoring recommendations, as well as to inform the related biodiversity impact assessment.

5.1 INTRODUCTION

This section adapts the typical ECD process to focus on the Project's development at Kranji Reservoir. In order to be able to assess potential impacts by the FPV on the Kranji Reservoir ecosystem, critical components and processes need to be identified that might be impacted by the FPV deployment. The following sections aim at identifying these components and processes, using models for conceptualization, including food-web dynamics.

5.2 CRITICAL COMPONENTS AND PROCESSES THAT MAY BE IMPACTED BY THE PROJECT

The following section attempts to simplify the findings based on the results of the desktop review and the Project's baseline survey results in order to conceptualise the Kranji Reservoir ecosystem.

Three broad trophic levels are assumed: primary producers, herbivores and aquatic carnivores. For each trophic level a review of key structuring forces is provided, followed by a summary of the baseline survey observations to support the concept model designed for Kranji Reservoir.

5.2.1 PRIMARY PRODUCERS

Primary production within Kranji Reservoir is driven by phytoplankton and macrophytes, and provides the food base for the majority of all other aquatic taxa within it. The phytoplankton and macrophytes rely on light, temperature and nutrients for growth.

Solar radiation is the major source of light and heat in the Kranji Reservoir. Light entering the Kranji Reservoir is captured by phytoplankton and macrophytes for photosynthesis or converted to heat by absorption by dissolved substances and particles. The depth to which light penetrates the water column is determined by the dissolved and suspended sediments. The maximum depth where net photosynthesis can occur is where light intensity is approximately 1% of surface intensity. This depth is called the compensation zone, above which is the photic zone (where photosynthesis > respiration) and below is the aphotic zone (where photosynthesis < respiration). At Kranji Reservoir, the limit of the photic zone varies throughout the Reservoir. Light available for photosynthesis below 3 m was found to be negligible during baseline measurements, however photosynthetic organisms were still found below that threshold. This suggests that outside the period of light measured for this study, there are times of greater water clarity where light penetrates to greater depth.

The reservoir has a shallow depth, meaning the majority of the water column and benthos are within the photic zone. Macrophytes were found recorded in deeper areas but these plants grow upwards to reach better light conditions whilst being rooted at depths where there is not enough light for photosynthesis.

Heat captured in the Reservoir is distributed by wind-generated currents to a depth of 3 -4 m.

The monthly sampled vertical depth water profiles suggest that daytime warming and stratified conditions followed by night time cooling and well mixed conditions occurs for most of the year. Stratification was not strong. A layer of plankton was observed around approximately 3-4 metres depth indicating that this mixing affects the distribution of phytoplankton in the Reservoir. Whilst not measured, it is also expected that diurnal mixing occurs too, with phytoplankton migrating vertically as light intensity changes during the day and night.

Seasonal temperature variations within Kranji Reservoir presents higher temperatures in March, April and May (inter-monsoon) than December or January (northeast monsoon). The monthly variation in temperature is relatively low (5ºC across the sampling period) due to its equatorial location. Given the Reservoir's tropical location, the seasonal effects of temperature variation on primary production are likely to be relatively small compared to waterbodies at higher latitudes, where stratification and circulation processes occur more strongly in response to larger seasonal variations in temperature.

In terms of nutrients, phosphorus (P) is understood to be the key determinant of primary production in freshwater ecosystems. It also affects the abundance of major phytoplankton and macrophyte taxa. Total phosphorus (TP) concentration (equivalent to an estimate of reservoir fertility) was found to be very high in the Reservoirs water column indicating (hyper-) eutrophic conditions (i.e. >100 ug/l). The benthic sediments were also high in P. As a eutrophic reservoir, primary production increases the pH of the water and thereby promotes P release from the sediment, which in turn promotes even higher primary production. The highest TP concentrations were recorded at the south of the reservoir (WQ05 in the Sungei Tengah, outside the Reservoir Project Site). Generally higher nutrient concentrations were recorded in southern areas compared to northern areas of the Reservoir.

The relative importance of individual abiotic factors to phytoplankton growth at Kranji Reservoir was investigated by Gin et al. (2011). Xing et al. identified that P is the limiting factor controlling the biomass of algae in the Reservoir. Increased (eutrophic) P concentrations resulted in higher abundances of phytoplankton, particularly during warmer weather between June and September (the southwest monsoon and when algal blooms occurred in 2005).

The Project's baseline study also observed nutrient pulses as a likely driver of change within the phytoplankton community. During the inter-monsoon (March, April and May 2021) the abundance of *Aulacoseira* spp. decreased and a shift in the phytoplankton community occurred with *Pediastrum* sp and *Staurastrum* spp. becoming more abundant. These latter species are typical of eutrophic conditions (Nicholls, 1997; Reynolds, 1980; Sitkowska, 1992; Pasztaleniec et al. 2004). A cause of this change is likely to be the increased input of P during the rainfall events, although Pediastrum are also known to pulse during the northern spring (Reynolds 1980) and this may explain some of the variation.

With regards to the driving forces for the distribution of phytoplankton in Kranji Reservoir, Xing et al. determined three key forces, in order of importance:

- Light – the main force driving stratification and mixing;
- Wind – causing turbulence and mixing; and
- Cold water inflows from the three rivers upstream.

Except for the latter (which was not measured specifically), the Project's baseline results appear to be partially explained by these processes. *Aulacoseira* spp. was the most abundant phytoplankton recorded and they proliferate in well-mixed conditions in nutrient rich waters with high P and silica availability (Hoetzel and Croome, 1994, 1996; Harris and Baxter, 1996; Sherman et. al., 1998). These species require regular, strong vertical mixing to maintain a larger, growing population and is at a competitive disadvantage in still conditions (Reynolds et al. 1986; Hoetzel and Croome, 1996; McCausland et. al., 2001). Thus, a reduction in mixing during the inter-monsoon period (March – May inclusive) could be another factor affecting *Aulacoseira* spp. abundance. With temperatures being cooler between December and February mixing may have been more pronounced and generated more suitable conditions for *Aulacoseira* spp.

To some degree, the distribution of phytoplankton may also be affected by macrophytes. Macrophytes provide structural complexity to the Reservoir and increase the diversity of attached algae by providing a structure to grow on (macrophytes also provide a refuge from predation for invertebrates and fish and a food resource waterfowl, etc.). The most abundant macrophyte recorded within the Reservoir is water hyacinth. Water hyacinth is known to have the following effects on phytoplankton and other macrophyte taxa (Wang and Yan, 2017):

- Reducing light incidence in the water column due to its floating matts, consequently reducing underwater light available for photosynthesis;
- Reducing nutrient concentrations and creating unfavourable nutritional conditions for growth and reproduction;
- Secreting compounds that inhibit growth; and
- For plankton, adsorbs individuals to its root system.

The prolific growth of water hyacinth between March to May 2021 inclusive is also likely to have resulted from the pulse of pollution (P input) to the Reservoir following storms events in March 2021. The increased abundance of water hyacinth may then have resulted in some (or all) of the competitive effects listed above and this may have also influenced the phytoplankton community.

Tilman et al (1986) found that phytoplankton communities are affected by a combination of factors, including temperature, stratification, nutrients and the effects of biotic interactions. From the Project's baseline results and the above analysis, it appears similar factors are influencing primary production at Kranji Reservoir, in summary:

- The high P concentrations are the key driver, releasing macrophytes and phytoplankton from nutrient limitations;
- Light drives the abundance and distribution of phytoplankton through physical effects on the water column (heating and mixing), with wind providing additional influence; and
- Biotic competition between phytoplankton and macrophyte taxa (and possibly within the same taxa) modify the abundance and distribution of primary producers too.

At Kranji Reservoir, temperature is unlikely to exert a major effect given the variation in daily and seasonal temperatures are relatively small due to the location of the Reservoir at a low latitude.

5.2.2 HERBIVORES

Herbivorous taxa considered here within the Reservoir are macroinvertebrates and fish which feed upon phytoplankton and/ or macrophytes. Particular focus is given to zooplankton. These species have a high grazing efficiency and can strongly influence the phytoplankton community in terms of biomass and species abundance. They are also an important food source for many fish. It should be noted that many zooplankton and fishes may be omnivores and eat other prey items besides phytoplankton. In addition, several other important taxa feed on phytoplankton including the juvenile life stages of numerous insects and amphibians (e.g. the nymphs of mayflies, caddisflies and Chironomids). However, for simplicity the following focuses on the activities of plankton-eating zooplankton and fish only.

ZOOPLANKTON

Zooplankton distribution is influenced by light intensity, turbulence, temperature and dissolved oxygen. Changes to the distribution and abundance are driven by shifts in the phytoplankton abundance (food availability), macrophyte community (habitat changes), and the density and composition of predators (Villamagna and Murphy, 2010).

The first three abiotic factors (light intensity, turbulence, temperature) have been described for Kranji Reservoir above for phytoplankton. In terms of dissolved oxygen, this is necessary for respiration. Dissolved oxygen variability is driven via mixing of the water column. Dissolved oxygen levels below the hypolimnion were recorded at <2 mg/L (at WQ02). Due to the eutrophic conditions in the Reservoir, the amount of organic material in the hypolimnion will be relatively large and, when reduced water column mixing occurs, the rate of oxygen depletion will be faster than were the Reservoir in a different trophic state.

The most abundant zooplankton herbivore within the Reservoir was the rotifer *Keratella* sp. Most rotifers are filter feeders and are generalist feeders, eating bacteria, algae and small ciliates. Filter-feeding rotifers are able to eat particles up to about 18 µm i.e. small algae. Their filtering capacity can be up to 1,000 times their own body volume per hour which means they incorporate a lot of food particles into their biomass which, as energy, can be used by organisms further up the food chain. Predatory rotifers such as Asplanchna, recorded in Kranji Reservoir in December 2020, March and September 2021, eat other rotifers and ciliates but also eat algae.

Daphnia sp were the most abundant crustacean zooplankton, whose abundance peaked during February and May 2021. Daphnia species are large, pelagic filter-feeders that mainly eat algae. They are generalist filter-feeders and, with a large acceptance of food-size, are less vulnerable to fluctuations in abundance of specific size-classes of food than other species, as alternative size classes can be grazed. Daphnia are able to tolerate the toxic effects of cyanobacteria and prey on these taxa (Gustafsson and Hanson 1994). However, at Kranji Reservoir, no relationship was observed between cyanobacteria abundance and Daphnia was observed.

The variation in abundance between *Keratella* sp and *Daphnia* sp in March and September 2021 is most likely caused by the heavy rainfall events which occurred during these monitoring periods. As mentioned above, Daphnia are sensitive to pollutants and are used as bioindicators for water pollution. There is a very strong negative correlation between monthly average abundances of *Keratella* sp. and *Daphnia* sp. (R^2 = 0.95), with the peak abundance of *Keratella* sp. coinciding with the complete absence of *Daphnia* sp. in March 2021, which may suggest increased pollution pressures during that month. This is also the likely cause for the absence of Daphnia in September 2021 when reservoir sampling occurred after a storm.

The effects of macrophyte abundance, including water hyacinth, on zooplankton are inconsistent, with some showing positive relationships and others negative (Villamagna and Murphy, 2010). This suggests that factors such as algal concentrations and fish predation may be more important factors driving zooplankton abundance and distribution.

PLANKTIVOROUS FISH

The drivers of the abundance and distribution of fish in reservoirs are light, temperature, the distribution of plankton (prey), and shelter for spawning or avoiding predation. In respect to the latter, small-sized fish are known to shelter in the littoral zone or deeper waters during the day to reduce predation risk, moving to pelagic areas at night to increase foraging opportunities (Arunjith et al., 2022).

Nine fish have been recorded within the Reservoir that graze on phytoplankton and macrophytes: Cichlidae, *Notopterus notopterus*, *Gambusia affinis, Trichopodus pectoralis, Oreochromis niloticus, Anabas testudineus, Osphronemus goramy, Clarias gariepinus,* and *Xiphophorus maculatus*. All of these fishes are generalist omnivores that also prey on a wide range of other taxa besides primary producers. This is typical of fish communities in lakes in the tropics which are characterised by a higher proportion of omnivores than temperate waterbodies (González-Bergonzoni et al., 2012).

Although the hydroacoustic sampling method does not allow for the location of these individual fish species to be determined, none are obligate herbivores that only graze phytoplankton and/ or macrophytes or have highly specialised diets restricted to certain taxa. The hydroacoustic survey results do indicate, however, that most fish activity was >3 m depth across the reservoir. These fish were therefore within the hypolimnion and the zone of low dissolved oxygen. Most likely these were smaller fish sheltering from predation during the day.

This Project's surveys were carried out at night when likely prey items such as phytoplankton (and zooplankton) move to the surface. Fish movement patterns during the day were not measured but will differ from that captured during surveys. It is likely fish movement will be reduced during the day, reflecting increased predation risk and decreased prey availability.

5.2.3 AQUATIC CARNIVORES

Primary aquatic carnivores within the Reservoir likely comprise taxa that eat other invertebrates, small fish and tadpoles. These include, for example, odonata, midges and the majority of water bugs.

Secondary aquatic carnivores are predominantly fishes. The community structure of fishes is likely driven by the availability of food, avoidance of predation and the abiotic conditions in the water (as per the herbivourous fish discussed above). Dissolved oxygen is a key limiting factor affecting the fish community. As mentioned above, most fish were found at deep depths where dissolved oxygen is expected to be limited, indicating the existing fish community comprises species that tolerate lower oxygen conditions (viz. snakehead and catfish species etc).

Moustaka-Gouni et al (2014) have shown that in tropical waterbodies, fish are able to feed and reproduce almost year round. This means fish are able to keep zooplankton grazer abundances relatively low and constant. By lifting the grazing pressure of zooplankton on phytoplankton, the effects of seasonal fluctuations on phytoplankton biomass are reduced in tropical waterbodies compared to temperate ones. This concurs with the assumption stated above that temperature probably has limited influence on primary production within Kranji Reservoir due to its tropical location.

Many of these aquatic carnivores may switch prey items and habitat use as they grow from juvenile to adult stages. Examples include odonata and fish. Fish may feed on zooplankton as a juvenile, then turn to benthic macroinvertebrates and when it reaches a larger size becomes piscivorous. The introduced (but globally EN) Asian arowana is a case in point. Young individuals feed on invertebrates at the surface whilst adults feed on fishes and smaller vertebrates. As mentioned above, smaller fish are likely to have been sheltering at deeper water depths whilst larger fish occupied shallower habitats during the night, notably in the southern of the reservoir.

5.2.4 TRANSFERS BETWEEN THE RESERVOIR AND TERRESTRIAL HABITATS

Nutrients and organic materials enter Kranji Reservoir via inflow rivers in the south and directly from adjacent terrestrial habitats, notably the NSRCC Kranji Sanctuary Golf Course and storm drains to the east from Sungei Kadut Industrial Estate (Kwik et al., 2020). These are the main pathways which drive the P concentration in the Reservoir (the other being via release from benthic sediment due to eutrophic processes and, to a lesser degree, following disturbance by benthic foragers).

Other transfers are facilitated by animals moving between aquatic reservoir habitats and terrestrial habitats, in particular birds, aquatic reptiles and otters. Bird taxa associated with the Reservoir include terns, herons, egrets and birds of prey. These birds feed primarily on fish. Compared to other freshwater organisms, these birds and mammals can easily leave and move around among different waterbodies in the area to forage, for example in response to changes in prey availability.

Birds which rest at the Reservoir, for example the black crowned night heron, may increase nutrient input to the reservoir, especially if the birds have been feeding in other habitats (Dessborn et al., 2016; Lim et al., 2021). However, given the frequency and number of herons roosting at the Reservoir it is unlikely that their inputs have any strong effects on primary and secondary production.

5.3 CONCEPTUAL MODEL OF KEY DRIVING FACTORS WITHIN THE KRANJI RESERVOIR

A conceptual model representing the above physical and ecological dynamics was developed to describe the key factors driving the structure and connections within the Kranji Reservoir (Figure 5-1). The model describes the key components and processes present in the Kranji Reservoir under the described baseline conditions, and builds on the four models presented in Section 3.9 above. These processes are built up from abiotic to biotic components.

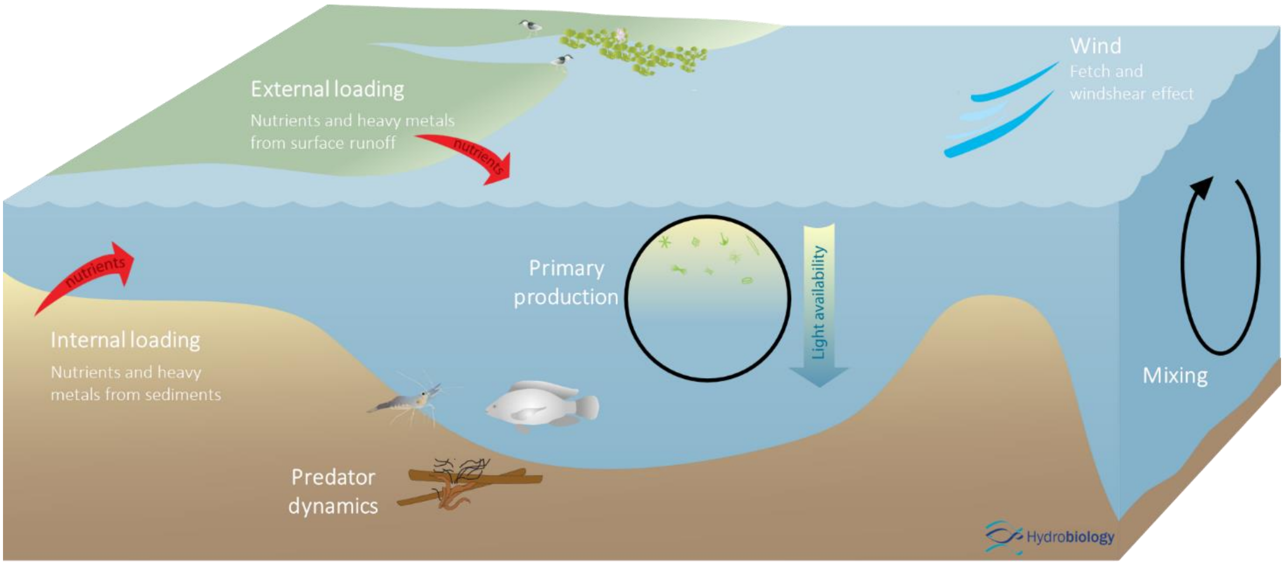


Figure 5-1 Model of key components and processes within existing Reservoir relevant to the Project.

5.4 SUMMARY

The abiotic and biotic conditions recorded at Kranji Reservoir by this Project's study generally concur with the findings of surveys carried out in 2005 (Xing et al., 2014) and in 2010 (Ng et al., 2010). All three studies report a eutrophic waterbody, dominated by high nutrient concentrations, turbid water and a relatively high number of invasive, non-native aquatic flora and fauna. Typically, under such eutrophic conditions with high primary productivity, species richness is reduced relative to waterbodies in lower trophic states (Dodson et al., 2000; Mittelbach et al., 2001).

At Kranji Reservoir, the high primary productivity is driven by nutrients which enter the Reservoir from external loading (surface run-off) and internal loading (via contributions from bottom sediments). It also appears to be driving the abundance and dominance of primary producing taxa. Light and inter- and intra-specific competition affects the distribution and abundance of these taxa too.

The structure of the herbivore community is driven by the same forces, although as heterotrophs, dissolved oxygen is an additional factor for these taxa and the remaining carnivore taxa. The community of herbivores and carnivores comprise generalist feeders meaning there is likely some flexibility in food choice should the structure of the community change. An important interaction between the macrophytes and higher trophic levels is that the vegetation provides a growth medium and refuge for a number of species. However, the macrophytes are actively managed and removed from the Reservoir given their invasive and prolific growth strategies.

5.5 CONCEPTUAL MODEL OF CONDITIONS FOLLOWING FPV DEPLOYMENT ON THE KRANJI RESERVOIR

The deployment of FPVs has consequences for water quality and the local ecosystem. Environmental impacts often depend on the design and proportion of the system relative to the size of the surface water, as well as the physical characteristics of the water system and climatic conditions. The following model (Figure 5-2) was developed to demonstrate how the development may result in changes to the key components and processes operating in the Reservoir and how those may cause alterations in food web dynamics.

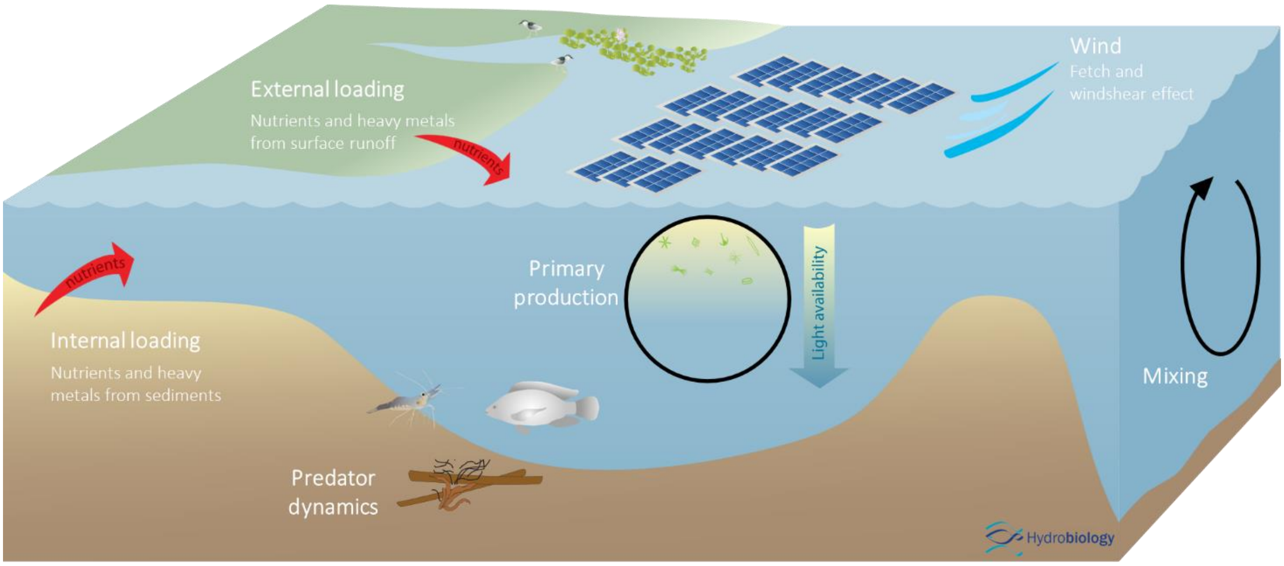


Figure 5-2 Key components and where key changes may occur in the Kranji Reservoir after the deployment of FPVs.

Wind was found to be one of the key driving forces for the distribution of phytoplankton in the Kranji Reservoir by Xing et al. (2014). Windshear, and fetch, across the reservoir surface create turbulence and stimulate the mixing of the water column. Limiting windshear across the Reservoir surface through the deployment of FPV systems may lead to reduced water column mixing as the low oxygenated water from the reservoir bottom is not exchanged with oxygen-rich surface water. Reduced mixing also may result in reservoir temperature modification and stratification; mixing layers are typically shallow. However, based on the Project team's understanding, temperature inversions occurring during diurnal cycles may be a larger driving force for mixing than wind in Kranji Reservoir. This would mean the risks associated from the FPVs reducing wind shear are less likely to occur or have a significant effect.

The major source of light and heat in the reservoir originates from solar radiation. The dissolved and suspended sediments determine the depth to which light penetrates the water column, i.e. the limit of the photic zone. By limiting light penetration, submerged macrophytes, found outside the photic zone, may experience reduced growth rates or result in the die-off of plants and phytoplankton in the littoral zones. Furthermore, reduced light penetration might inhibit the predation success of predatory species that rely on light to pursue and catch prey.

In a theoretical worse-case scenario, the installation of a FPV could result in reduced reservoir mixing and light penetration. If this occurred in combination with background increases in TP from runoff (unrelated to Project impacts) then these effects could promote anoxic conditions at the benthos. The anoxic conditions may consequently promote the release of phosphate from the sediment, further increasing TP concentrations. Such low oxygen and high TP conditions may then lead to cyanobacterial blooms in certain circumstances. However, this situation is considered unlikely to occur and has not been observed at other FPVs developed in Singapore, or elsewhere globally. This suggests the effects on mixing and light penetration are not significant enough to cause such worst-case scenarios. Water quality modelling carried out as part of the Project indicates dissolved oxygen concentrations at the benthos will not change significantly.

The drivers of the abundance and distribution of fish in reservoirs are light, temperature, the distribution of plankton (prey), and shelter for spawning or avoiding predation. Dissolved oxygen is also a key limiting factor affecting the fish community. Reduced phytoplankton richness in the reservoir caused by the FPV deployment, may lead to lower zooplankton diversity and abundances, which then influences the size class structure and abundances of predators, i.e. planktivorous fish and avian predators. Steinmetz et al. (2003) suggest avian predators consume certain size classes of the most abundant fish. Reduced food availability may therefore have an effect on bird breeding population sizes.

Besides the above potential negative effects of the FPV deployment there are some potential positive impacts which may occur within the ecosystem (De Lima et. al., 2021):

- Evaporation rates of water below the FPVs is reduced;
- Shading effect may lower (surface) water temperatures; and
- Submerged surfaces can get colonised by different organisms, such as filter feeders, and improve biodiversity and water clarity.

Further research is still required to achieve a complete understanding of the effects of FPVs on water quality at various locations and under different conditions. See Section 6.4 regarding recommended monitoring programme for the construction and post-construction phases of the Project.

Yang et al. 2022 investigated the impacts of an FPV system on hydrodynamics and water quality in the Tengeh and Poyan Reservoirs in Singapore, by combining a three-dimensional hydrodynamic-ecological reservoir model with field measurements and sampling.

The investigation indicated that:

- Small increase in surface water temperature beneath the PV panels by an average of 0.5°C;
- Surface-bottom temperature difference was a lot higher under panels than in open water, leading to increased stratification and stability;
- Overall decrease in mixing energy, taking wind shear into account;
- Greater water column stability;
- Increase in Total Nitrogen and Total phosphorus, especially near reservoir bottom below the panels; and
- Decreases in Chl-a, Dissolved Oxygen and Organic Carbon concentrations beneath the panels.

The Tengeh and Poyan Reservoir study sites are located at similar longitudes to the Kranji Reservoir. However, the characteristics of the water system in the Kranji Reservoir are very different to the Tengeh and Poyan Reservoir. Furthermore, field monitoring and sampling in the investigation by Yang et al. (2022) were only conducted over a 24 month period. As such, it must be emphasized that the effects observed in the investigation by Yang et. al. (2022) on the Tengeh Reservoir cannot be expected to be the same as the effects FPV deployment may have in the longer term on the Kranji Reservoir. However, should such effects present themselves in Kranji, the ecological changes arising from those are unlikely to significantly alter the state of the ecosystem.

6. LIMITS OF ACCEPTABLE CHANGE

This section presents the limits of acceptable change (LAC) for the key components, processes and services/ benefits of Kranji Reservoir based on available data.

6.1 BACKGROUND

LAC are defined as:

> “The variation that is considered acceptable in a particular measure or feature of the ecological character of the ecosystem. This may include population measures, hectares covered by a particular wetland ecosystem type, the range of a certain water quality parameter, etc. The inference is that if the particular measure or parameter moves outside the ‘limits of acceptable change’ this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed [or in this Project’s case its baseline values pre-development). In most cases, change is considered in a negative context, leading to a reduction in the values for which a site was listed” (Hale and Butcher, 2007).

The LAC may be equal to natural variability or may be set at some other value determined by appropriate responsible parties and/ or stakeholders. Determination of a LAC value is based on quantitative information produced by relevant monitoring programs, scientific papers, technical reports and other available information or input provided by ecosystem scientists and experts.

LACs are a tool by which ecological change can be measured. Once a LAC criteria is exceeded, or not met, it is likely that changes in ecosystem components, processes and services will occur, which can be difficult to reverse (e.g. reduction of species population), i.e. the ecological character could be approaching a tipping point.

Thus, the LACs are proposed to be used in this Project to set a sensible framework that will be integrated into the EIA process, in particular the EMMP, to proactively monitor ecosystem changes, provide early indicators and trigger the need for additional monitoring, investigation of the change, and the need and type of intervention required, so that adaptive management measures can be designed and implemented before significant impacts occur to features of conservation interest.

The relatively short data timelines available for Kranji Reservoir make the LAC process challenging, as longer term cyclical patterns may not be detected, resulting in an increased level of uncertainty in the data (Figure 6-1). Historical data for Kranji Reservoir is sparse and largely limited to the past decade. As a result, it is difficult to determine LAC's for this site and identify whether a LAC for any given parameter has been exceeded. Section 6.2 describes how LACs are derived within the information currently available, supplemented by information and guidance that is available here. Given the data limitations a precautionary approach to setting LACs (and related monitoring programme) has been adopted.

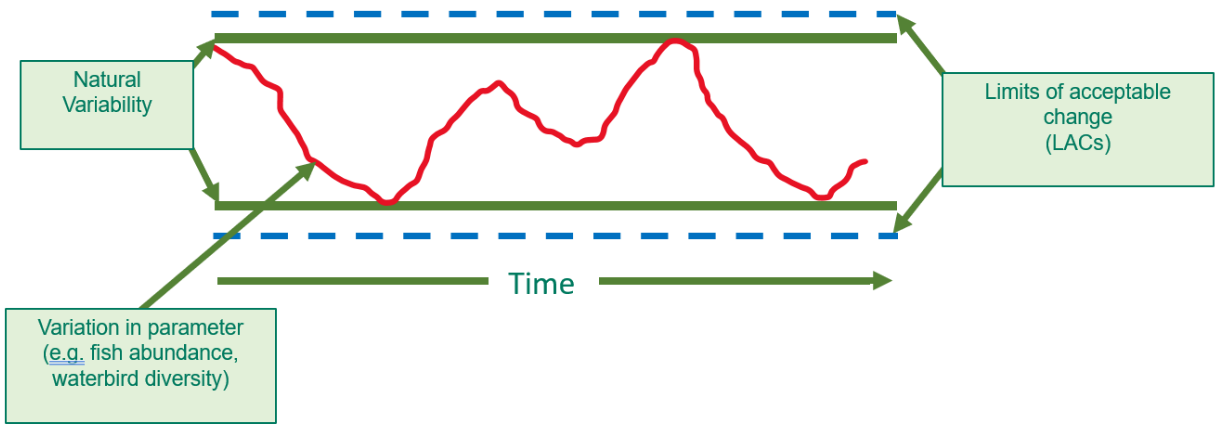


Figure 6-1 Example of natural variability and limits of acceptable change. Figure adapted from Phillips (2006).

6.2 DERIVATION OF LIMITS OF ACCEPTABLE CHANGE

6.2.1 NATURAL VARIABILITY AND PROBABILITY BASED LAC

DEFINING BASELINE CONDITIONS

As outlined in DEWHA (2008), LAC should be based on the known natural variability (over time) of a parameter. The LAC can then be set at the upper and lower bounds of that natural variability profile during the monitoring period. However, historical data on natural variability at Kranji Reservoir is largely unavailable. The work by Ng et al. (2010) found that the species richness and diversity of Kranji Reservoir was low at this time, despite relatively shallow waters throughout the reservoir area. Native species numbers of the dragonflies, molluscs, decapod crustaceans, and fishes were low due to the lentic nature of the reservoir, the lack of extensively shaded areas and the unsuitability of the water parameters (e.g. pH) and substrate. Both native and alien species were distributed uniformly through the reservoir. This result generally concurs with the results of the baseline studies carried out for this Project.

DEFINING BASELINE DATA QUALITY

The following typology can be used to characterise the baseline information required in deriving LACs (as defined in DEWHA, 2008):

- Level A – This type of LAC can be developed from data and/or information (such as water quality measurements, fish biomass) that has been reviewed and deemed to be sufficient for setting a LAC. This type of LAC is typically derived from long-term monitoring data.
- Level B – This type of LAC is derived from empirical data, but is unlikely to reflect the full extent of natural variability in time. This can include two sub-types:
  - repeated measurements but over a limited short term monitoring period.
  - single measurement (no temporal context) of habitat type extent, species abundance or diversity.
- Level C – This type of LAC is not defined by empirical data that describes patterns in natural variability. This can include two sub-types:
  - Based on a published or other reliable sources of information, such as personal correspondences with relevant scientists and researchers, or is taken from cited literature as part of management plans, journal articles or similar documents.
  - Where data sets and published information about the parameter are absent or limited, and the LAC has been derived based on the best professional judgement of the authors.

MEASURES USED TO DESCRIBE LAC

Depending on the LAC parameter that is being considered, several types of measures may be used to describe natural variability:

- Percentile values. The use of percentile values permit some change in the measured parameter, but still within the range of natural variability. Some common examples of this type of LAC include water quality and ecological indicator guideline values determined by statistical analysis of reference datasets.
- An allowable proportional change relative to a baseline value. While the use of percentile values to describe natural variability (and therefore LAC) is preferred, this cannot always be achieved due to data limitations (such as insufficient baseline data to derive percentile values), and/or in some cases it is not meaningful to use percentiles due to the behaviour of variability of the measured parameter (for example, some habitat type extents may demonstrate low natural variability).
- Broad ecosystem state and function. This type of LAC is based on a regime shift in an ecosystem from one state to another or on the basis of the ecosystem being able to continue providing a particular function (such as provision of breeding habitat). An example of this type of LAC is a change in the abundance of a particular ecosystem type. This type of LAC includes a diverse range of indicators, and specifically addresses ecosystem end-points that can be directly related to high level key components and services.

LACS can be defined across a range of variable timescales that includes several decades (DEWHA, 2008). This period takes into consideration the frequency of large-scale climatic phenomena that impact the site, such as extreme El Niño–Southern Oscillation (ENSO) events which occur over an approximate twenty year interval (Cai et al., 2014) and is therefore ecologically meaningful in the interpretation of climatic processes that impact the site. A timescale of ten years is commonly chosen, rather than a twenty year timescale, since the twenty year period is deemed too long term to facilitate management intervention, if required. Sampling events typically require a minimum of three events separated by at least 2 year intervals. This is to ensure the complete range of natural variability is accounted for.

LACs should also be developed in consultation with relevant stakeholders interested in the Reservoir management, its values and uses. This process is anticipated to take place through engagement of relevant Government Agencies/ Authorities as part of the EIA and EMMP process, as well as being informed through the broader stakeholder engagement and disclosure for the Project's EIA.

6.3 LIMITS OF ACCEPTABLE CHANGE

Seven LACs have been determined based on the available baseline findings (Table 6-2).

In most cases, the biological LAC in the current study have been subjectively derived (Level C) based on the best scientific judgement of the authors. This is due to:

1. A recently detailed, but limited time series, data set for key parameters such as ecosystem condition and extent, waterbird usage, fish usage and environment condition (both geographically and temporally) since the reservoir was formed; and
2. The general lack of scientific knowledge about the response of particular species and habitats to multiple stressors (for instance a combination of water quality variation), infrastructure (i.e. FPV deployment) and habitat availability.

For each LAC a confidence level is estimated using the following scale:

- High – Quantitative site specific data; good understanding linking the indicator to the ecological character of the site; LAC is objectively measurable.
- Medium – Some site specific data or strong evidence for similar systems elsewhere derived from the scientific literature; or informed expert opinion; LAC is objectively measurable.
- Low – no site specific data or reliable evidence from the scientific literature or expert opinion, LAC may not be objectively measurable and/ or the importance of the indicator to the ecological character of the site is unknown.

As it is predominantly the physical components (e.g. light and temperature etc.) and chemical components (e.g. nutrients, oxygen etc.) of the Reservoir that determine what lives and breeds in it, many LACs focus on these aspects. However, biological structuring processes such as predation and competition also occur and accordingly LACs for these aspects are also proposed; e.g. fish biomass monitoring and counts of piscivorous bird species.

Light levels have not been included as a particular LAC, however, as these do not reflect the ecological conditions in the Kranji Reservoir. Rather, light influences other measurable ecological drivers, such as phytoplankton and macrophytes dynamics and water temperature etc. As such, focus was put on monitoring the parameters which *depend* on light availability. Notwithstanding this, light is recommended to be measured as part of the LAC monitoring programme (translated into the EMMP) in order to allow analysis of changes in light conditions to any other effects, should they occur.

6.3.1 LAC BASELINE AND DISCUSSION

LACs have been set for the Kranji Reservoir based on the conditions identified in the baseline study. Where possible, site specific information has been used to determine LACs. In the absence of, or a lack of, sufficient site specific information, LACs were based on recognised standards or from relevant scientific literature or good practice industry guidelines. The following section elaborates on the determined LACs reported in Table 6-2 and Table 6-3 (LAC monitoring), based on the current baseline findings, and the established benchmarks for components of the EIA.

LAC 1 – KEY COMPONENT/ PROCESS; RESERVOIR WATER TEMPERATURE

Changes in surface water temperatures in proximity to the FPV are a potential impact as a result of the introduction of a FPV system on Kranji Reservoir. The FPV system will increase shading, reducing solar radiation, while the reduced wind speed results in reduced back radiation and evaporative heat loss from the water surface, thereby trapping more heat in and thus the heating of surface waters. Impacts on water temperature also influence the phototrophic organisms, and consequently limits dissolved oxygen production and disrupts the food chain (De Lima et. Al., 2021). Water temperature impacts of an FPV system will vary with incoming solar radiation, which can fluctuate dynamically across daily and seasonal scales depending on the geographic location of the water body (Exley et al., 2021).

Kranji Reservoir has a mean annual temperature of 27°C with mean monthly temperatures ranging between 26.2°C in January and 27.8°C in May. The Project's baseline study measured a range of 25.7°C to 31.7 °C and a peak of 35.7°C in water surface temperature. The hydrodynamic modelling suggests the water temperature under the FPV area will warm up by about 0.2°C when compared to the case without FPV.

The guidance criteria set by PUB for change in water temperature across the whole water column is 0.3°C, and hence this is set as the LAC criteria.

LAC 2 – KEY COMPONENT/ PROCESS; NUTRIENTS

The empirical data suggests Kranji Reservoir is a eutrophic system, where nutrients, are readily available. In temperate lakes, algal scums and low macrophyte abundance are already observed when TP ranges between 0.19 – 0.38 mg/L (Gibson et al., 2000), and because of the differences in temperature of tropical freshwater systems, thresholds are assumed to be lower in tropical freshwater systems. Nutrient enrichment experiments performed in the laboratory suggested that Kranji Reservoir was P-limited in 2011 (Gin et al., 2011), although algal bloom events that occurred after 2011, and the baseline results from this Project's surveys, indicate the reservoir is no longer P-limited. Experiments by Gin et al. (2011) have estimated that compared to nitrogen, relatively larger proportions of P are released from sediments at Kranji Reservoir. Acceptable nutrient levels for Kranji Reservoir can be determined based on thresholds for different trophic states. Historical data produced by Appan (1994) identified a shift in trophic states at Kranji Reservoir when the concentration of dissolved P at that time had increased to 0.33 – 1.22 mg/L. Thus the LAC criteria proposed seeks establishing alert levels for TP and TN, given the sensitivity of the system to trophic change.

The mean and 75th percentile total phosphorus concentrations recorded over a six month period for this project was 0.06 mg/L (5 sites, 0.5m above reservoir bed), with a 95th percentile of 0.15 mg/L. To prevent any potential shifts in trophic states two-tier alert levels are proposed in discussion with PUB, during construction and operation, i.e. 75th and 95th percentiles of baseline values, based on latest baseline data sets from PUB, within an agreed time period, for Kranji Reservoir. Exact levels are to be agreed with PUB closer to the commencement of construction and operational stages.

LAC 3 – KEY COMPONENT/ PROCESS; PLANKTON

The impacts of FPVs on plankton population abundance and species richness are pivotal as they are the food source for all higher trophic levels, and some plankton exert a considerable influence over water quality (Exley et. Al., 2021).

This Project's baseline study identified a total of 13 taxa of phytoplankton (belonging to 6 phyla) and 14 taxa of zooplankton (belonging to 3 phyla) during monthly water quality sampling carried out over 6 months from Dec 2020 to May 2021; with an additional reservoir sampling event carried out in September 2021 to capture storm event conditions in the Kranji Reservoir. Based on these findings and in discussion with PUB, it is proposed that the LAC criteria are set based on any large deviations that exceed those normally found by PUB in abundance of species that are indicative of eutrophic waters should be a trigger for more frequent monitoring surveys and investigation. Follow up investigation should ensure that sampling is representative of the whole project and includes sampling locations both along the shoreline and sites further away from the shoreline where water depth is likely to be greater. Sampling method should be consistent throughout, and replicates expected to produce similar results. This is assuming species composition reflects the abiotic conditions, including light availability, within the Reservoir and allow sufficient early warning to take action if the species composition of plankton in Kranji Reservoir changes substantially.

LAC 4 – KEY COMPONENT/ PROCESS; SUBMERGED AQUATIC VEGETATION

Submerged aquatic vegetation forms part of the base of the food chain (along with phytoplankton- see LAC 3 above) and provides a notable food source and habitat for fauna utilising the reservoir (e.g. invertebrates, fish, and herbivorous waterbirds). It also provides foraging habitat for insectivorous and piscivorous birds. Submerged vegetation mapping by sonar estimated approximately 108 ha of submerged vegetation was present in Reservoir Project Site at the time of survey, plus 13.6 ha of inaccessible areas within the Reservoir Project Site. A LAC criteria is proposed for continued persistence of submerged aquatic vegetation somewhere within the Reservoir Project Site and vicinity, e.g. including shoreline buffers, subject to reservoir operational requirements to ensure FPV system and reservoir operations are not impeded.

LAC 5 – KEY COMPONENT/ PROCESS; FISH BIOMASS AND SIZE CLASS

Changes in Kranji Reservoir are expected to have an impact on the biomass of fish present. Work has been done on fish habitat mapping and identification of fish species present in Kranji Reservoir. However, relatively few data are available for fish biomass in Kranji Reservoir. This Project's baseline work shows current water quality of Kranji Reservoir is acceptable for supporting a relatively high biodiversity of fish fauna, albeit mostly non-native and invasive species. However, it is assumed that if one or multiple LACs identified in this work are exceeded, then the result will be an undesirable decline in fish biomass.

For the purpose of setting LACs for fish biomass, fish tracks [8] can be used as a proxy for fish biomass. The hydroacoustics data carried out for this Project indicate fish tracks were detected in approximately 24% of the Reservoir Project Site survey area. Based on these findings, in discussion with PUB and professional judgement, it is proposed that the LAC criteria be set at a fish biomass (fish tracks) reduction no more than 50% for of baseline values (based on high levels of natural variation reported in other reservoirs) across Reservoir Project Site, to trigger a need for further monitoring and, if necessary adaptive management, before there is a loss of fish biomass and activity. Greater biomass in deeper parts of the reservoir and to the south of the Reservoir Project Site.

LAC 6 – KEY COMPONENT/ PROCESS; FOCAL BIRD SPECIES AND OVERALL WATERBIRD COMMUNITY

Sixteen focal bird species use the reservoir as a foraging habitat and are dependent on food availability, primarily fish. The piscivorous focal bird species are likely to be impacted by changes in the reservoir system if fish availability decreases. The overall wetland bird community could also be affected by broader changes to the system, including prey availability but also changes to habitat structure and function.

Two LACs are proposed for the bird community. Significant changes beyond these numbers would exceed the LAC. Results to be based on 12 months of data (e.g. Jan - Dec).

The LAC criteria are:

---

[8] The number of tracks detected corresponds to the quantity of individual fish (of any size/weight) identified by the software on the transects performed.

a) Foraging by focal bird populations to not fall below average count number recorded during baseline surveys (excluding occasions when birds were not present), and control site(s) (if any), e.g. if species X was present in July (max. 3 foraging birds), October (max. 10 foraging birds) and November (max. 5 foraging birds), the minimum count target would be 6 (i.e. 3+10+5=18; 18 /3 months = 6 average count number of foraging observations. Annual average not to fall below 6). Refer to Table 6-1 below for species-specific targets.

b) Waterbird assemblage to not fall below average number of species recorded during baseline surveys and control site(s) (if any). The average number is 8 species (the average number of waterbirds (excluding any raptors) recorded between May 2021 and October 2021, when the entire extent of the western and eastern bank was covered during baseline surveys).

Table 6-1 Minimum Target Counts for Focal Bird Species over 12 months

Scientific Name	Common Name	Maximum number of birds observed in any month	Maximum monthly count	No. of months observed in Baseline VPS survey	LAC – Average number of birds observations (sum of max. counts/no. of months observed), rounded up
Haliaeetus leucogaster	White-bellied sea eagle	2	18	15	2
Haliaeetus ichthyaetus	Grey-headed fish eagle	1	1	1	1
Haliastur indus	Brahminy kite	3	13	11	2
Pandion haliaetus	Western osprey	1	8	8	1
Ardea purpurea	Purple heron	2	19	15	2
Ardea cinerea	Grey heron	2	8	7	2
Ardea alba	Great egret	3	8	6	2
Ardea intermedia	Intermediate egret	14	55	16	4
Egretta garzetta	Little egret	21	67	15	5
Bubulcus coromandus	Eastern cattle egret	1	1	1	1
Butorides striata	Striated heron	5	29	14	2
Ixobrychus sinensis	Yellow bittern	2	7	5	2
Chlidonias hybrida	Whiskered tern	7	14	4	4
Chlidonias leucopterus	White-winged tern	3	3	1	3

Scientific Name	Common Name	Maximum number of birds observed in any month	Maximum monthly count	No. of months observed in Baseline VPS survey	LAC – Average number of birds observations (sum of max. counts/no. of months observed), rounded up
Sternula albifrons	Little tern	15	60	11	6

LAC 7 – KEY COMPONENT/ PROCESS; FOCUS SPECIES OF HIGH CONSERVATION CONCERN

Species dependent, or partly dependent, on the reservoir with a high (VU), very high (EN) or extremely high risk (CR) of extinction in Singapore (based on Singapore Red Data Book v3) are key biodiversity values that are key characteristics of Kranji Reservoir These include: the black-crowned night heron, grey-headed fish eagle and smooth-coated otter. The Project is likely to affect the foraging habitat used by these species.

The LAC criteria proposed for these species are:

a) Continued presence of black-crowned night heron (nationally EN) roost, detected on at least two occasions each year, 6 months apart.
b) Continued sighting within Kranji Reservoir and/ or active use of nest by grey-headed fish eagle (nationally VU) at Sungei Kadut Forest during this species' breeding season.
c) Continued foraging of smooth coated otter (nationally EN) within Kranji Reservoir and immediately surrounding habitats.

Table 6-2 Limits of Acceptable Change (LAC)

No.	Key Component / Process	Justification	LAC Criteria (against which further investigation is recommended)	Confidence Level* (based on professional judgment, refer text above for criteria)	Secondary Key Components / Processes or Services addressed through this LAC
1	Reservoir Water Temperature	Temperature governs the kinds and types of aquatic life, it partly regulates the maximum dissolved oxygen concentrations, mixing within the Kranji Reservoir and influences the rates of chemical and biological reactions, as well as the toxicity of chemicals. Temperature could be increased via the presence of the FPVs and also climate change effects.	Not more than >0.3°C increase in temperature throughout the whole water column (PUB guideline criteria). Alerts (% of agreed baseline data): - Level 1: 75th-percentile = investigation into cause (both construction and operation) - Level 2: 95th-percentile = cease works (during construction) and implement mitigation agreed with relevant stakeholders (during operation).	Medium	• Surface water quality • Fish fauna • Macrophyte growth rates • Phytoplankton and Zooplankton • Reservoir mixing & stratification
2	Nutrients	The empirical data suggest Kranji is a eutrophic system, where nutrients, in particular phosphorus (P), are readily available. Nutrients entering the reservoir, via surface runoff, appears to be driving the abundance and dominance of primary producing taxa and a main determinant of primary production. Nutrients could be affected by disturbance of the benthos during construction and run-off from the catchment.	Two-tier alert levels are proposed in discussion with PUB, during construction and operation. Limits will be based on latest baseline data sets, within an agreed time period, from PUB in Kranji Reservoir. Exact limit levels are to be agreed with PUB closer to the commencement of construction and operational stages. Parameters (monitored as part of a suite of parameters to be agreed with PUB): - Total Phosphorous (TP) - Total Nitrogen (TN) Alerts (% of agreed baseline data): - Level 1: 75th-percentile = investigation into cause (both construction and operation) - Level 2: 95th-percentile = cease works (during construction) and implement mitigation agreed with relevant stakeholders (during operation)	High	• Surface water quality • Fish fauna • Macrophyte growth rates • Phytoplankton and Zooplankton • Recreation (fishing, visual amenity)
3	Plankton	Zooplankton and/ or Phytoplankton serve as indicators of environmental conditions, trophic status, and maximum photosynthetic rates, and are sensitive to changes in water quality in the Kranji Reservoir, either as a result of the FPV or pressures from the catchment.	Large deviations that exceed those normally found by PUB in abundance of species that are indicative of eutrophic waters should be a trigger for more frequent monitoring surveys and investigation, where appropriate. Follow up investigation should ensure that sampling is representative of the whole project and includes sampling locations both along the shoreline and sites further away from the shoreline where water depth is likely to be greater. Sampling method should be consistent throughout, and replicates expected to produce similar results.	High	• Surface water quality • Fish fauna • Macrophytes

No.	Key Component / Process	Justification	LAC Criteria (against which further investigation is recommended)	Confidence Level* (based on professional judgment, refer text above for criteria)	Secondary Key Components / Processes or Services addressed through this LAC
4	Submerged aquatic vegetation	Submerged aquatic vegetation forms part of the base of the food chain (along with phytoplankton – see LAC 3 above) and provides a notable food source and habitat for fauna utilising the reservoir (e.g. invertebrates, fish, herbivorous waterbirds). It also provides foraging habitat for insectivorous and piscivorous birds. Vegetation in the top 1m of the water column will be trimmed as part of the construction phase (vegetation will be retained below 1 m depth). Subsequently shading of aquatic vegetation will occur under the FPVs.	Continued persistence of submerged aquatic vegetation somewhere within the Reservoir Project Site and vicinity, e.g. including shoreline buffers, subject to reservoir operational requirements to ensure FPV system and reservoir operations are not impeded.	Low	• Water quality • Fish fauna • Habitat for biota
5	Fish biomass and size class	Changes in Kranji Reservoir water quality may have an impact on the biomass of fish species present in the reservoir.	Fish biomass reduction no more than 50% of baseline values (based on high levels of natural variation reported in other reservoirs and professional judgement) across Reservoir Project Site[9]. Greater biomass was recorded in deeper parts of the reservoir and to the south of the Reservoir Project Site.	Medium	• Fish fauna • Recreation (fishing) • Nature conservation (Bird habitat preservation) • Terrestrial fauna
6	Focal Bird Species and overall waterbird community	Migratory and resident waterbirds use the reservoir as a foraging/ nesting/ roosting ground and are utilising the natural resources there. Potential to be impacted by changes in the system, including prey availability but also changes to habitat structure and function, as well as the change of ecosystems/ habitats outside the Kranji Reservoir.	Foraging by focal bird populations to not significantly fall below average count number recorded during baseline surveys and control site(s) (if any). Refer to Table 6-3 below for species-specific targets. This includes species of conservation concern and others representative of the bird community. Waterbird assemblage to not significantly fall below average number of species recorded during baseline surveys and control sites(s) (if any). The average number during baseline surveys is 8 species.	High	• Nature conservation • Recreation (bird watching)
7	Focus Species of High Conservation Concern	Species dependent, or partly dependent, on the reservoir with a high (VU), very high (EN) or extremely high risk (CR) of extinction in Singapore (based on Singapore Red Data Book[10]). These species are likely to be affected by loss of foraging habitat, decreased prey abundance and changes within the wider catchment.	Continued presence of black-crowned night heron (nationally EN) roost, detected on at least two occasions each year, 6 months apart. Continued sighting within Kranji Reservoir and/or active use of nest by grey-headed fish eagle (nationally VU) at Sungei Kadut Forest during this species' breeding season. Continued foraging of smooth-coated otter (nationally EN) within Kranji Reservoir and immediately surrounding habitats	High	• Nature conservation • Recreation (bird / wildlife watching)

9 Based on assumed level of tolerance to change.
10 Singapore Red Data Book status of species as of 28 July 2023. This may be subject to change.

6.4 MONITORING

6.4.1 MONITORING APPROACH

Monitoring of LACs will be fundamental to the adaptive management of the environmental impacts of the Project during its pre-construction, construction and operational phases.

Through this ECD (and related EIA), key monitoring recommendations of critical ecosystem components (both biotic and abiotic) are proposed (see Table 6-3). It is recommended that monitoring programmes are carried out:

- Throughout construction, and
- Initial three years post-construction (i.e. initial operation).

At the end of this initial three years post-construction period, a review is recommended to be undertaken in consultation with relevant Government Agencies/ Authorities, and stakeholders, where appropriate.

The objective of the review would include, but not limited to, the following:

- Confirm the significance of impacts predicted in the EIA;
- The data trends against the LAC criteria;
- Whether the LAC criteria are being met or not;
- The cause of any changes in LAC criteria;
- If change, if any, is attributable to the Project, or not;
- Whether adaptive management actions have been carried out, and their success,
- Whether future management actions are required (and the responsible party for those actions, including relevant responsible Government Agencies/ Authorities if causes of LAC exceedance is not attributable to the Project); and
- Whether ongoing monitoring is required, and if so, whether changes, or refinement, to the monitoring programme are necessary. It is anticipated that within three years of post-construction operation any variation in site conditions as a result of the FPVs will be detected and inform the need for any ongoing monitoring after that time or not.

The review should take account of any new information, monitoring results (e.g. throughout construction and initial three years post-construction), or changes in the conservation context of the site. Any monitoring programme upon decommissioning should be reviewed in advance of decommissioning commencing.

The LAC monitoring protocol is described in Figure 6-2. The monitoring programme for the LAC are summarised in Table 6-3.

6.4.2 LAC MONITORING PROTOCOL

LACs and related monitoring programmes provide early indicators to enable effective adaptive management, if required. The Developer/ Owner will take responsibility for managing effects identified to be directly attributable to impacts from the Project.

Should any notable deterioration or adverse trend in the LACs and monitoring data be observed, the cause should be notified to relevant Government Technical Agencies/ Authorities and investigated. The investigation should determine whether or not the observed deterioration/ trend can be attributed to the construction or operation of the Project. If affirmative, the cause of the events should be reviewed and adaptive management through targeted mitigation. The Developer/ Owner should liaise with relevant Government Technical Agencies/ Authorities closely on monitoring results and investigation findings and seek agreement on management action(s) which may include potential layout changes, removal of the FPV etc where appropriately agreed between responsible agencies and the Developer/ Owner. Where observations are not attributable to the Project, the Developer/ Owner will liaise with relevant Government Agencies responsible for managing the identified effect for their action. The LAC monitoring protocol flow is depicted in Figure 6-2.

The details of monitoring programme and relationship to each LAC are set out in Table 6-3, the details of which should be finalised and agreed with relevant Government Technical Agencies/ Authorities prior to the commencement of construction.

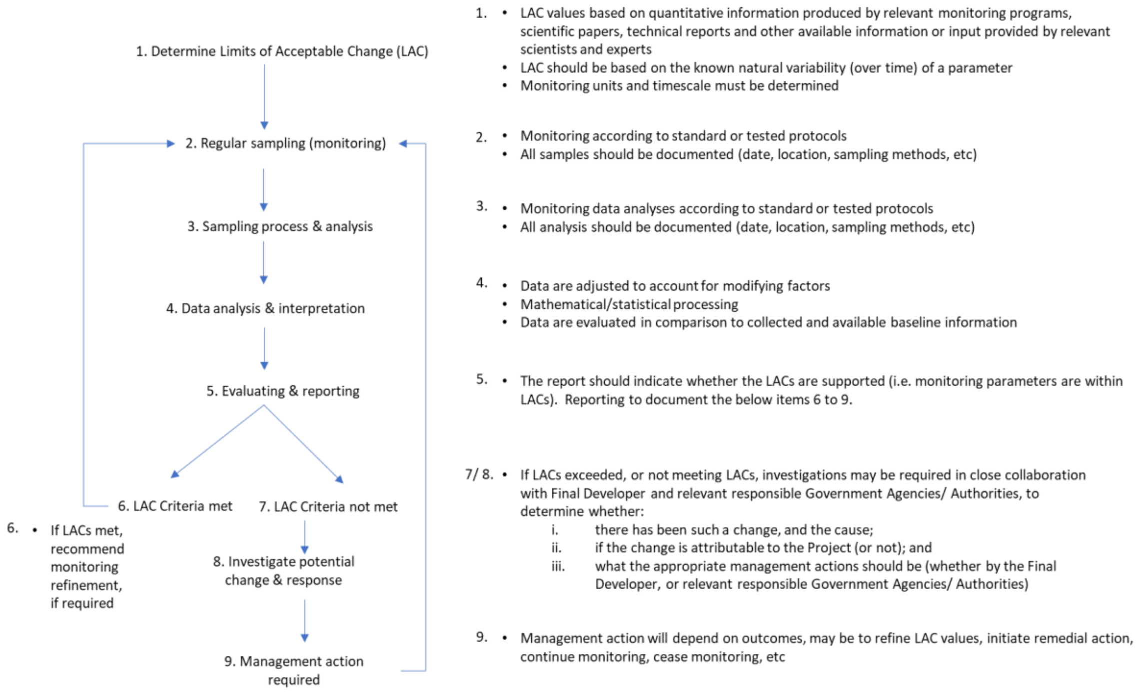


Figure 6-2 Monitoring Protocol of LACs (adapted from the Monitoring & Reporting Guidelines and the framework for designing a wetland monitoring program adopted by the Ramsar Wetland Convention (Ramsar Convention 1996, Finlayson 1996))

Table 6-3 Recommended Monitoring for LAC

No.	Aspects	Project Phase (PC, C, O[11])	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
1	Surface Water Quality (physio-chemical)	PC, C, O	Temperature (°C)	In-situ measurement via calibrated YSI probe, 0.5 m below water surface, mid-depth, and 0.5 m above reservoir bed. Water sampling for lab analyses will be carried out at mid-depth and 0.5 m above the reservoir bed. Vertical profiles using Fine Scale instrument at <0.1m vertical resolution using Fine Scale profiler (e.g. high end YSI or Seabird). Temperature probe to detect 0.1 °C differences. All equipment to be calibrated according to manufacturer's guidelines. Analysis completed at accredited laboratory. Also, continuous online monitoring meters at multiple locations (at least three locations).	At least 3 months pre-construction Monthly throughout construction Post-construction monitoring monthly for initial three years. Online water quality profilers will be used throughout the abovementioned periods and throughout operation (including decommissioning).. Reassess frequency/ duration and location after initial 3 years post-construction. Locations to be confirmed with relevant Government Agencies/ Authorities based on final design.	Developer/ Owner	Informs LAC 1. Temperature informs LAC accuracy. Reporting of trends, monthly during construction and monthly during operations. Compare data against meteorological data and any available complementary biological monitoring (e.g. plankton) Supplement data set with ongoing PUB water quality monitoring results If guideline or LAC criteria not met, then investigation process to be initiated (which may include additional water quality parameters not listed).. LAC 1 Criteria: Not more than >0.3°C increase in temperature throughout the whole water column (PUB guideline criteria). <3 mg/L for dissolved oxygen
2	Light penetration into water column	PC, C, O	Light (PAR)	Self-cleaning PAR logger Underwater PAR to facilitate Extinction coefficient (cf with Secchi depth measurements) All equipment to be calibrated according to manufacturer's guidelines. Analysis completed at accredited laboratory. Regularly serviced for cleanliness, power, malfunctions Deployment of paired loggers (for failsafe and data correlation) deployed coincidentally under 3 scenarios at depth of 1m:	Continuous measurements taken during daylight hours every 10 minutes At least 3 months during Pre-Construction Throughout construction - Reassess the number of sites after the first 6 months of construction. If there is little variability between the then consider reducing number of PAR loggers. 6-monthly post-construction for three years Reassess frequency/ duration and location after initial 3 years post-construction.	Developer/ Owner	Informs LAC 4 & 5. Reporting of trends, monthly during construction and 6 monthly during first 3 years of operations. Compare against meteorological data and any available complementary biological monitoring (e.g. plankton).

11 PC = Pre-Construction, C = Construction, O = Operation.

No.	Aspects	Project Phase (PC, C, O[11])	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
				- Beneath panel array - Within corridors between panel arrays - Distant from panel arrays and other shading factors - At 1 site within each scenario, additional paired loggers deployed at 2m depth. - N= 14 loggers (at 1m) 6 loggers (at 2m) + another pair deployed above water surface away from shading factors = 20 loggers Regularly serviced for cleanliness, power, malfunctions Number of sites could be reassessed after the first 6 months of construction. If little variability between the replicates then consider reducing to 1 site per scenario instead of 2 to 3.	Locations to be confirmed with relevant Government Agencies/ Authorities based on final design		
3	Nutrients	PC, C, O	Nutrients (TP, TN and TOC)	Water sampling can be carried out and reported alongside S/N 1, if appropriate All equipment to be calibrated according to manufacturer's guidelines. Analysis completed at accredited laboratory. Supplement with data from ongoing PUB WQ monitoring program	At least 3 months pre-construction Monthly throughout construction Monthly post-construction monitoring for three years monthly for total nitrogen, total phosphorous and TOC Reassess frequency/ duration and location after initial 3 years post-construction, as monitoring may be able to taper off once biotic and abiotic relationships is well established/ understood. Locations to be confirmed with relevant Government Agencies/ Authorities based on final design	Developer/ Owner	Informs LAC 2. TP concentration informs LAC accuracy. Reporting of trends, monthly during construction and monthly during first 3 years of operations. Compare TP trends against any water quality monitoring data, meteorological data and any available complementary biological monitoring (e.g. plankton). Supplement data set with ongoing PUB water quality monitoring results If guideline or LAC criteria not met, then investigation process to be initiated. LAC 2 Criteria: Two-tier alert levels are proposed in discussion with PUB, during construction and operation, based on latest baseline data sets from PUB, within an agreed time period, for Kranji Reservoir. Exact levels are to be agreed with PUB closer to the commencement of construction and operational stages. Parameters: - Total Phosphorous (TP) - Total Nitrogen (TN)

No.	Aspects	Project Phase (PC, C, O[11])	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
							Alerts (% of agreed baseline data): - Level 1: 75th-percentile = investigation into cause (both construction and operation) - Level 2: 95th-percentile = cease works (during construction) and implement mitigation agreed with relevant stakeholders (during operation)
4	Sediment Quality	PC, C, O	Nutrients, contaminants/metals and hydrocarbons	Sediment sampling via Ekman grab sampler Analysis completed at accredited laboratory.	A single sample event during pre-construction at various locations At least one sampling event within 24 hours after unplanned event (spill) during construction or operation. Additional monitoring as per unplanned event, as agreed with relevant Government Agencies/ Authorities Locations to be confirmed with relevant Government Agencies/ Authorities	Developer/ Owner	Monitoring to be included in Spill Prevention and Emergency Response Plan, including unplanned event management process.
5	Plankton	PC, C, O	Zooplankton and/or Phytoplankton	Method to be aligned with PUB's existing survey method statement, I.e. 1L water sample collection at 0.5m from water surface without the use of plankton net, alongside water sampling programme. • Supplement with PUB ongoing monitoring program data	At least 3 months pre-construction Monthly throughout construction Quarterly post-construction for three years Reassess frequency/ duration and location after initial 3 years post-construction. Locations to be confirmed with relevant Government Agencies/ Authorities	Developer/ Owner	Informs LAC 3 & 4. Reporting of trends, monthly during construction and quarterly during first 3 years of operations. Compare against water quality (chlorophyll-a) measurements (fluorescence-based spectrophotometer and lab analysis) and meteorological data and any available complementary monitoring. Supplement with PUB ongoing monitoring program data If guideline or LAC criteria not met, then investigation process to be initiated. LAC 3 Criteria: Large deviations that exceed those normally found by PUB in abundance of species that are indicative of eutrophic waters should be a trigger for more frequent monitoring surveys and investigation, where appropriate. Follow up investigation should ensure that sampling is representative of the whole project and includes sampling locations both along the shoreline and sites further away from the shoreline where water depth is likely to be greater. Sampling method should be consistent throughout, and replicates expected to produce similar results.

No.	Aspects	Project Phase (PC, C, O[11])	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
6	Fish	PC, C, O	Fish biomass & size class	Hydroacoustic survey A minimum of ten tracks around the reservoir edges and access between panels repeated using the same technique as Baseline surveys (as allowed within final project footprint) to determine whether biomass is increasing or decreasing. Location of tracks that will be assessed to be based on final FPV layout. Consideration to be given to ongoing PUB management of aquatic vegetation outside of Reservoir Project Site (subject to further discussions between PUB and the Developer/ Owner)	A single sample event during pre-construction Annually throughout construction in areas that are accessible Annually for three years post-construction. Reassess frequency/ duration and location after initial 3 years post-construction, as monitoring may be able to taper off once biotic and abiotic relationships is well established/ understood. Locations to be confirmed with relevant Government Agencies/ Authorities	Developer/ Owner	Informs LAC 4 & 5. Reporting of trends, annually during construction and three years post-construction. Compare to fish biomass data from previous years. If guideline or LAC criteria not met, then investigation process to be initiated. LAC 5 Criteria: Fish biomass reduction no more than 50% of baseline values (based on high levels of natural variation reported in other reservoirs and professional judgement) across Reservoir Project Site. Greater biomass were recorded in deeper parts of the reservoir and to the south of the Reservoir Project Site.
7	Focal Bird Species and overall waterbird community	PC, C, O	Minimum counts of species richness (focal birds) and species abundance (waterbirds)	Point counts of focal bird species foraging and waterbirds by Vantage Point Survey (VPS). Focal bird foraging events: • 3 hrs per month per VP (36 hrs per VP per year). Waterbirds number of species: • 20-minute count for waterbirds from each VPS each month. Mapping of flight paths to identify if any behavioural changes post construction	At least 1 sample event at each VP during pre-construction. Monthly at each VP throughout construction. Monthly at each VP for three years post-construction. Reassess frequency/ duration and location after initial 3 years post-construction, as monitoring may be able to taper off once biotic and abiotic relationships is well established/ understood. Locations to be confirmed with relevant Government Agencies/ Authorities.	Developer/ Owner	Informs LAC 6. Reporting of trends, annually during construction and three years post-construction. Compare to focal species and overall waterbird community data from previous years. If guideline or LAC criteria not met, then investigation process to be initiated. LAC 6 Criteria: Foraging by focal bird populations to not significantly fall below average count number recorded during baseline surveys and control site(s) (if any). Refer to Table 6-1 for species-specific targets. This includes species of conservation concern and others representative of the bird community. Waterbird assemblage to not significantly fall below average number of species recorded during baseline surveys and control sites(s) (if any). The average number during baseline surveys is 8 species.
8	Focal Species of high Conservation Concern	PC, C, O	Continued presence at Kranji Reservoir	Focal birds: • Point counts via VPS (see above). Black-crowned night heron (BCNH): • Incidental observations during bird point counts (see above) to confirm BCNH	At least 1 sample event (i.e. for birds, see above) during pre-construction Throughout construction (i.e. monthly for birds, see above). Monthly at each VP for three years post-construction (i.e. monthly for birds, see above). Reassess frequency/ duration and location after initial 3 years post-construction, as monitoring may be	Developer/ Owner	Informs LAC 7. Reporting of presence/ trends, annually during construction and three years post-construction. If guideline or LAC criteria not met, then investigation process to be initiated. LAC 7 Criteria: • Continued presence of black-crowned night heron (nationally EN)

No.	Aspects	Project Phase (PC, C, O[11])	Monitoring Parameters	Monitoring Method	Frequency/ Duration/ Location	Responsible Person	Reporting/ Notes
				continue to roost at eastern and western shoreline. Grey-headed fish eagle: • Incidental observations during bird point counts (see above) to confirm breeding behaviour at recorded nest site (during breeding season). Smooth-coated otter: • Incidental observations during bird point counts (see above) of smooth coated otter activity on reservoir.	able to taper off once biotic and abiotic relationships is well established/ understood. Locations to be confirmed with relevant Government Agencies/ Authorities.		roost, detected on at least two occasions each year, 6 months apart. • Continued sighting within Kranji Reservoir and/ or active use of nest by grey-headed fish eagle (nationally VU) at Sungei Kadut Forest during this species' breeding season. • Continued foraging of smooth coated otter foraging within Kranji Reservoir and immediately surrounding habitats.

7. CONCLUSIONS

This Report documents the adoption of the ECD approach to describe the condition and function of Kranji Reservoir ecosystem. The ECD approach is normally used to inform the management of Ramsar Sites. Whilst Kranji Reservoir is not designated as a Ramsar Site, and would not qualify as such either, the ECD approach has allowed for the identification of the key components, processes and services that characterise Kranji Reservoir's ecosystem. In addition the current and future threats to the ecological character have been identified.

These aspects have been described by reviewing historical studies carried out at the Reservoir as well as primary data collected as part of the Project's EIA process. The data present a hyper-eutrophic waterbody, unlimited by phosphorus, with relatively poor aquatic biodiversity value. Biodiversity comprises generalist species, many of which are non-native and/or invasive. Despite this degraded condition, a number of terrestrial species of conservation interest use the Kranji Reservoir for feeding or resting to some degree, and some use the edge vegetation for nesting.

Together this information has been used to conceptualise the changes that may occur to the reservoir ecosystem as a result of the proposed FPV development. Conceptualisation was provided through a model which mapped out the key changes the presence of the FPV development would have on the physical and chemical processes within the Reservoir. The effects of these on the biota were also appraised.

The appraisal found that, whilst some changes will occur, the effects on the Reservoir's ecosystem are likely to be limited. The generalist species within the aquatic habitats of the Reservoir are already tolerant to degraded conditions and occasional disturbances from which they readily recolonise. Any changes to the aquatic biodiversity, in terms of species richness or abundance, is not likely to affect the terrestrial biodiversity values using the Reservoir.

Limits of acceptable change (LACs) are a tool by which ecological change can be measured. These LACs proposed for this Project relate to physical, chemical and biological components and processes within the Reservoir. Once a LAC criteria is exceeded, or not met, it is likely that changes in ecosystem components, processes and services will occur, which can be difficult to reverse (e.g. reduction of species population), i.e. the ecological character could be approaching a tipping point. The recommended LAC, LAC criteria and related monitoring have been developed to set a sensible framework that will be integrated into the EIA process, in particular the EMMP, to proactively monitor ecosystem changes, provide early indicators and trigger the need for additional monitoring, investigation of the change, and the need and type of intervention required, so that adaptive management measures can be designed and implemented before significant impacts occur to features of conservation interest.

8. REFERENCES

Alvarado, C., Ramírez, J.M., Herrera-López, E.J., Cortez-Valladolid, D. and Ramírez, G. (2019) Bioaccumulation of Metals in Cultured Carp (Cyprinus carpio) from Lake Chapala, Mexico. *Biological Trace Element Research*, 195, 226-238. DOI: 10.1007/s12011-019-01845-w.

ANZECC (2022) Australian & New Zealand Guidelines for Fresh & Marine Water Quality. Available at: https://www.waterquality.gov.au/anz-guidelines [Access date: 7th October 2022].

Appan, A. (1994) Interpreted land and waste management towards enhancement of reservoirs nutrient levels – a successful case study in Singapore. Proc., Stockholm Water Symp., 535-550.

Appan, A. and Wang, H. (2000) Sorption, Isotherms and Kinetics of Sediment phosphorus in a Tropical Reservoir. Journal of Environmental Engineering, 126(11), 993-998. DOI: 10.1061/(asce)0733-9372(2000)126:11(993).

Arunjith, T.S., Cheng, Fei, Wang, Z., Divya, K.R. and Xie, S. (2022) Diurnal distribution of fish abundance and size composition in the Danjiangkou Reservour, China. Indian Journal of Fisheries, 69(1), 54-60. DOI: 10.21077/ijf.2022.69.1.108072-06.

Bannister, W., McGowan, S., Santos-Borja, A.C., Quak, J., Fong, L., Mendoza, M.,..., and Taylor, D. (2019) Potential anthropogenic regime shifts in three freshwater lakes in Tropical East Asia. Freshwater Biology, 64(10), 1-15. DOI: 10.1111/fwb.13256.

Blakely, T., Harding, J. and Eikaas, H.S. (2014) The Singscore: a macroinvertebrate biotic index for assessing the health of Singapore's streams and canals. Raffles Bulletin of Zoology, 62, 540-548.

Cai, W., Borlace, S., Lengaigne, M., van Rensch, P., Collins, M., Vecchi, G.,..., and Jin, F-F. (2014) Increasing frequency of extreme El Niño events due to greenhouse warming. Nature Climate Change, 4(2), 111-116. DOI: 10.1038/nclimate2100.

Callisto, M., Molozzi, J. and Barbosa, J.L.E. (2014) Eutrophication of Lakes, in A.A. Ansari and S.S. Gill (Eds.) Eutrophication: causes, consequences and control. Volume 2. Springer, London. pp. 55-72.

Centre for Climate Research Singapore (CCRS) (2022) Understanding Weather and Climate Processes. Available at: http://ccrs.weather.gov.sg/understanding-weather-and-climate-processes/ [Access date: 14th November 2022].

Chen, H., Zhang, H., Chen, Y. and Freyhof, J. (2019) A review of the Barbatula loaches (Teleostei: Nemacheilidae) from north-eastern China, with the description of four new species. Zootaxa, 4565 (1), 1. DOI: 10.11646/zootaxa.4565.1.1.

Chen, M., Boyle, E.A., Switzer, A.D. and Gouramanis, C. (2016) A century long sedimentary record of anthropogenic lead (Pb), Pb isotopes and other trace metals in Singapore. Environmental pollution, 213, 446-459. DOI: 10.1016/j.envpol.2016.02.040.

Chrétien, E. and Chapman, L.J. (2016) Tropical fish in a warming world: thermal tolerance of Nile perch Lates niloticus (L.) in Lake Nabugabo, Uganda. Conservation Physiology, 4, 1-14. DOI: 10.1093/conphys/cow062.

Chua, L.H.C., Tan, S.B.K., Sim, C.H. and Goyal, M.K. (2012) Treatment of baseflow from an urban catchment by a floating wetland system. Ecological Engineering, 49, 170-180. DOI: 10.1016/j.ecoleng.2012.08.031.

Clews, E., Low, E. W., Belle, C. C., Todd, P. A., Eikaas, H. S., and Ng, P. K. L. (2014) A pilot macroinvertebrate index of the water quality of Singapore's reservoirs. Ecological Indicators, 38, 90–103. https://doi.org/10.1016/j.ecolind.2013.10.030.

Climatic Research Unit (CRU) (2020) Climatic Research Unit website. Available at: http://www.cru.uea.ac.uk/ [Access date 1st June 2021].

Cohen, A.S., Gergurich, E.L., Kraemer, B.M., McGlue, M.M., McIntyre, P.B., Russell, J.M.,..., and Swarzenski, P.W. (2016) Climate warming reduces fish production and benthic habitat in Lake Tanganyika, one of the most biodiverse freshwater ecosystems. Proceedings of the National Academy of Sciences, 113(34), 9563-9568. DOI: 10.1073/pnas.1603237113.

Dakos, V., Carpenter, S. R., van Nes, E. H. and Scheffer, M. (2015) Resilience indicators: Prospects and limitations for early warnings of regime shifts. Philosophical Transactions of the Royal Society B: Biological Sciences, 370, 1-10. DOI: 10.1098/rstb.2013.0263.

Davison, G.W.H., Ng, P.K.L. and Ho, H.C. (Eds.) (2008) The Singapore Red Data Book: Threatened Plants & Animals of Singapore. Singapore: The Nature Society.

Dean, W.E. (1974) Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. Journal of Sedimentary Petrology, 44(1), 242-248. DOI: 10.1306/74d729d2-2b21-11d7-8648000102c1865d.

De Lima, R. L. P., Paxinou, K., Boogaard, F., Akkerman, O., Lin, F.-Y. (2021) Observations under a Large-Scale Floating Solar Farm Using Sensors and Underwater Drones. Sustainability, 13, 6421. https://doi.org/10.3390/su13116421

Deesborn, L. Jessel, R. and Elmberg, J. (2016) Geese as vectors of nitrogen and phosphorus to freshwater systems. Inland Waters 6, 111-122.

Department of the Environment, Water, Heritage and the Arts (DEWHA) (2008). National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands. Module 2 of the national Guidelines for Ramsar Wetlands – Implementing the Ramsar Convention in Australia.

Dersseh, M.G., Melesse, A.M., Tilahun, S.A., Abate, M. and Dagnew, D.C. (2019) Water Hyacinth: Review of its Impacts on Hydrology and Ecosystem Services - Lessons for Management of Lake Tana, in A.M. Melesse, W. Abtew and G. Senay (Eds.) Extreme Hydrology and Climate Variability: Monitoring, Modelling, Adaptation and Mitigation. USA: Elsevier.

Dessborn, L., Hessel, R. and Elmberg, J. (2016) Geese as vectors of nitrogen and phosphorus to freshwater systems. Inland Waters, 6(1), 111-122. DOI: 10.5268/IW-6.1.897.

Dodson, S.I., Arnott, S.E. and Cottingham, K.L. (2000) The relationship in lake communities between primary productivity and species richness. Ecology, 81, 2662-2679. DOI: 10.1890/0012-9658(2000)081[2662:trilcb]2.0.co;2.

Domis, L., Elser, J.J., Gsell, A.S., Huszar, V.L.M., Ibelings, B.W., Jeppesen, E.,..., and Lürling, M. (2013) Plankton dynamics under different climatic conditions in space and time. Freshwater Biology, 58, 463–482. DOI: 10.1111/fwb.12053.

East Asian-Australasian Flyway Partnership (EAAFP) (2017) Sungei Buloh Wetland Reserve, Singapore, Site Information Sheet on East Asian-Australasian Flyway Network Sites (SIS) – 2017 Version, Accessed at: https://www.eaaflyway.net/wp-content/uploads/2018/12/SIS_EAAF073_Singapore_Sungei-Buloh-Wetland-Reserve_v.2018-1.pdf [12th March 2021].

Egerton, J. P., Johnson, A. F., Turner, J., LeVay, L., Mascarenas-Osorio, I. and Aburto-Oropeza, O. (2018) 'Hydroacoustics as a tool to examine the effects of Marine Protected Areas and habitat type on marine fish communities', Scientific reports. Nature Publishing Group, 8(1), p. 47.

Environmental Protection Agency (EPA) (2008) Chapter 3: Boron, in EPA (2008) Regulatory Determinations Support Document for Selected Contaminants from the Second Drinking Water Contaminant Candidate List (CCL 2), EPA Report 815-R-08-012, 1-27. Available at: https://www.epa.gov/sites/default/files/2014-09/documents/chapter_3_boron.pdf [Access date: 7th October 2022].

Exley, G., Armstrong, A., Page, T., Jones, I. D. (2021) Floating photovoltaics could mitigate climate change impacts on water body temperature and stratification. Solar Energy, 219, 24-33. https://doi.org/10.1016/j.solener.2021.01.076

Fishbase (2022) Fish Species in Singapore. Available at: https://www.fishbase.se/identification/RegionSpeciesList.php?resultPage=5&c_code=702 [Accessed on 10th March 2022.]

Fong, L.S., Leng, M.J. and Taylor, D. (2020) A century of anthropogenic environmental change in tropical Asia: Multi-proxy palaeolimnological evidence from Singapore's Central Catchment. The Holocene, 30(1), 162-177. DOI: 10.1177/0959683619875.

Fukushima, T., Matsushita, B., Subehi, L., Setiawan, F. and Wibowo, H. (2017) Will hypolimnetic waters become anoxic in all deep tropical lakes? Scientific Reports, 7(1), 1-8. DOI: 10.1038/srep45320.

Gaikwad, R.P. and Gavande, S. (2017) Major factors contributing growth of water hyacinth in natural water bodies. International Journal of Engineering Research, 6 (6). DOI: 10.5958/2319-6890.2017.00024.1.s.

Gibson, G., Carlson, R., Simpson, J., Smeltzer, E., Gerritson, J., Chapra, S.,..., and Kennedy, R. (2000) Nutrient Criteria Technical Guidance Manual Lakes and Reservoirs. U.S. Environmental Protection Agency. EPA-822-B00-001.

Garza, C., Posadas, Y., Quintanar, L., Gonsebatt, M.E. and Franco, R. (2018) Neurotoxicity Linked to Dysfunctional Metal Ion Homeostasis and Xenobiotic Metal Exposure: Redox Signaling and Oxidative Stress. Antioxidants and Redox Signaling, 28(18), 1669–1703. DOI: 10.1089/ars.2017.7272.

Gin, K.Y-H., Ramaswamy, U. and Gopalakrishnan, A.P. (2011) Comparison of Nutrient Limitation in Freshwater and Estuarine Reservoirs in Tropical Urban Singapore. Journal of Environmental Engineering, 137(10), 913-919. DOI: 10.1061/(asce)ee.1943-7870.0000397.

González-Bergonzoni, I., Meerhoff, M., Davidson, T.A., Teixeira-de Mello, F., Baattrup-Pedersen, A. and Jeppesen, E. (2012) Meta-analysis Shows a Consistent and Strong Latitudinal Pattern in Fish Omnivory Across Ecosystems. Ecosystems, 15, 492-503. DOI: 10.1007/s10021-012-9524-4.

Guo, P., Lu, D., Jiang, J., Zhan, L. and Wang, R. (2017) Temporal-spatial distribution, environmental significance and release risks of phosphorus in the sediments of a tropical mountain's deep drinking water reservoir in southeastern China. Chemical Speciation & Bioavailability, 29(1), 170-178. DOI: 10.1080/09542299.2017.1392261

Haberman, J. and Haldna, M. (2014) Indices of zooplankton community as valuable tools in assessing the trophic state and water quality of eutrophic lakes: long term study of Lake Vortsjarv. Journal of Limnology, 73(2), 263-273. DOI: 10.4081/jlimnol.2014.828.

Hale, J. and Butcher, R. (2007) Ecological Character Description of the Peel-Yalgorup Ramsar Site, Report to the Department of Environment and Conservation and the Peel Harvey Catchment, Perth, Western Australia.

Harris, G.P. and Baxter, G. (1996) Interannual variability in phytoplankton biomass and species composition in a subtropical reservoir. Freshwater Biology, 35(3), 545-560. DOI: 10.1111/j.1365-2427.1996.tb01768.x.

Hassim, M.E.E. and Timbal, B. (2018) Observed rainfall trends over Singapore and the Maritime Continent from the perspective of regional-scale weather regimes. Journal of Applied Meteorology and Climatology. DOI: 10.1175/jamc-d-18-0136.1

Heino, J. (2000) Lentic macroinvertebrate assemblage structure along gradients in spatial heterogeneity, habitat size and water chemistry. Hydrobiologia, 418, 229-242. DOI: 10.1023/A:1003969217686

Heok Hui, T., Peng, K.L.K., Huan, L.J., Bi Wei, L., Hing, R.L.B., Benk, J.K.T. and Yeo, D.C.J. (2020) The non-native freshwater fishes of Singapore: an annoted compilation. Raffles Bulletin of Zoology, 68, 150-195. DOI: 10.26107/RBZ-2020-0016.

Hoetzel, G. and Croome, R. (1994) Long-term phytoplankton monitoring of the Darling River at Burtundy, New South Wales: Incidence and significance of cyanobacterial blooms. Marine and Freshwater Research, 45(5), 747, DOI: 10.1071/MF9940747.

Hoetzel, G. and Croome, R. (1996) Population dynamics of Aulacoseira granulata (EHR.) SIMONSON (Bacillariophyceae, Centrales), the dominant alga in the Murray River, Australia. Archiv fuer Hydrobiologie, 136, 191-215. DOI: 10.1127/archiv-hydrobiol/136/1996/191.

Ho, H.C. (n.d.) PUB bund marshes. Nature Watch. http://habitatnews.nus.edu.sg/pub/naturewatch/text/a102a.htm (Accessed 11 January 2021).

Ho, J.K.I., Quek, R.F., Ramchunder, S.J., Memory, A., Theng, M.T.Y., & Clews, E. (2018). Aquatic macroinvertebrate richness, abundance and distribution in the Nee Soon freshwater swamp forest, Singapore. Gardens' Bulletin Singapore,70,71-108. DOI: 10.26492/gbs70(suppl.1).2018-05.

Hossain, M.B., Bin Habib, S., Hossain, Md. S., Jolly, Y.N., Kamal, A.H.M., Idris, M.H. and Rakib, Md. R. J. (2020) Data set on trace metals in surface sediment and water from a sub-tropical estuarine system, Bay of Bengal, Bangladesh. Data in Brief, 31, 105911. DOI: 10.1016/j.dib.2020.105911.

Huey, R.B. and Hertz, P.E. (1984) Effects of body size and slope on acceleration of a lizard (Stellio stellio). Journal of Experimental Biology, 110, 113–123.

Ibelings, B.W., Portielje, R., Lammens, E.H.R.R., Noordhuis, R., van den Berg, M.S., Joosse, W. and Meijer, M.L. (2007) Resilience of Alternative Stable States during the Recovery of Shallow Lakes from Eutrophication: Lake Veluwe as a Case Study. Ecosystems, 10(1), 4-16. DOI: 10.1007/s10021-006-9009-4.

IUCN Red List (2022) The IUCN Red List Of Threatened Species. Available at: https://www.iucnredlist.org/ [Access date: 24th March 2022].

Jindal, R., Thakur, R.K., Singh, U.B. and Ahluwalia, A.S. (2014) Phytoplankton dynamics and species diversity in a shallow eutrophic, natural mid-altitude lake in Himachal Pradesh (India): role of physicochemical factors. Chemistry and Ecology, 30(4), 328-338.

Johnson, J.A. and Newman, R.M. (2011) A comparison of two methods for sampling biomass of aquatic plants. Journal of Aquatic Plant Management, 49(1), 1-8.

Kwik, J.T.B., Lim, B.H.R., Saw, C.Y.A., Tan, L.Y.C., Liu, S.S., Chan, W.W.R.,..., and Yeo, D.C.J. (2020) Biodiversity and Biological Interactions in Singapore's Reservoirs and Waterways – A study of Food Web and Trophic Structure, and Implications for Environmental and Water Quality Management (Phase 2). Progress Report 8: Kranji Reservoir.

Krupa, E., Romanova, S., Berkinbaev, G., Yakovleva, N. and Sadvakasov, E. (2020) Zooplankton as Indicator of the Ecological State of Protected Aquatic Ecosystems (Lake Borovoe, Burabay National Nature Park, Northern Kazakhstan), Water, 12, 1-19. DOI: 10.3390/w12092580.

Kutty, S.N., Loh, R.K., Bannister, W. and Taylor, D. (2022) Evaluation of a diatom eDNA-based technique for assessing water quality variations in tropical lakes and reservoirs. Ecological Indicators, 141, 109108. DOI: 10.1016/j.ecolind.2022.109108.

Larson, H.K., Jaafar, Z. and Lim, K.K.P. (2016) An updated checklist of the gobioid fishes of Singapore. Raffles Bulletin of Zoology, 34, 744-757.

Li, P., Qian, H., Howard, K.W.F., Wu, J. and Lyu, X. (2014) Anthropogenic pollution and variability of manganese in alluvial sediments of the Yellow River, Ningxia, northwest China. Environmental Monitoring and Assessment, 186, 1385-1398. DOI: 10.1007/s10661-013-3461-3.

Liew, J.H. Tan, H.H., Yi, Y. and Yeo, D.C.J. (2014) Ecology and origin of the introduced cichlid Acarichthys heckelii in Singapore's fresh waters—first instance of establishment. Environmental Biology of Fishes. DOI: 10.1007/s10641-013-0201-z.

Lim, J.E., Duda, M.P. and Smol, J.P. (2021) Chironomid assemblage changes and chitin degradation in response to ~ 1700-years of seabird population fluctuations at the world's largest colony of Leach's Storm-Petrels (Atlantic Canada). Journal of Paleolimnology, 65(4), 1-15. DOI: 10.1007/s10933-021-00181-1.

Loke, L.H.L., Clews, E., Low, E., Belle, C.C., Todd, P.A.,..., and Ng, P.K.L. (2010) Methods for sampling benthic macroinvertebrates in tropical lentic systems. Aquatic Biology, 10, 119-130. DOI: 10.3354/ab00274.

Low, E. W., Clews, E., Todd, P. A., Tai, Y. C., & Ng, P. K. (2010). Top-down control of phytoplankton by zooplankton in tropical reservoirs in Singapore?. Raffles Bulletin of Zoology, 58(2).

Madsen, J.D. (1993) Biomass techniques for monitoring and assessing control of aquatic vegetation. Lake and Reservoir Management, 7, 141-154. DOI: 10.1080/07438149309354266.

Makhanu, K.S. (1997) Impact of water hyacinth in Lake Victoria. Water and sanitation for all: partnerships and innovations, in 23rd Water Engineering and Development Centre Conference Durban, South Africa.

McCausland, M., Thompson, P.A. and Blackburn, S.I. (2001) The effect of changes in light availability caused by mixing on the growth of Anabaena circinalis (Nostocales, Cyanobacteria) and Aulacoseira sp. (Centrales, Bacillariophyceae), Phycologia, 40(6), 530-541. DOI: 10.2216/i0031-8884-40-6-530.1.

Mesquita, V.A., Silva, C.F. and Soares, E.V. (2016) Toxicity Induced by a Metal Mixture (Cd, Pb and Zn) in the Yeast Pichia kudriavzevii: The Role of Oxidative Stress, Current Microbiology, 72(5), 545–550. DOI: 10.1007/s00284-016-0987-y.

Mittelbach, G.G., Steiner, C.F. Scheiner, S.M., Gross, K.L., Reyonlds, H.L., Waide, R.N.,..., and Gough, L. (2001) What is the observed relationship between species richness and productivity? Ecology, 82, 2381-2396. DOI: 10.1890/0012-9658(2001)082[2381:witorb]2.0.co;2.

Moustaka-Gouini, M., Michaloudi, E. and Sommer, U. (2014) Modifying the PEG model for Mediterranean lakes – no biological winter and strong fish predation. Freshwater Biology, 59, 1136-1144. DOI: 10.1111/fwb.12335.

Muška, M., Tušer, M., Frouzová, J., Mrkvička, T., Ricard, D., Seďa, J., Morelli, F. and Kubečka, J. (2018) 'Real-time distribution of pelagic fish: combining hydroacoustics, GIS and spatial modelling at a fine spatial scale', Scientific reports. Nature Publishing Group, 8(1), pp. 1–11.

National Heritage Board (NHB) (n.d.) Battle at Kranji Beach. https://www.roots.gov.sg/places/places-landing/Places/historic-sites/Battle-at-Kranji-Beach (Accessed 11 January 2011).

National Parks (NParks) (2021) Flora & Fauna Web. Accessed at: https://www.nparks.gov.sg/florafaunaweb [22nd July 2021].

NParks (2023) Nature Park Network & Nature Corridors Accessed at: https://www.nparks.gov.sg/gardens-parks-and-nature/nature-park-network [9th february 2023]

Nature Society Singapore (NSS) (2009) History of the Kranji Marsh. [Accessed 30th September 2022].

Neil, K. and Gajewski, K. (2018) An 11,000-yr record of diatom assemblage responses to climate and terrestrial vegetation changes, southwestern Québec. Ecosphere, 9(11), 1-20. DOI: 10.1002/ecs2.2505.

Ng, H.H. and Tan, H.H. (2010) An annotated checklist of the non-native freshwater fish species in the reservoirs of Singapore. COSMOS, 6(1), 95-116.

Ng, P.K.L., Tan, H.T.W., Hui, T.H., Yeo, D.C.J., Hui, N.T., Yen-ling, L. and Hee, N.H. (2010) Final Report of the Broad-Based Biodiversity Study of Singapore's Reservoirs Kranji Reservoir. A report on biodiversity at Kranji Reservoir in 2010. Singapore: National University of Singapore.

Nicholls, K.H. (1997) Planktonic green algae in western Lake Erie: the importance of temporal scale in the interpretation of change. Freshwater Biology, 38, 419-425. DOI: 10.1046/j.1365-2427.1997.00247.x.

Nöges, T., Anneville, O., Guillard, J., Haberman, J., Järvalt, A., Manca, M.,..., and Nõges, P. (2018) Fisheries impacts on lake ecosystem structure in the context of a changing climate and trophic state, Journal of limnology, 77(1), DOI: 10.4081/jlimnol.2017.1640.

NUS Libraries Historical Maps of Singapore (NUSLHMSG) (2021) Department of Geography, National University of Singapore. https://libmaps.nus.edu.sg/ (Accessed 11 January 2021).

Pasztaleniec, A. and Poniewozik, M. (2004) Pediastrum species (Hydrodictyaceae, sphaeropleales) in phytoplankton of Sumin Lake (Łęczna-Włodawa Lakeland). Acta Societatis Botanicorum Poloniae, 73(1), 39-46. DOI: 10.5586/asbp.2004.006.f

Pollom, R. A. and Rose, G. A. (2016) 'A global review of the spatial, taxonomic, and temporal scope of freshwater fisheries hydroacoustics research', Environmental Reviews. NRC Research Press, 24(3), pp. 333–347.

Rajeshkumar, S. and Li, X. (2018) Bioaccumulation of heavy metals in fish species from the Meiliang Bay, Taihu Lake, China. Toxicology Reports, 5, 288-29s5. DOI: 10.1016/j.toxrep.2018.01.007.

Rawer-Jost, C., Böhmer, J., Blank, J. and Rahmann, H. (2000). Macroinvertebrate functional feeding group methods in ecological assessment. Hydrobiologia, 422, 225-232. DOI: 10.1023/A:1017078401734.

Reynolds, C.S. (1980) Phytoplankton Assemblages and Their Periodicity in Stratifying Lake Systems. Holarctic Ecology, 3(3), 141-159. DOI: 10.2307/3682364.

Reynolds, C.S., Montecino, V., Graf, M.E. and Cabrera, S. (1986) Short-term dynamics of a Melosira population in the plankton of an impoundment in central Chile. Journal of Plankton Research, 8(4), 715-740. DOI: 10.1093/plankt/8.4.715.f

Rosa, B.J.F.V., Rodrigues, L.F.T., de Oliveira, G.S. and da Gama Alves, R. (2014) Chironomidae and Oligochaeta for water quality evaluation in an urban river in southeastern Brazil. Environmental Monitoring and Assessment, 186(11), 7771-7779. DOI: 10.1007/s10661-014-3965-5.

Salmaso, N., Boscaini, A., Capelli, C. and Cerasino, L. (2017) Ongoing ecological shifts in a large lake are driven by climate change and eutrophication: evidences from a three-decade study in Lake Garda. Hydrobiologia, 1-19. DOI: 10.1007/s10750-017-3402-1.

Saparudin, K. and Omar, M. (2007) Kranji Reclamation. Infopedia, National Library Board Singapore. Available at: https://eresources.nlb.gov.sg/infopedia/articles/SIP_1096_2010-05-14.html [Access date: 30th September 2022].

Sharip, Z. and Suratman, S. (2017) Formulating Specific Water Quality Criteria for Lakes: A Malaysian Perspective, in H. Tutu (Ed.) (2017) Water Quality. University of the Witwatersrand, South Africa.

Sherman, B.S., Webster, I.T., Jones, G.J. and Oliver, R.L. (1998) Transitions between Aulacoseira and Anabaena dominance in a turbid weir pool. Limnology and Oceanography, 43(8), 1902-1915. DOI: 10.4319/lo.1998.43.8.1902.

Sitkowska, M. (1992) Taksony rodzaju Pediastrum Meyen wystepujące w stawach Łodzi I okolicy. Acta Univ. Lodz., Folia Bot, 9, 47-104. (in Polish with English summary).

Steinmetz, J., Kohler, S. and Soluk, D.A. (2003) Birds Are Overlooked Top Predators in Aquatic Food Webs. Ecology, 84(5), 1324-1328. DOI: 10.1890/0012-9658(2003)084[1324:BAOTPI]2.0.CO;2.

Tewksbury, J.J., Huey, R.B. and Deutsch, C.A. (2008) ECOLOGY: Putting the heat on tropical animals. Science, 320(5881), 1296–1297. DOI: 10.1126/science.1159328.

The Straits Times (1972). The Straits Times, p. 4. https://eresources.nlb.gov.sg/newspapers/Digitised/Article/straitstimes19720309-1.2.18.3 (Accessed on 11 January 2021).

Thin, M.M., Sacchi, E., Setti, M. and Re, V. (2020) A Dual Source of Phosphorus to Lake Sediments Indicated by Distribution, Content, and Speciation: Inle Lake (Southern Shan State, Myanmar), Water, 12, 1993. DOI: 10.3390/w12071993.

Tibby, J., Adamson, K. and Kershaw, A.P. (2020) An 1800-year water-quality and vegetation record from Junction Park Billabong, Murray River, Australia: an assessment of European impacts and sensitivity to climate. Journal of Paleolimnology, 63, 159-175. DOI: 10.1007/s10933-019-00109-w.

Valko, M., Jomova, K., Rhodes, C.J., Kuča, K. and Musílek, K. (2016) Redox- and non-redox-metal-induced formation of free radicals and their role in human disease. Archives of Toxicology, 90(1), 1-37. DOI: 10.1007/s00204-015-1579-5.

Vázquez-Loureiro, D., Goncalves, V., Sáez, A., Hernández, A., Raposeiro, P.M., Giralt, S.,..., and Bao, R. (2019) Diatom-inferred ecological responses of an oceanic lake system to volcanism and anthropogenic perturbations since 1290 CE. Palaeogeography, Palaeoclimatology, Palaeoecology, 534, 1-15. DOI: 10.1016/j.palaeo.2019.109285.

Villamagna, A.M. and Murphy, B.R. (2010) Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): a review. Freshwater Biology, 55(2), 282-298. DOI: 10.1111/j.1365-2427.2009.02294.x.

Vinagre, C., Leal, I., Mendonça, V., Madeira, D., Narciso, L., Diniz, M.S. and Flores, A.A.V. (2016) Vulnerability to climate warming and acclimation capacity of tropical and temperate coastal organisms. Ecological Indicators, 62, 317–327. DOI: 10.1016/j.ecolind.2015.11.010.

Wang, L. and Liang, T. (2015) Distribution Characteristics of Phosphorus in the Sediments and Overlying Water of Poyang Lake. PLoS ONE, 10(5), e0125859. DOI:10.1371/journal.pone.0125859.

Water Research Center (2022) Dissolved Oxygen in Water. Available at: https://www.archive-water-research.net/index.php/dissovled-oxygen-in-water [Access date: 5th Mays 2022]

Watkins P (2000) Pandion haliaetus. Animal Diversity Web. https://animaldiversity.org/accounts/Pandion_haliaetus/#references

Wilkinson, C., Lim, R.B.H., Liew, J.H., Kwik, J.T.B., Tan, C.L.Y., Hui, T.H. and Yeo, D.C.J. (2022) Empirical food webs of 12 tropical reservoirs in Singapore. Biodiversity Data Journal, 10, e86192. DOI: 10.3897/BDJ.10.e86192.

Vuori, K-M., Luotonen, H. and Liljaniemi, P. (1999) Benthic macroinvertebrates and aquatic mosses in pristine streams of the Tolvajärvi region, Russian Karelia. Boreal Environment Research, 4, 187-200.

Xie, P. and Arkin, P.A. (1997) Global Precipitation: A 17-Year Monthly Analysis Based on Gauge Observations, Satellite Estimates, and Numerical Model Outputs. Bulletin of the American Meteorological Society, 78(11), DOI: 10.1175/1520-0477.

Xing, Z., Fong, D.A., Lo, E.Y-M. and Monismith, G. (2014) Thermal structure and variability of a shallow tropical reservoir. Limnology and Oceanography, 59(1), 115-128. DOI: 10.4319/lo.2014.59.01.0115.

Yang, H., Turner, S. and Rose, N.L. (2016) Mercury pollution in the lake sediments and catchment soils of anthropogenically-disturbed sites across England. Environmental Pollution, 219, 1092-1101. DOI: 10.1016/j.envpol.2016.09.012.

Yang, W., Deng, D.G., Meng, X.L. and Zhang, S. (2019) Temporal and Spatial Variations of Phytoplankton Community Structure in Lake Erhai, a Chinese Plateau Lake, with Reference to Environmental Factors. Russian Journal of Ecology, 50(4), 352-360. DOI: 10.1134/s1067413619040179.

Yang, P., Chua, L. H. C., Irvine, K. N., Nguyen, M. T., Low, E.-W. (2021) Impacts of a Floating Photovoltaic System on Temperature and Water Quality in a Shallow Tropical Reservoir. Limnology, 23, 441-454. doi: 10.1007/s10201-022-00698-y

Yee, A.T.K., Ang, W.F., Teo, S., Liew, S.C. and Tan, H.T.W. (2010) The present extent of mangrove forests in Singapore. Nature in Singapore, 3, 139-145.f

Yeo, D.C.J., Ho, J.K.I., Wei, L.B., Hui, N.T., Wilkinson, C., Yiwen, Z.,..., and Yeo, (J.W.L.) (2016) Kranji Marsh aquatic organism survey 7–8 January 2016. An identification key of aquatic organisms identified in a Kranji Marsh survey performed in January 2016.

Yeo, D.C.J., Keng, W.L. and Lim, K.K.P. (2010) Private Lives: An Exposé of Singapore's Freshwaters. Singapore: The Raffles Museum of Biodiversity Research.

Yin, Y. and Kreiling, R.M. (2011) The evaluation of a rake method to quantify submersed vegetation in the Upper Missssippi River. Hydrobiologia, 675, 187-195. DOI: 10.1007/s10750-011-0817-y

Hydrobiology

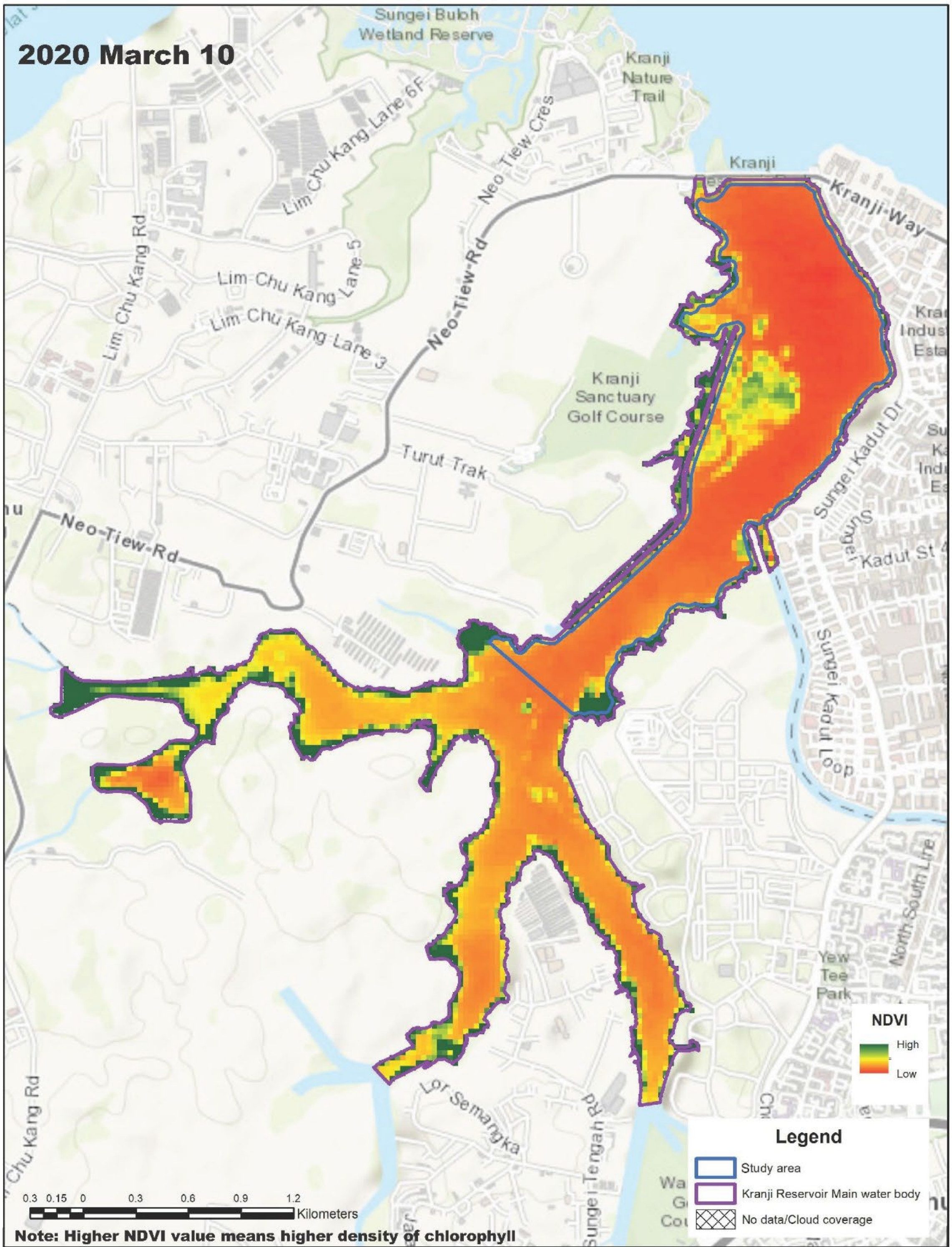
STREET
Singapore Water Exchange
84 Toh Guan Road East
#04-08/09
SINGAPORE 608501

CONTACT
singapore@hydrobiology.com

www.hydrobiology.com

APPENDIX 7.4 FLOATING VEGETATION ANALYSIS

APPENDIX 7.4: FLOATING VEGETATION ANALYSIS



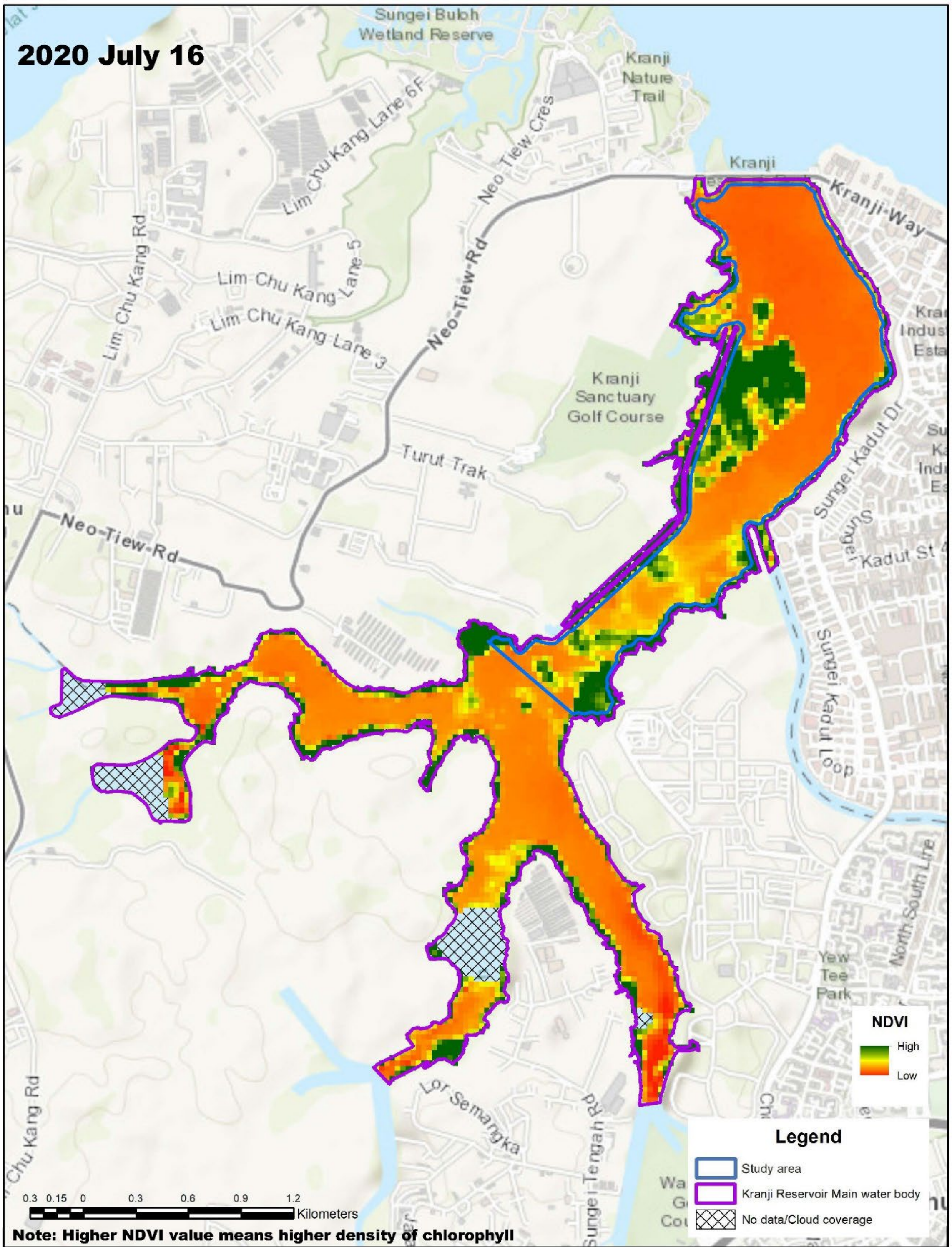
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2020Mar10 Satellite LandSat TM8

Date: 17/2/2022

ERM



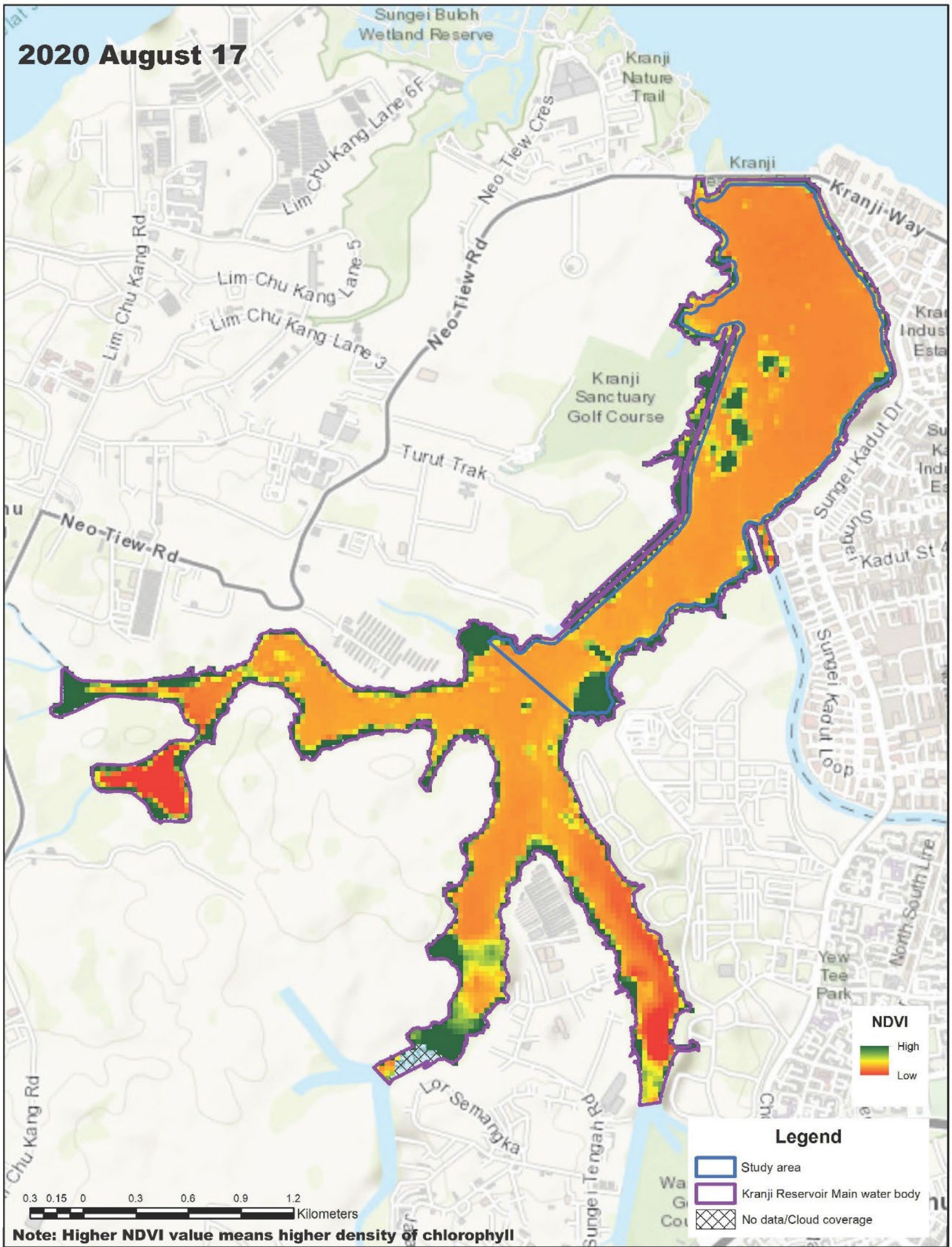
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2020July16 Satellite LandSat TM8

Date: 17/2/2022

ERM

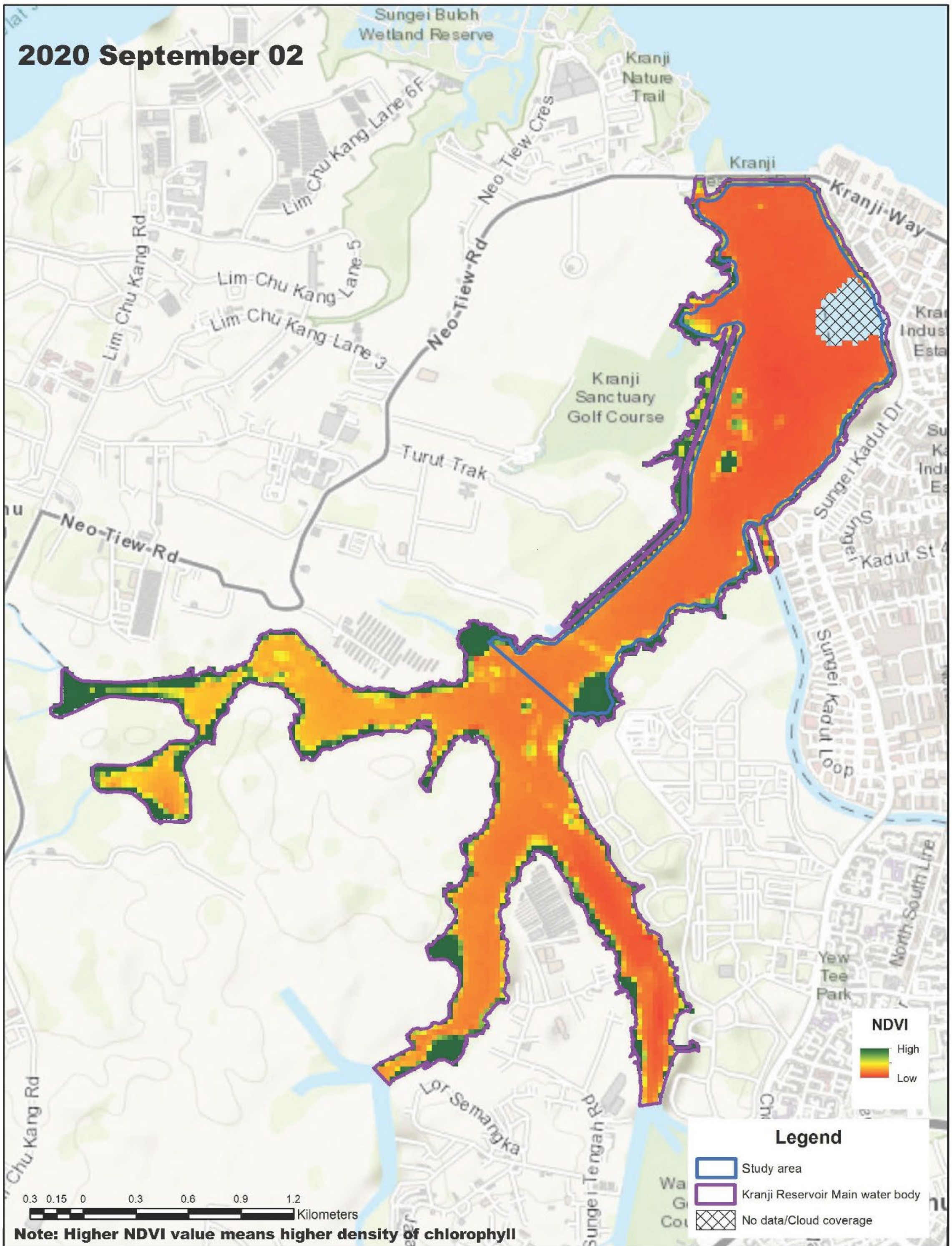


Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2020Aug17 Satellite LandSat TM8

Date: 17/2/2022



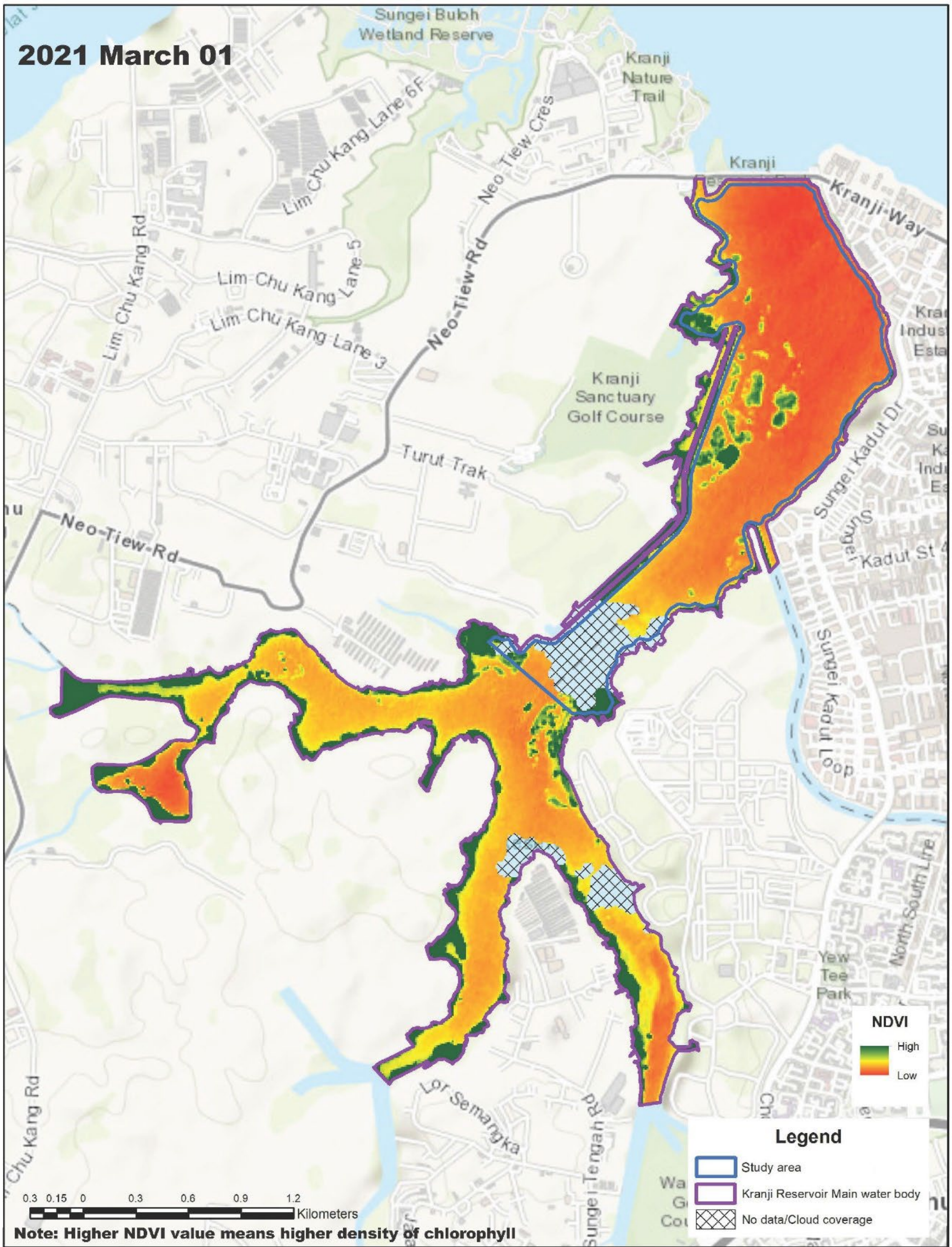
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2020Sept02 Satellite LandSat TM8

Date: 17/2/2022

ERM



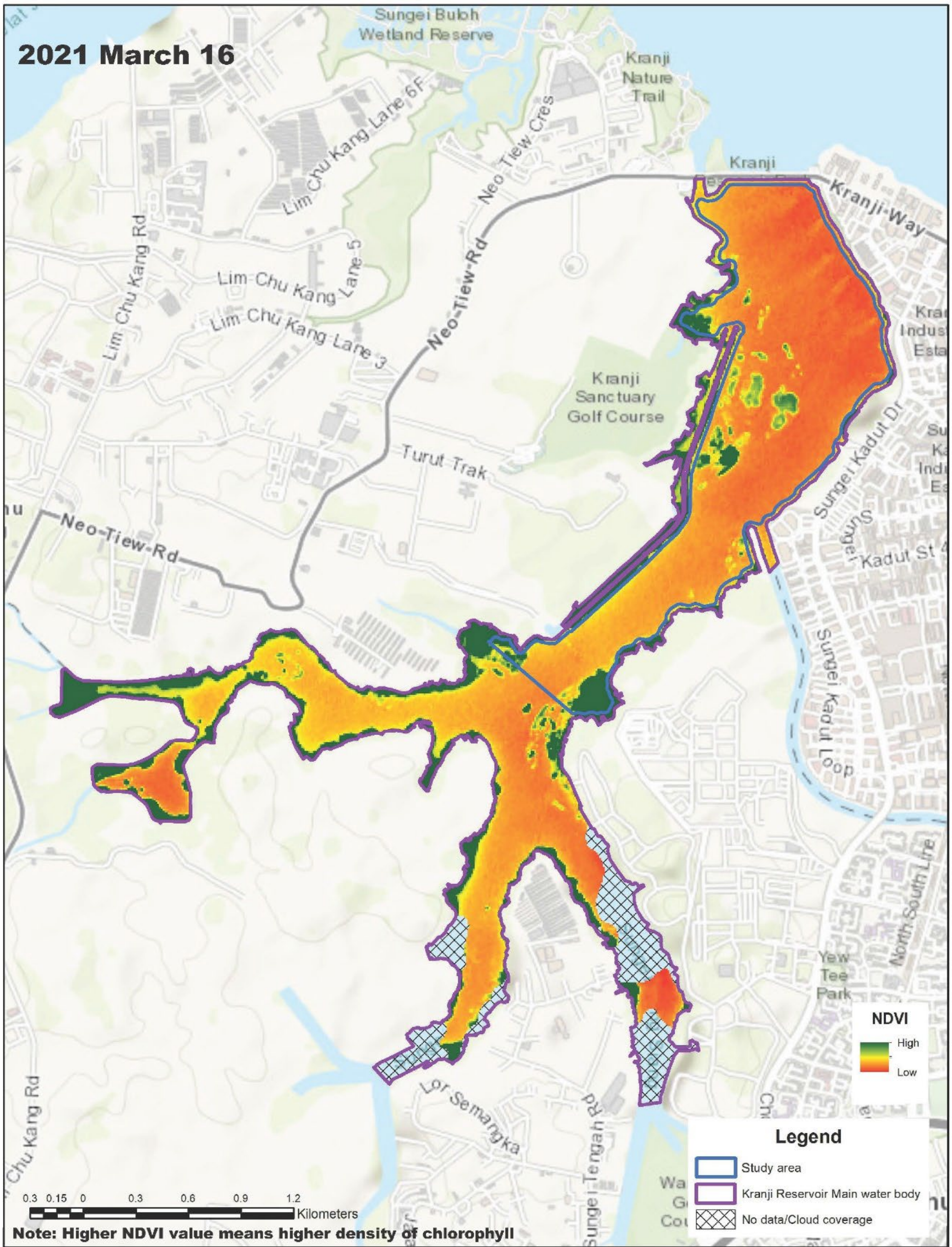
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021Mar01 Satellite Sentinel 2A

Date: 17/2/2022

ERM

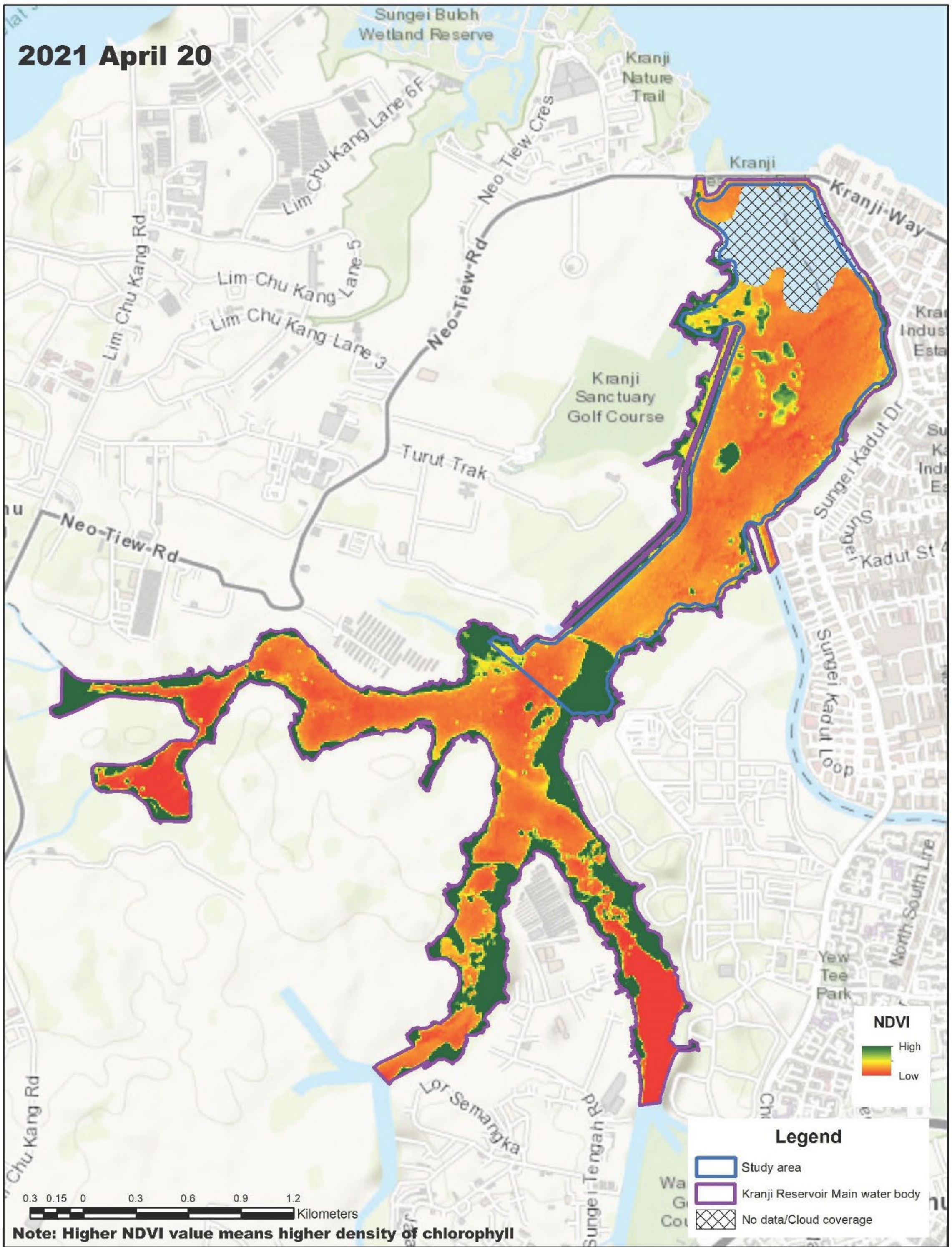


Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021Mar16 Satellite Sentinel 2A

Date: 17/2/2022



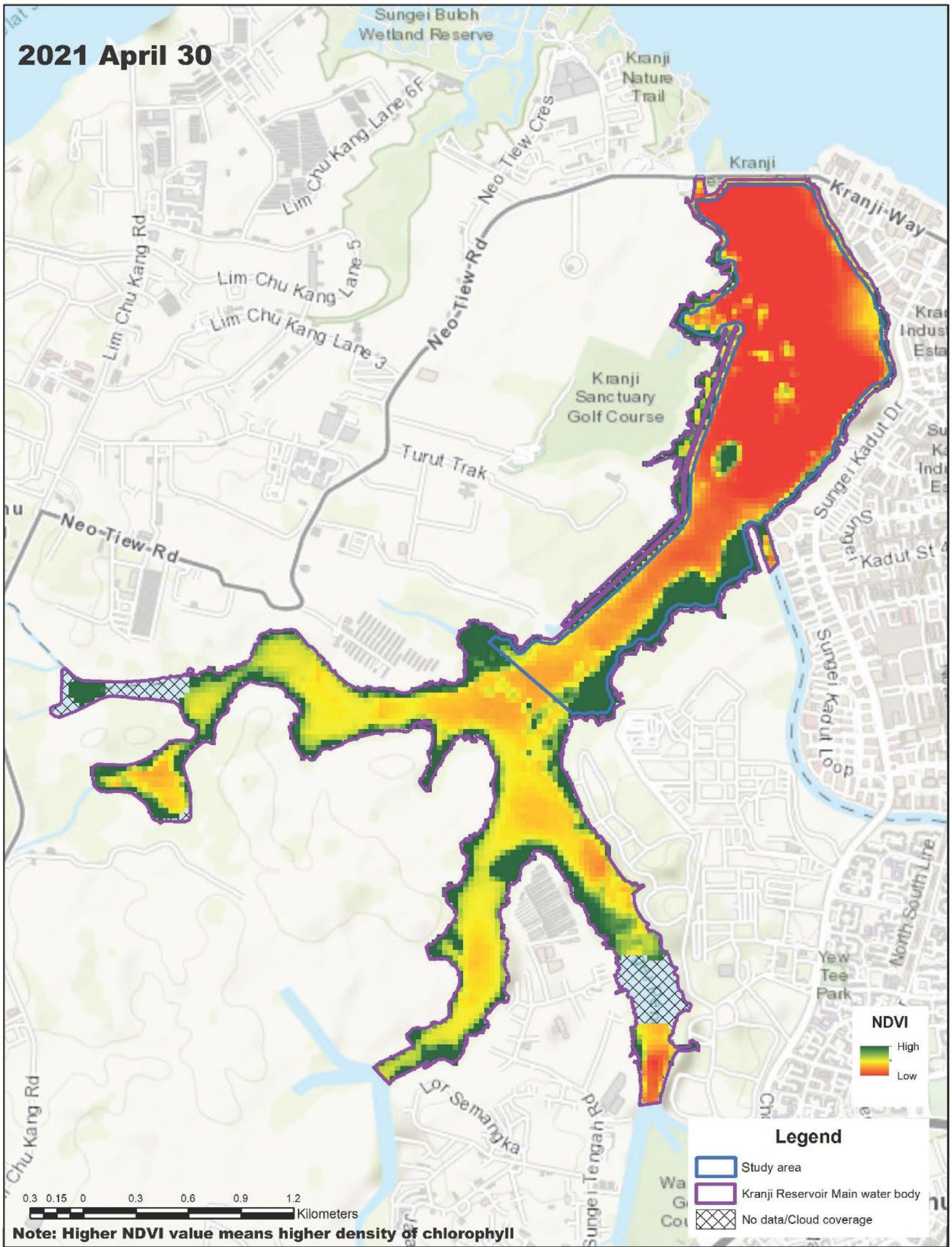
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021Apr20 Satellite Sentinel 2A

Date: 17/2/2022

ERM



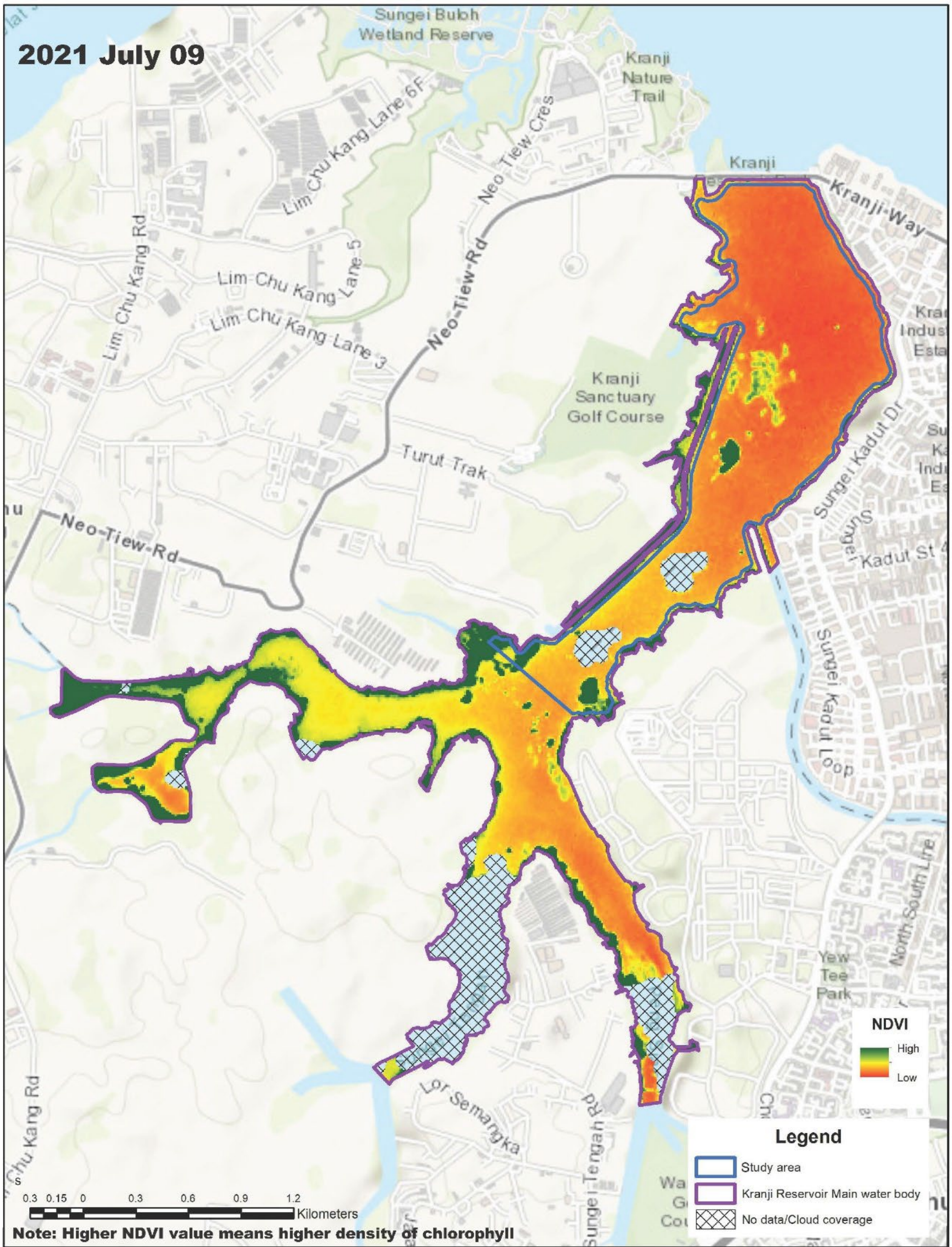
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021Apr30 Satellite LandSat TM8

Date: 17/2/2022

ERM

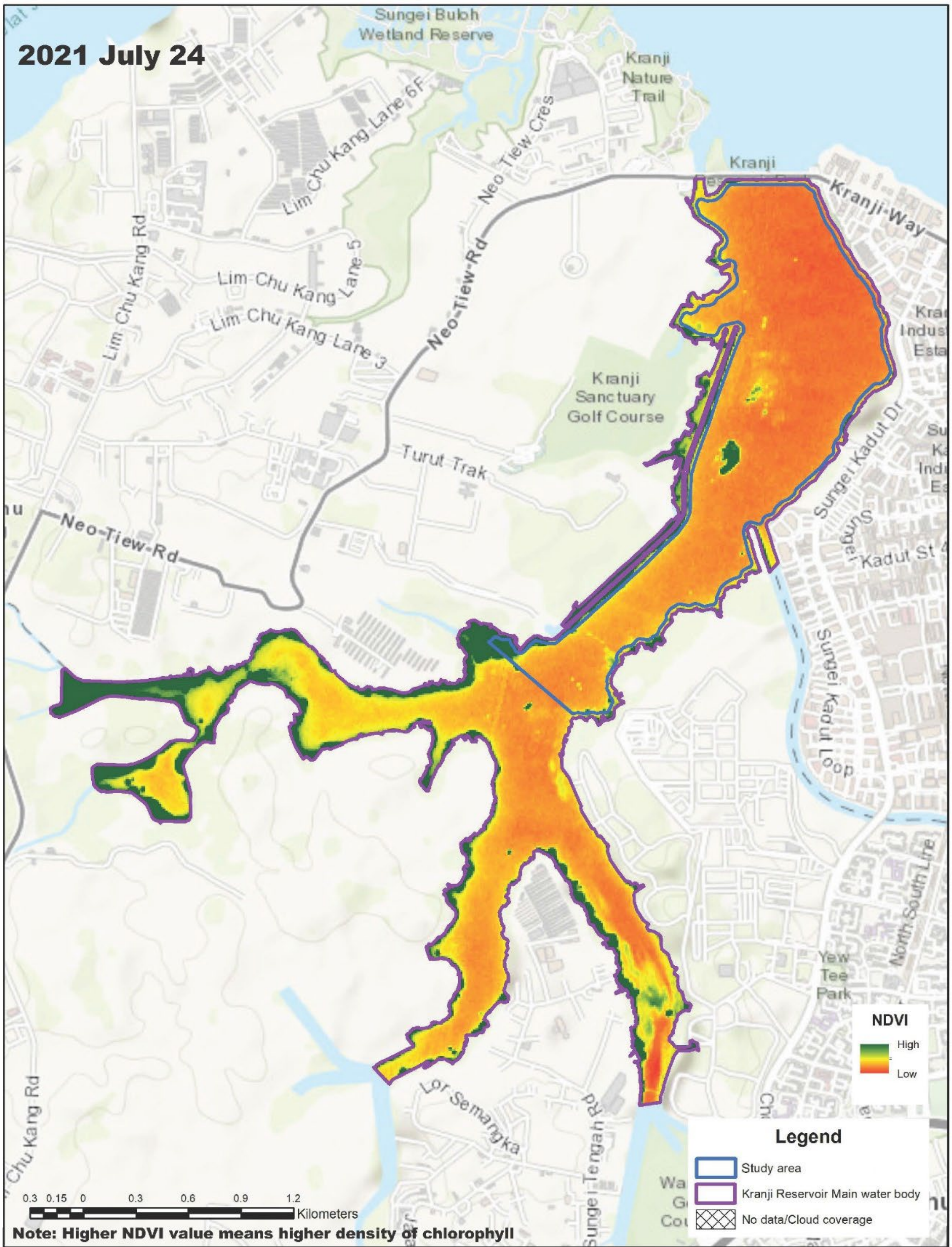


Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021July09 Satellite Sentinel 2A

Date: 17/2/2022



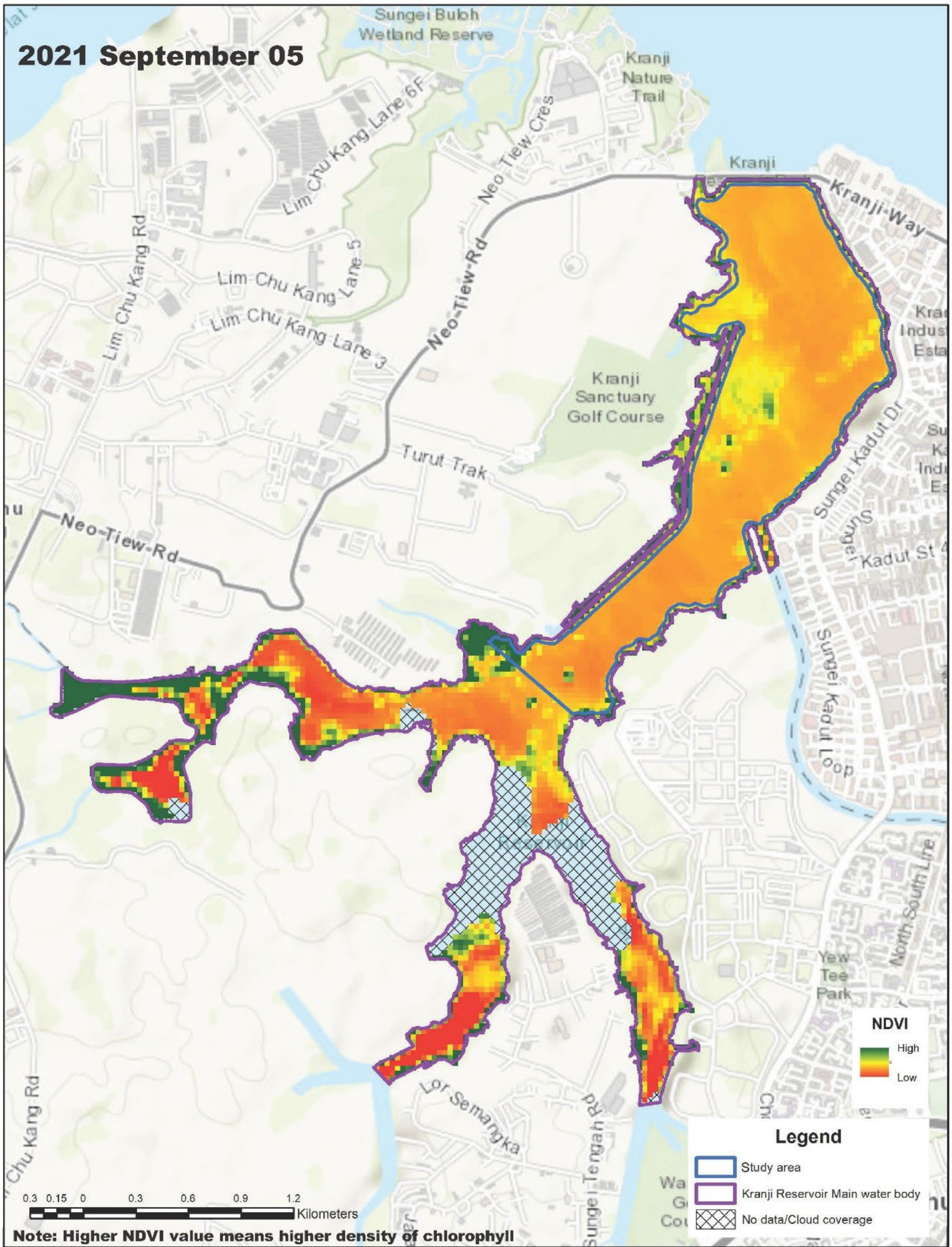
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021July24 Satellite Sentinel 2A

Date: 17/2/2022

ERM



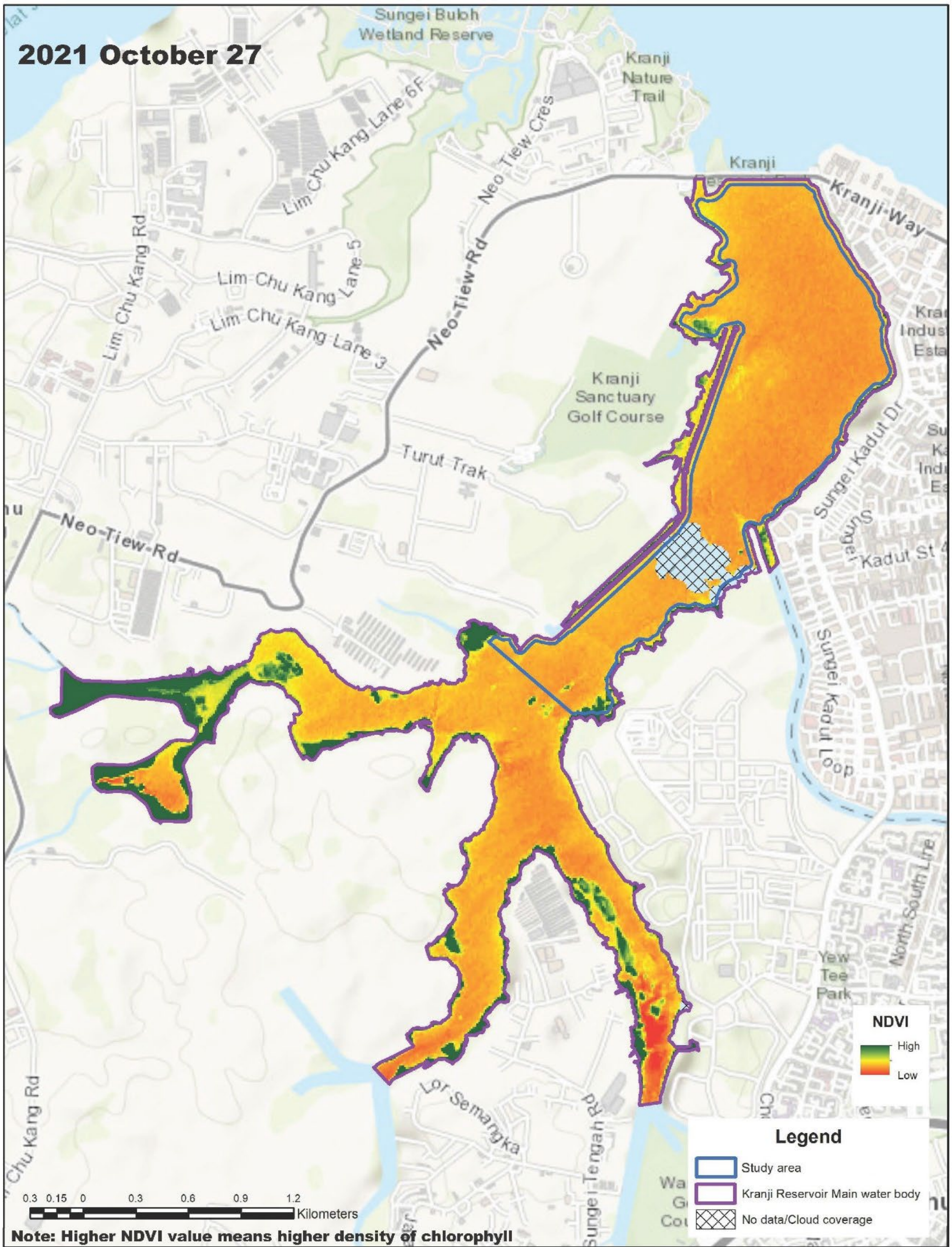
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021Sept05 Satellite LandSat TM8

Date: 17/2/2022

ERM



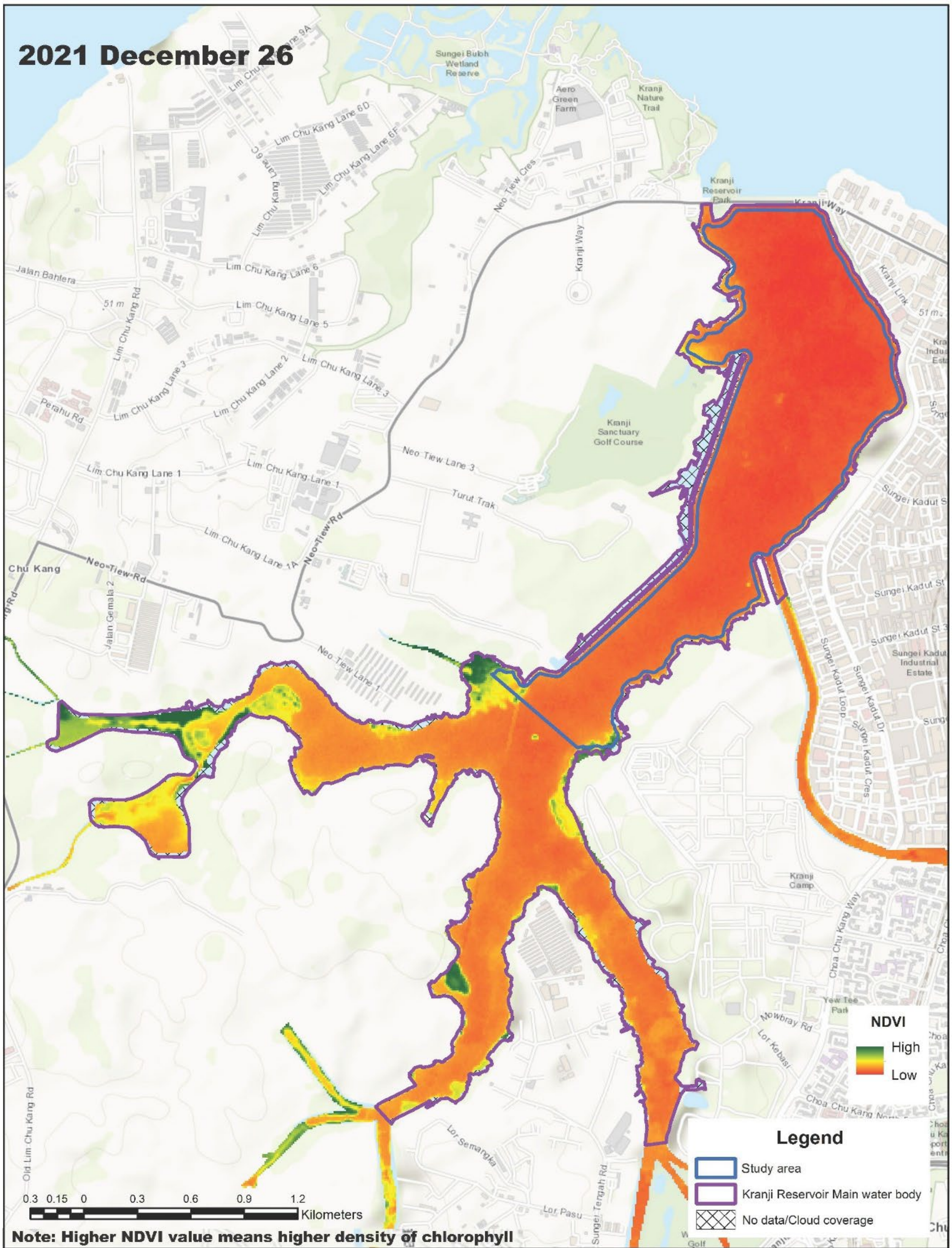
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021Oct27 Satellite Sentinel 2A

Date: 17/2/2022

ERM



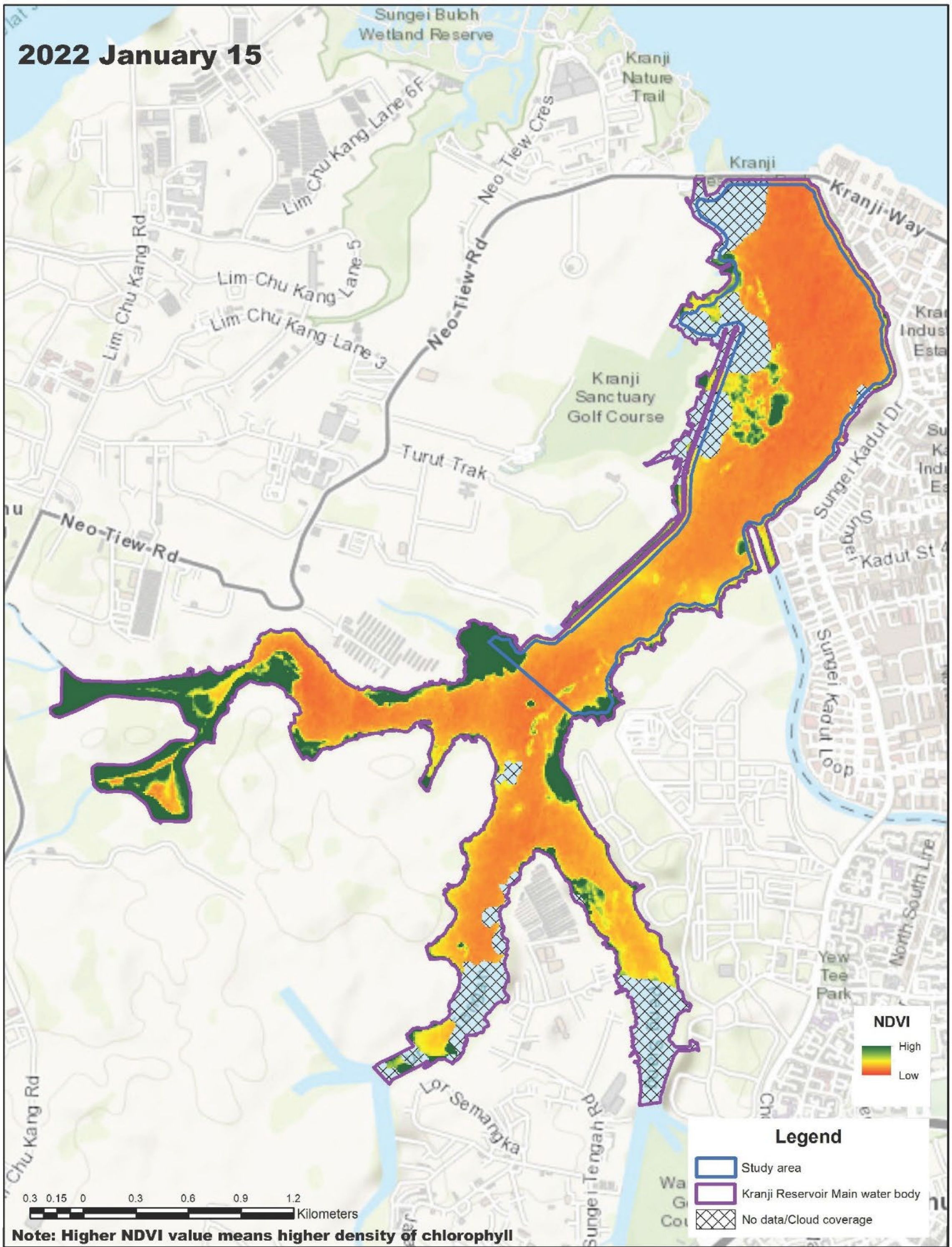
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2021Dec26 Satellite Sentinel 2A

Date: 18/6/2022

ERM



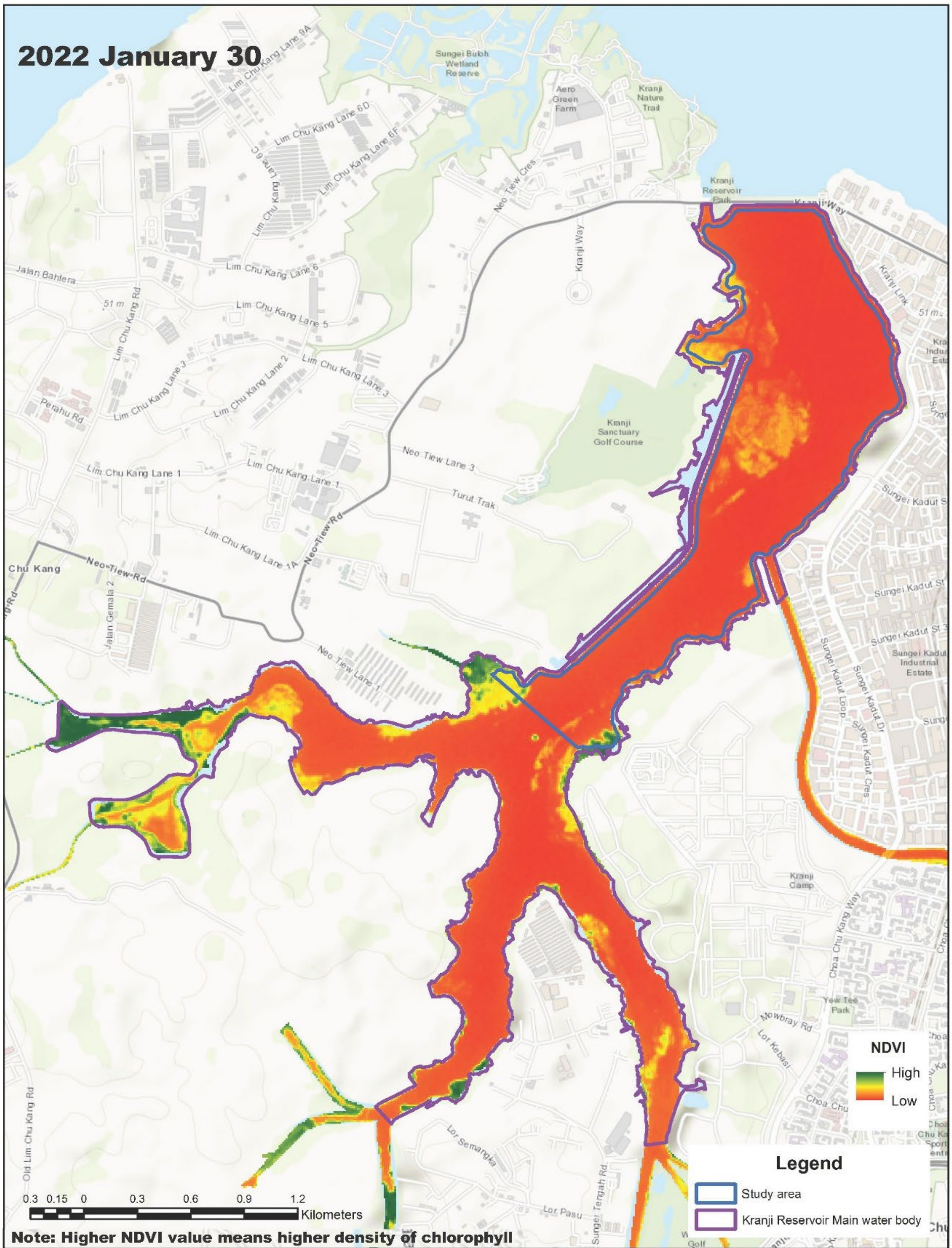
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2022Jan15 Satellite Sentinel 2A

Date: 17/2/2022

ERM



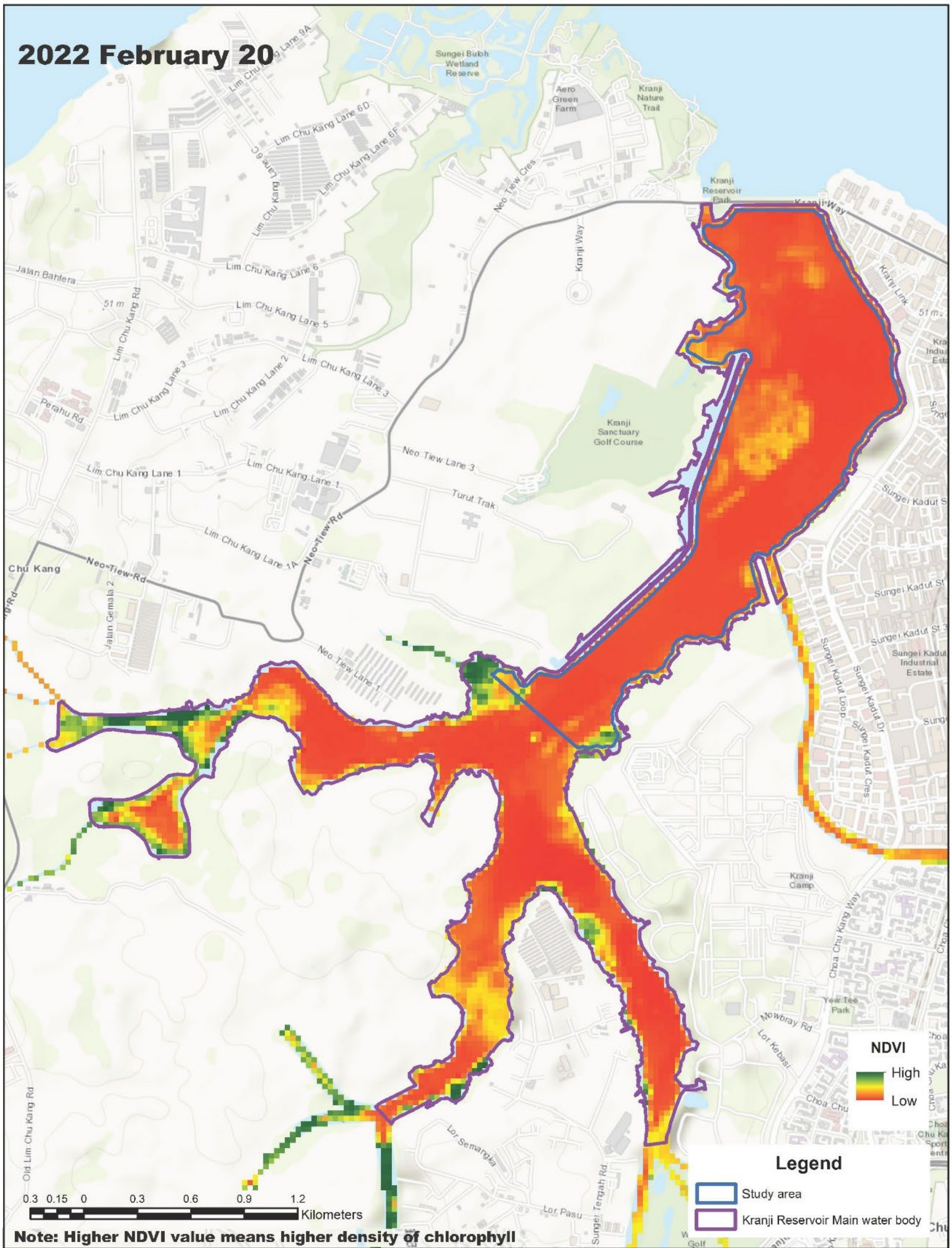
Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2022Jan30 Satellite Sentinel 2A

Date: 18/6/2022

ERM



Figure

Kranji Reservoir Map of Normalised Difference Vegetation Index

NDVI(Normalised Difference Vegetation Index) Based on 2022Feb20 Satellite LandSat TM8

Date: 18/6/2022

ERM

APPENDIX 7.5 SPATIAL SENSITIVITY MAPPING OF FOCAL BIRD SPECIES

APPENDIX 7.5: SPATIAL SENSITIVITY MAPPING OF FOCAL BIRD SPECIES

1.1 Flight Paths of Little Tern

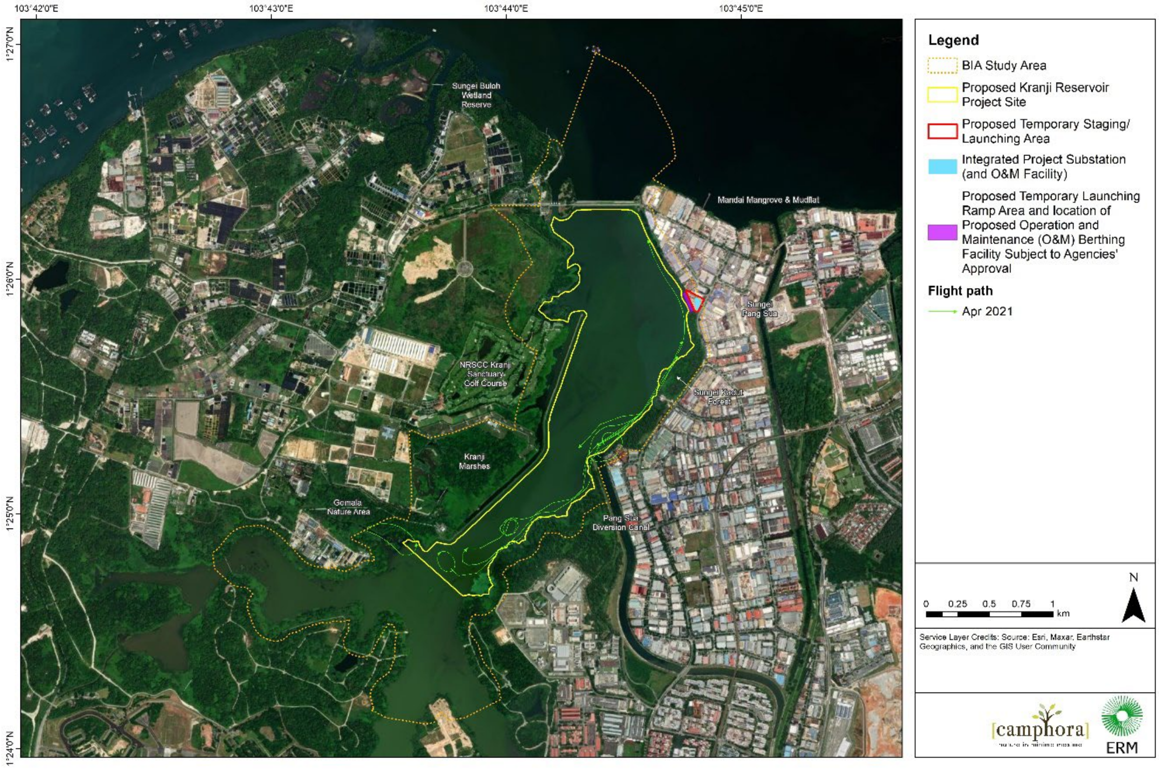


Figure 1: Flight Paths of Little Tern in April 2021

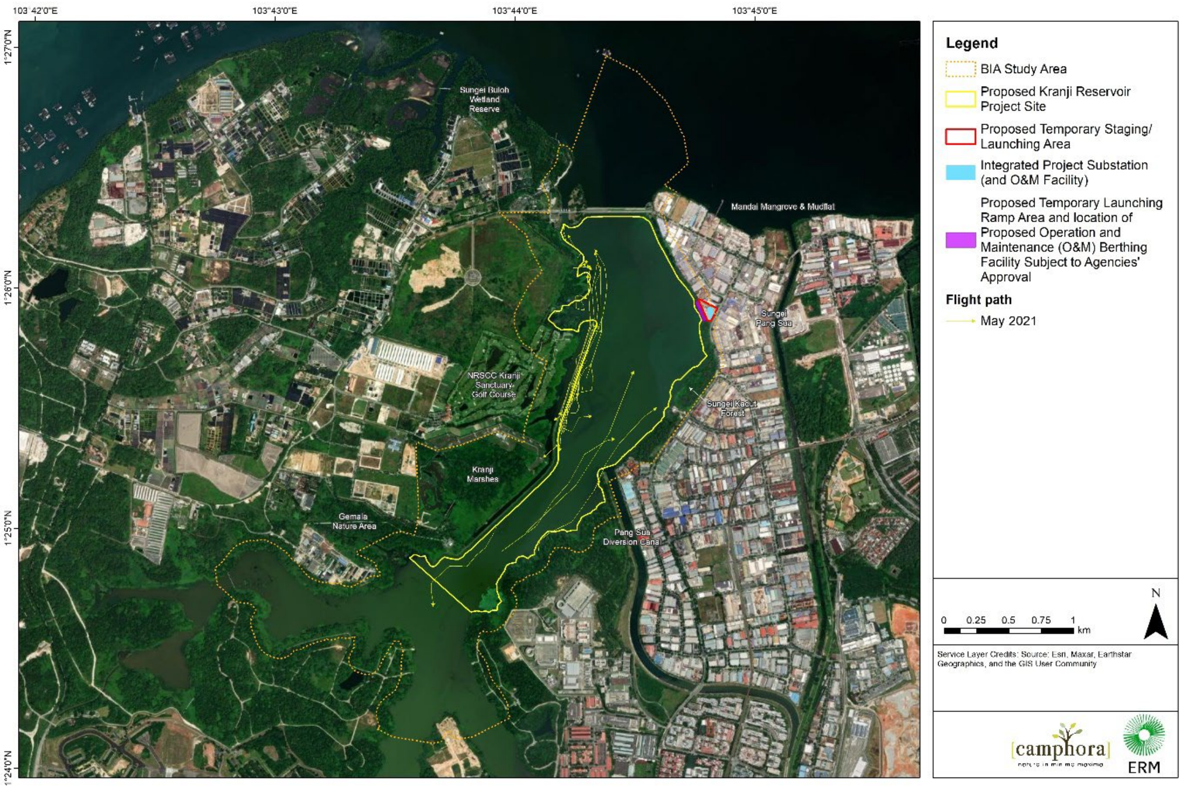


Figure 2: Flight Paths of Little Tern in May 2021

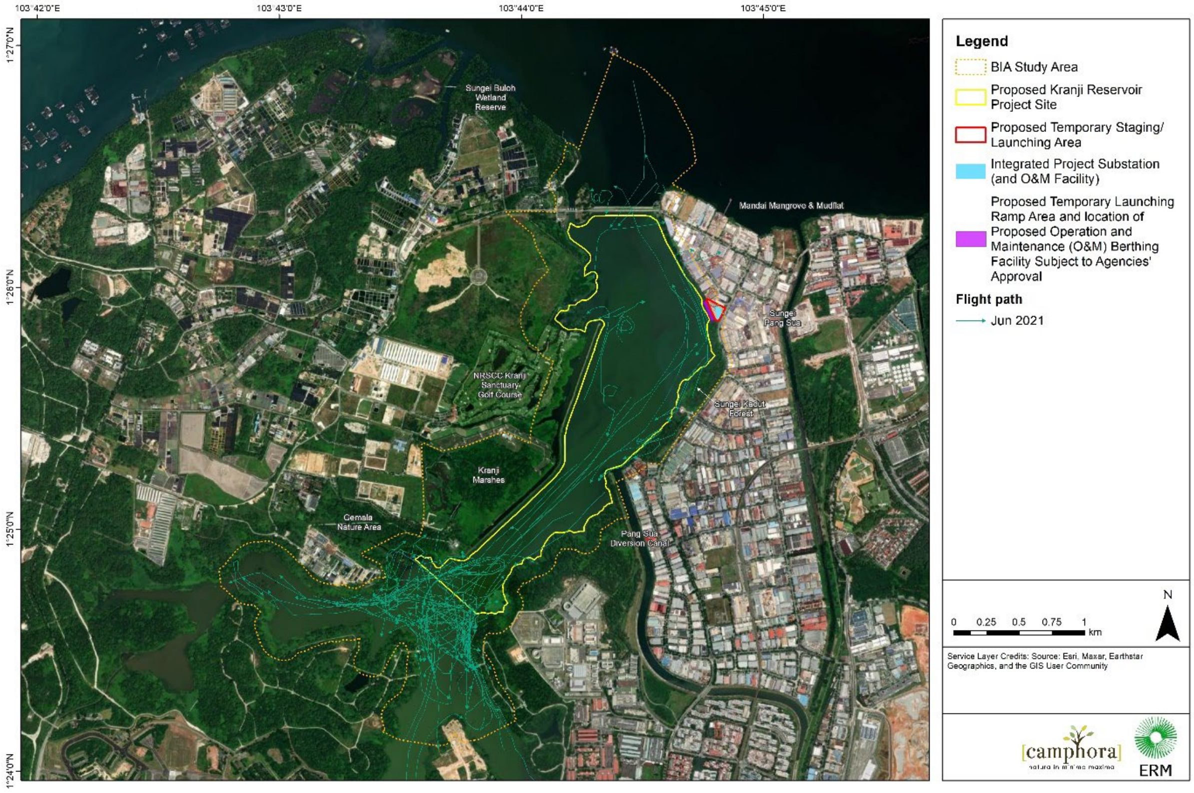


Figure 3: Flight Paths of Little Tern in June 2021

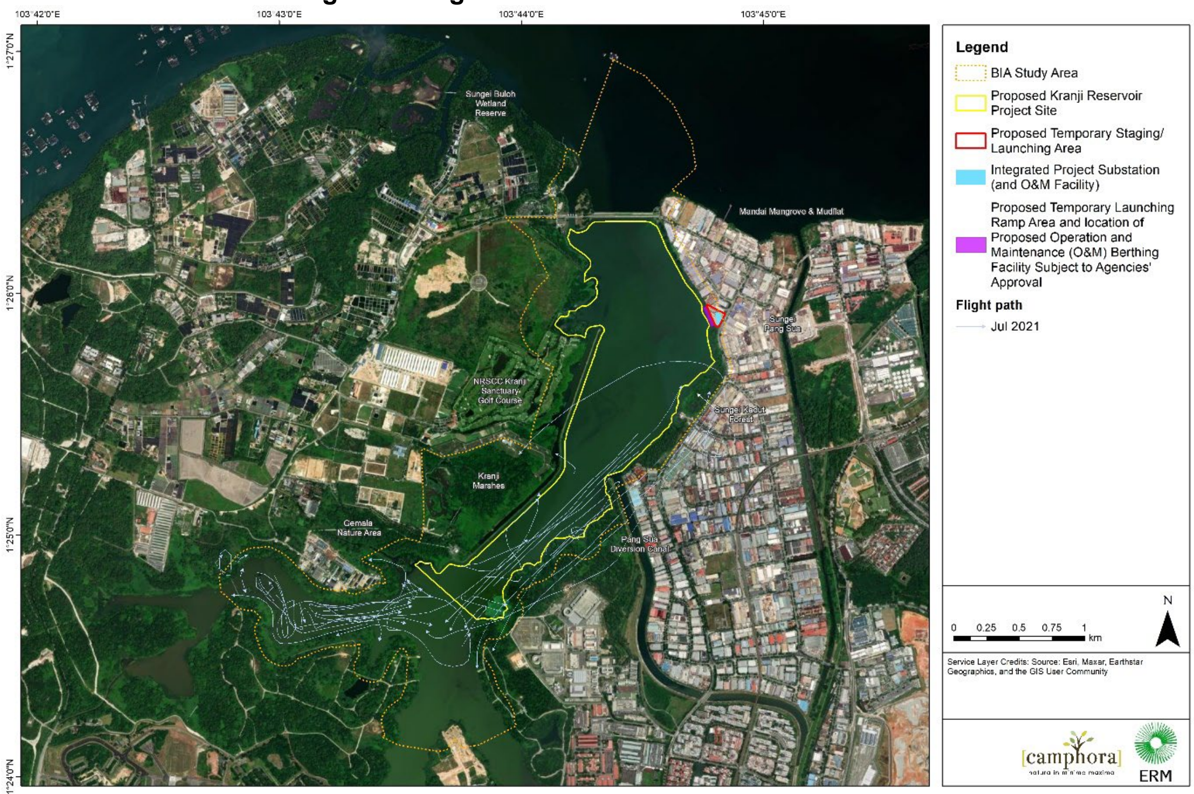


Figure 4: Flight Paths of Little Tern in Jul 2021

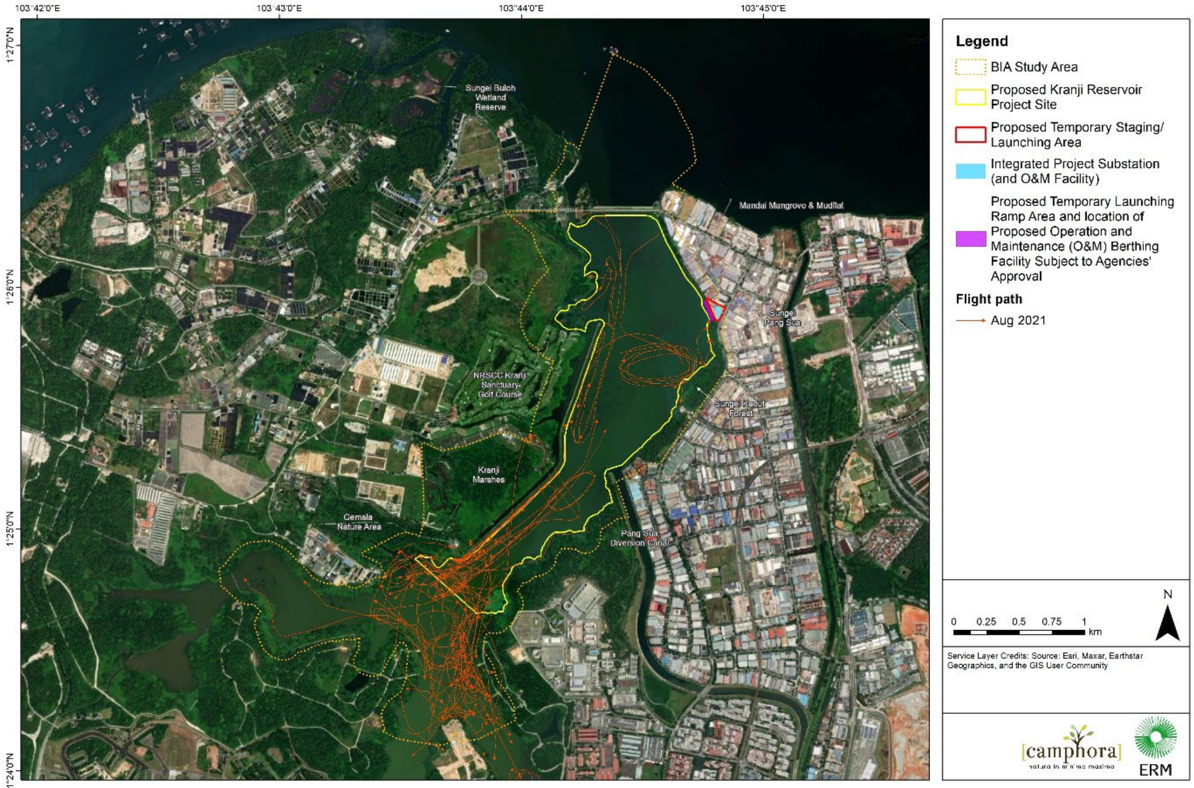


Figure 5: Flight Paths of Little Tern in Aug 2021

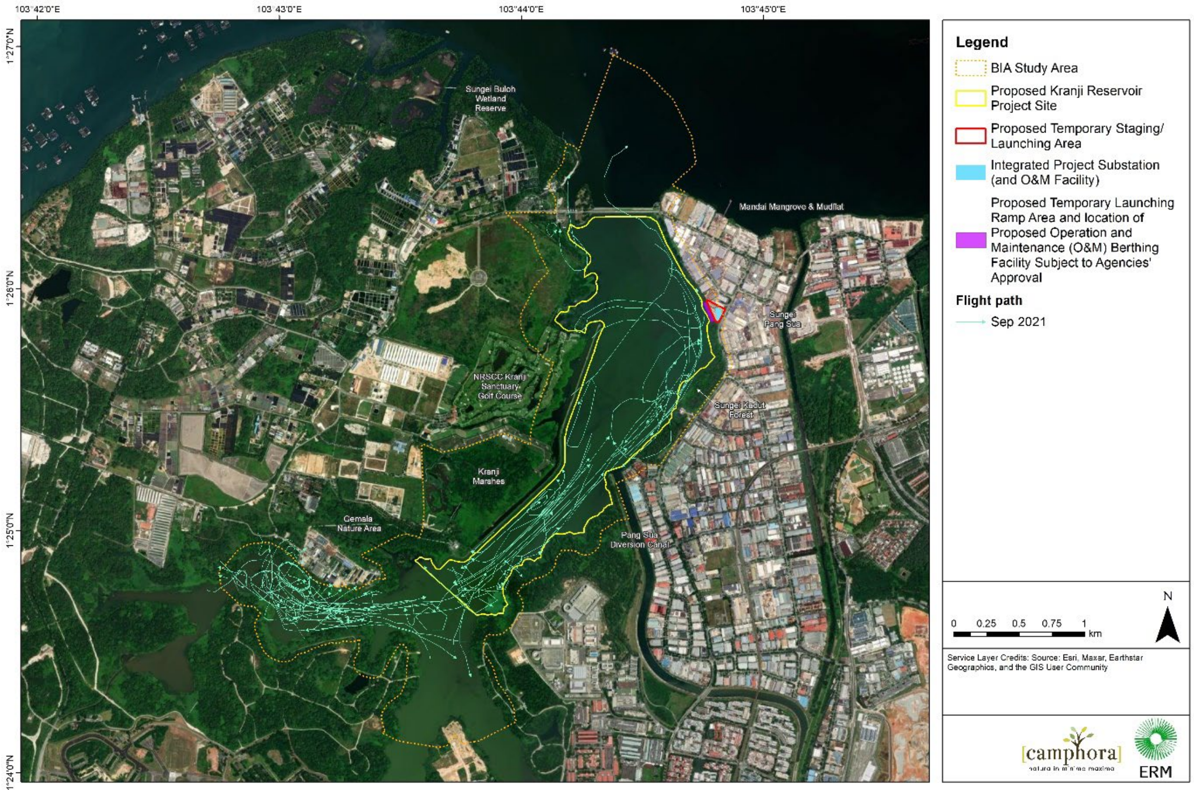


Figure 6: Flight Paths of Little Tern in Sep 2021

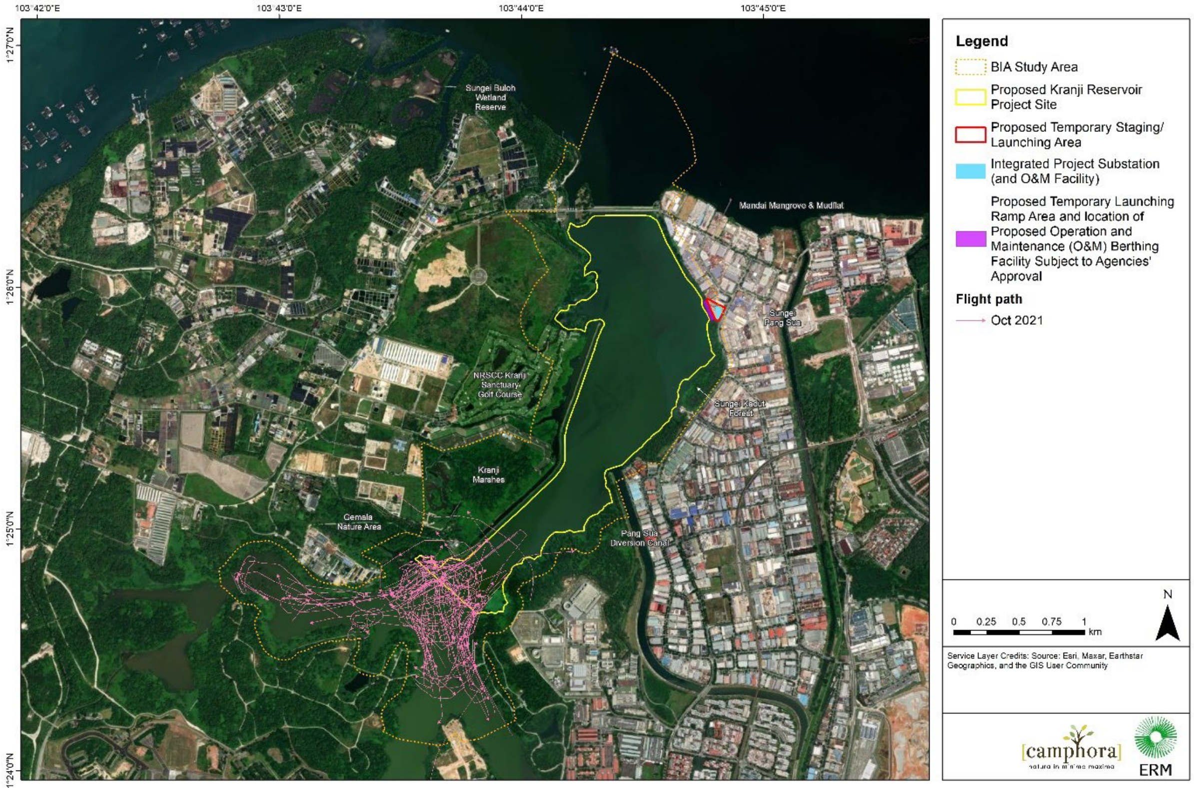


Figure 7: Flight Paths of Little Tern in Oct 2021

1.2 Foraging Events per Hour

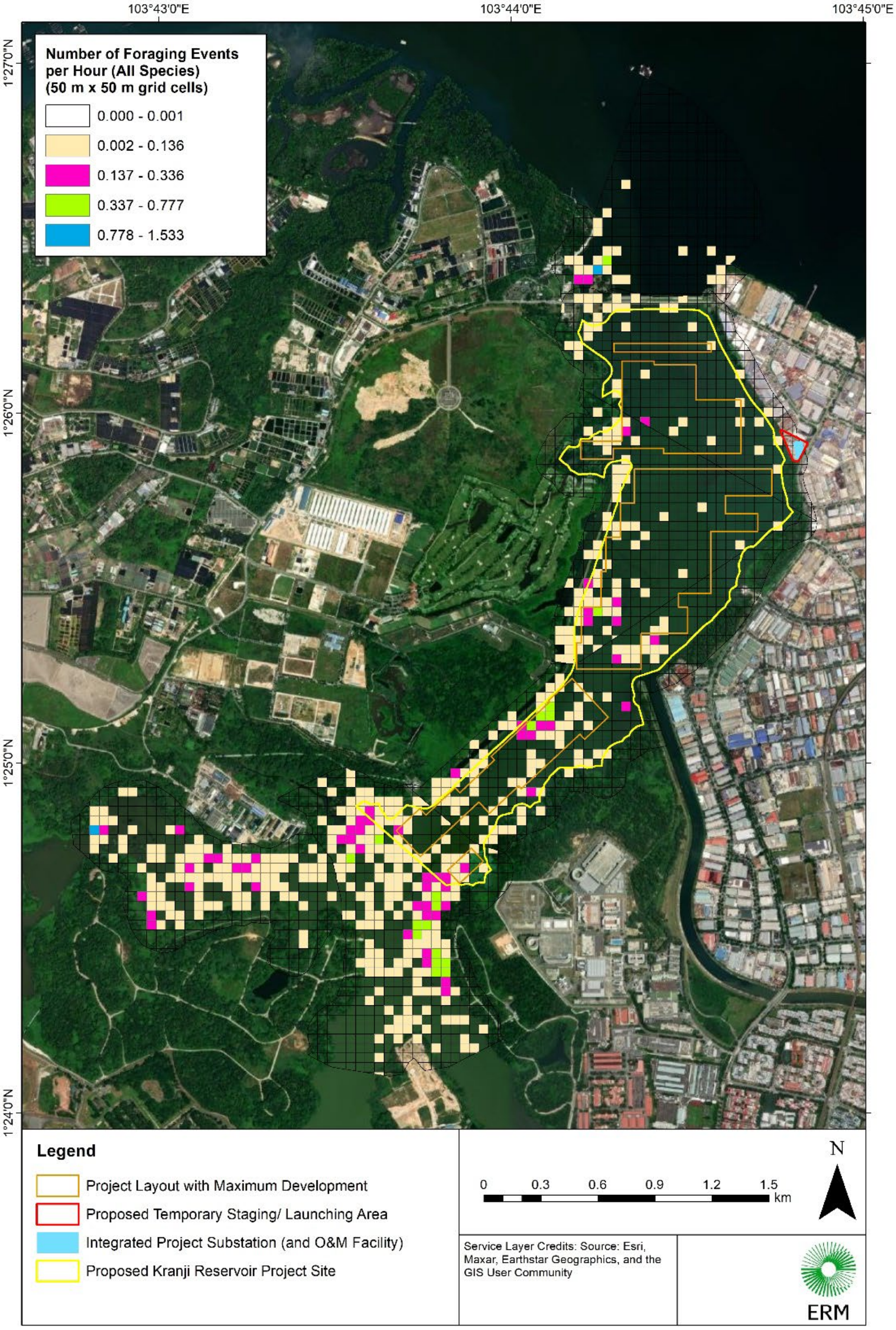


Figure 8: Number of Foraging Events per Hour of all Species (Unmitigated Maximum FPV Layout)

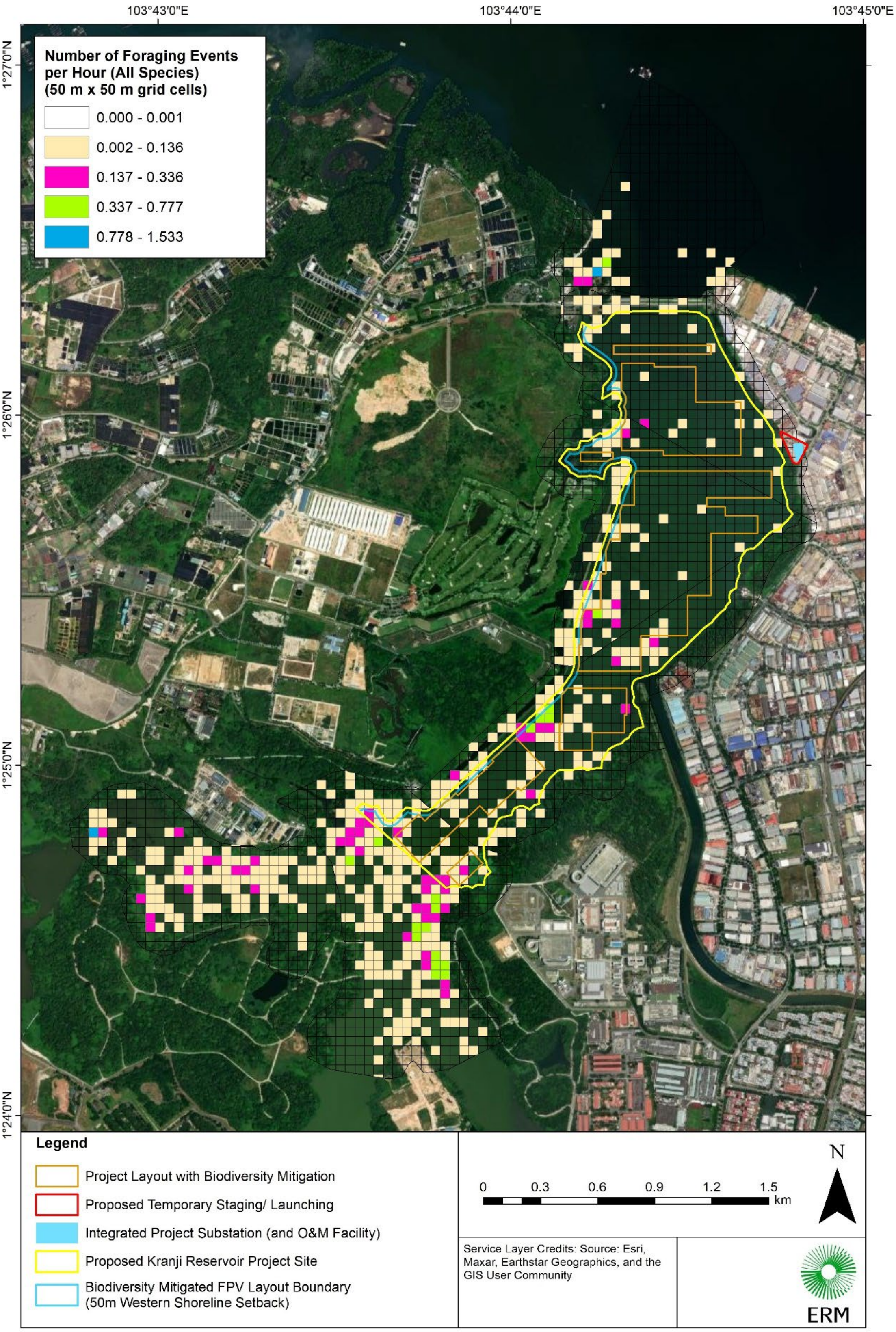


Figure 9: Number of Foraging Events per Hour of all Species (Mitigated Biodiversity FPV Layout)

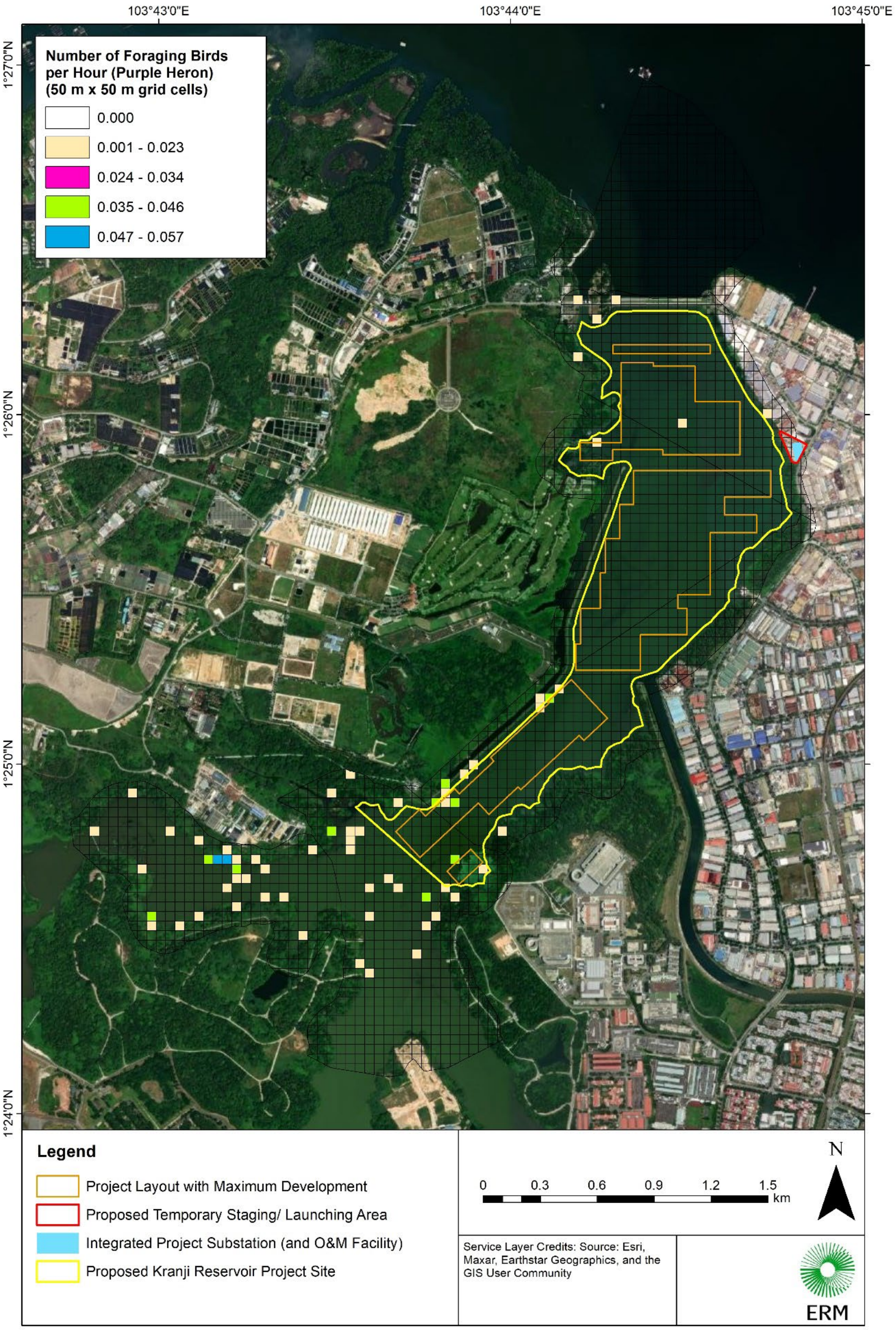


Figure 10: Number of Foraging Events per Hour of Purple Heron (Unmitigated Maximum FPV Layout)

Figure 11: Number of Foraging Events per Hour of Purple Heron (Mitigated Biodiversity FPV Layout)

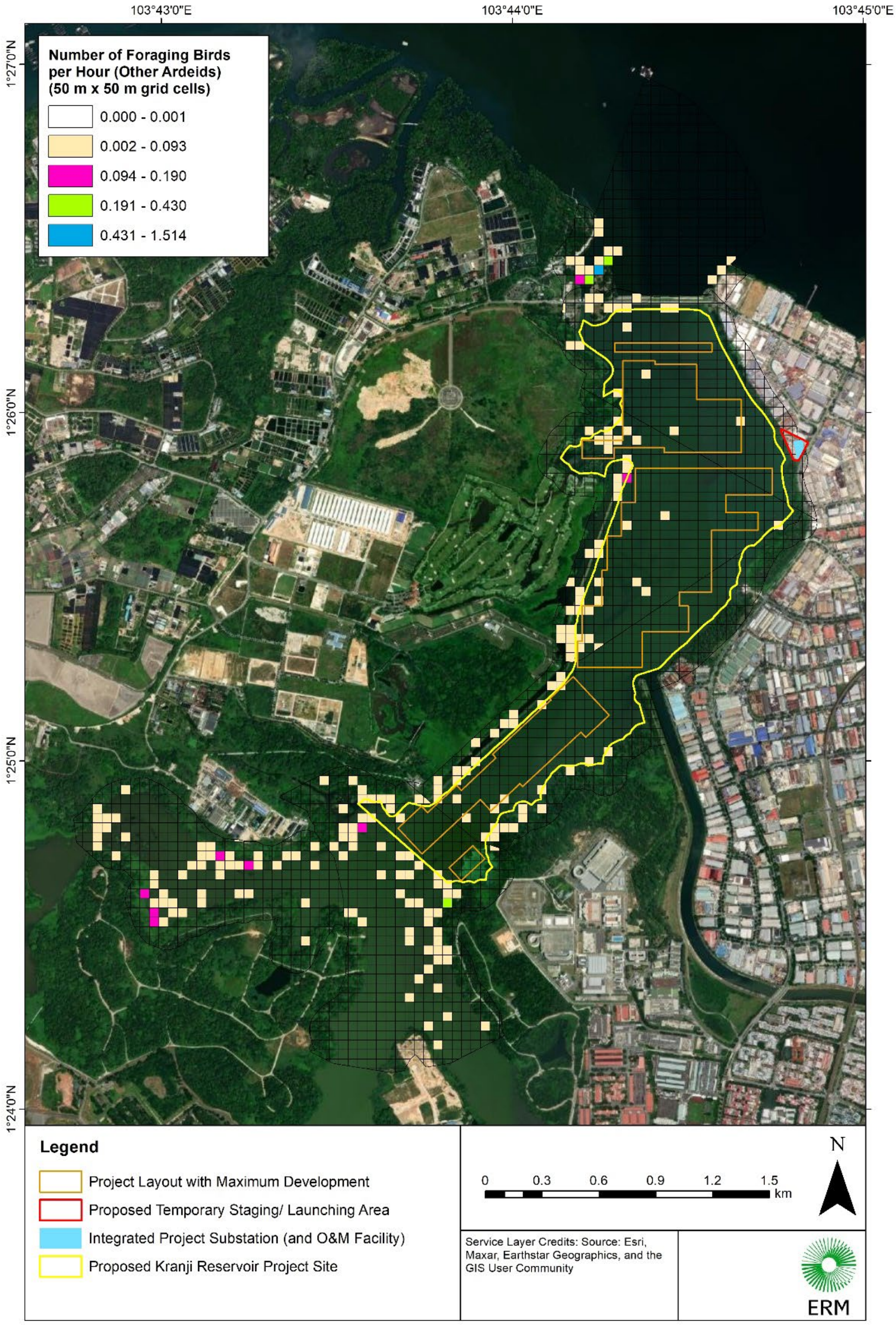


Figure 12: Number of Foraging Events per Hour of Other Ardeids (Unmitigated Maximum FPV Layout)

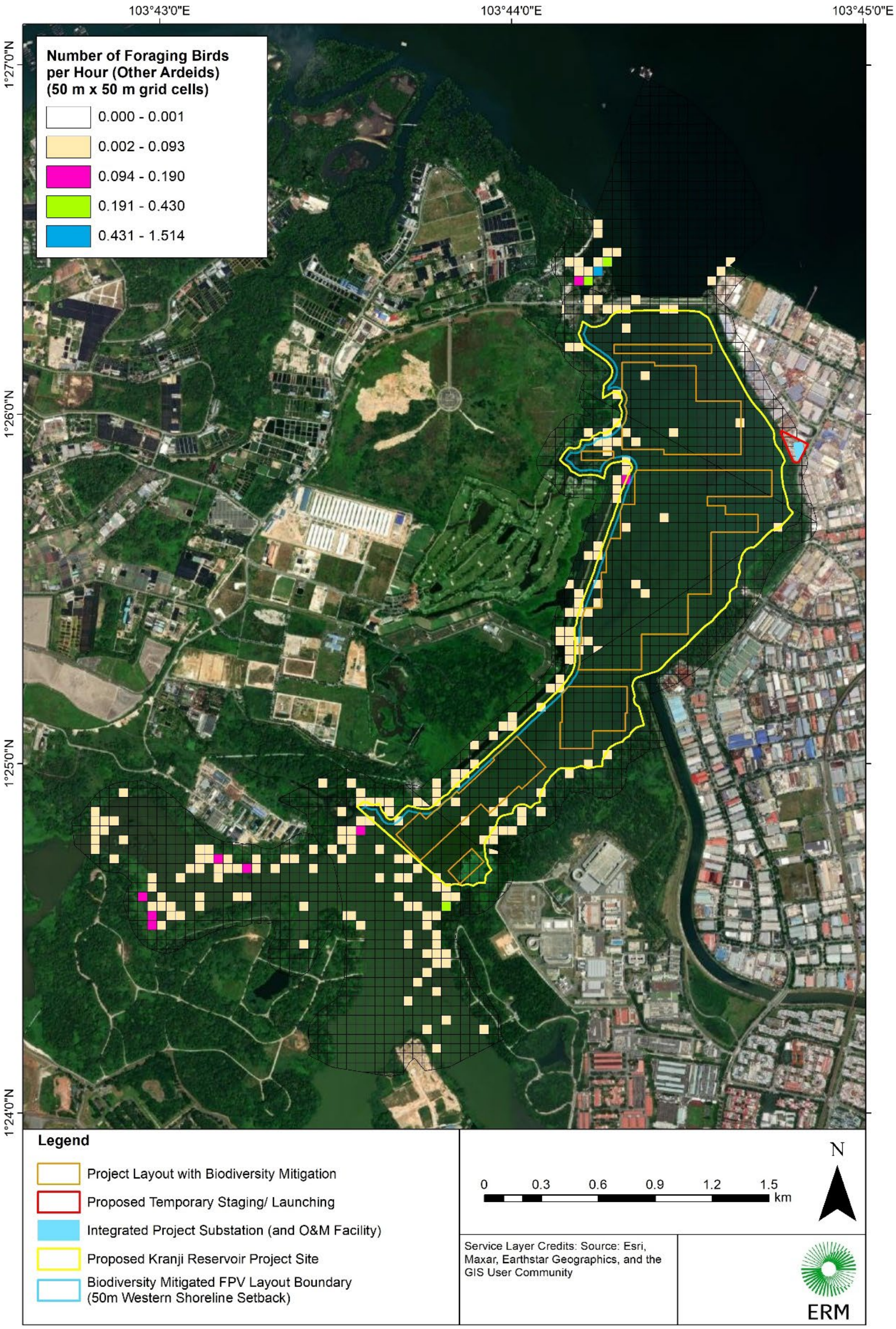


Figure 13: Number of Foraging Events per Hour of Other Ardeids (Mitigated Biodiversity FPV Layout)

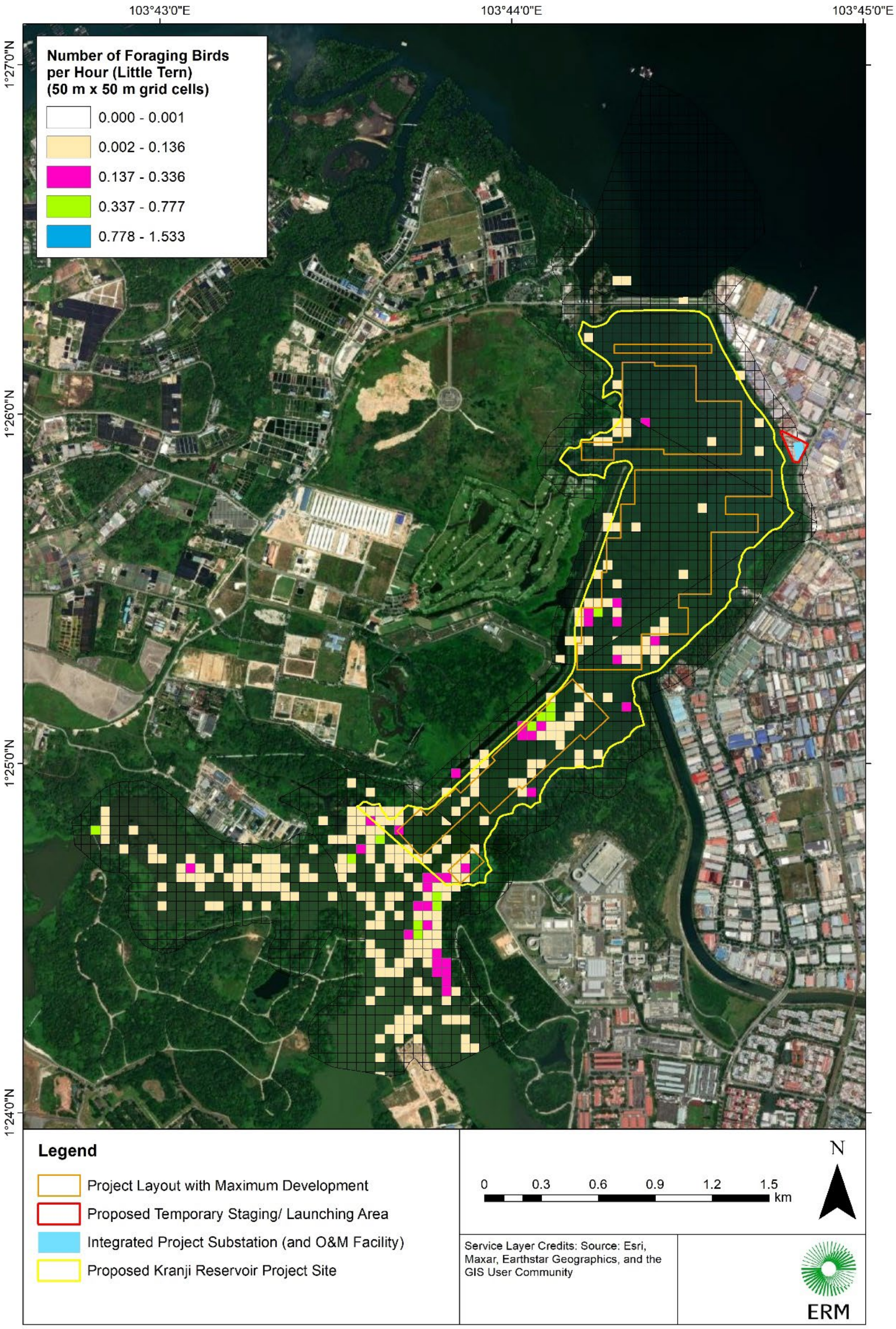


Figure 14: Number of Foraging Events per Hour of Little Tern (Unmitigated Maximum FPV Layout)

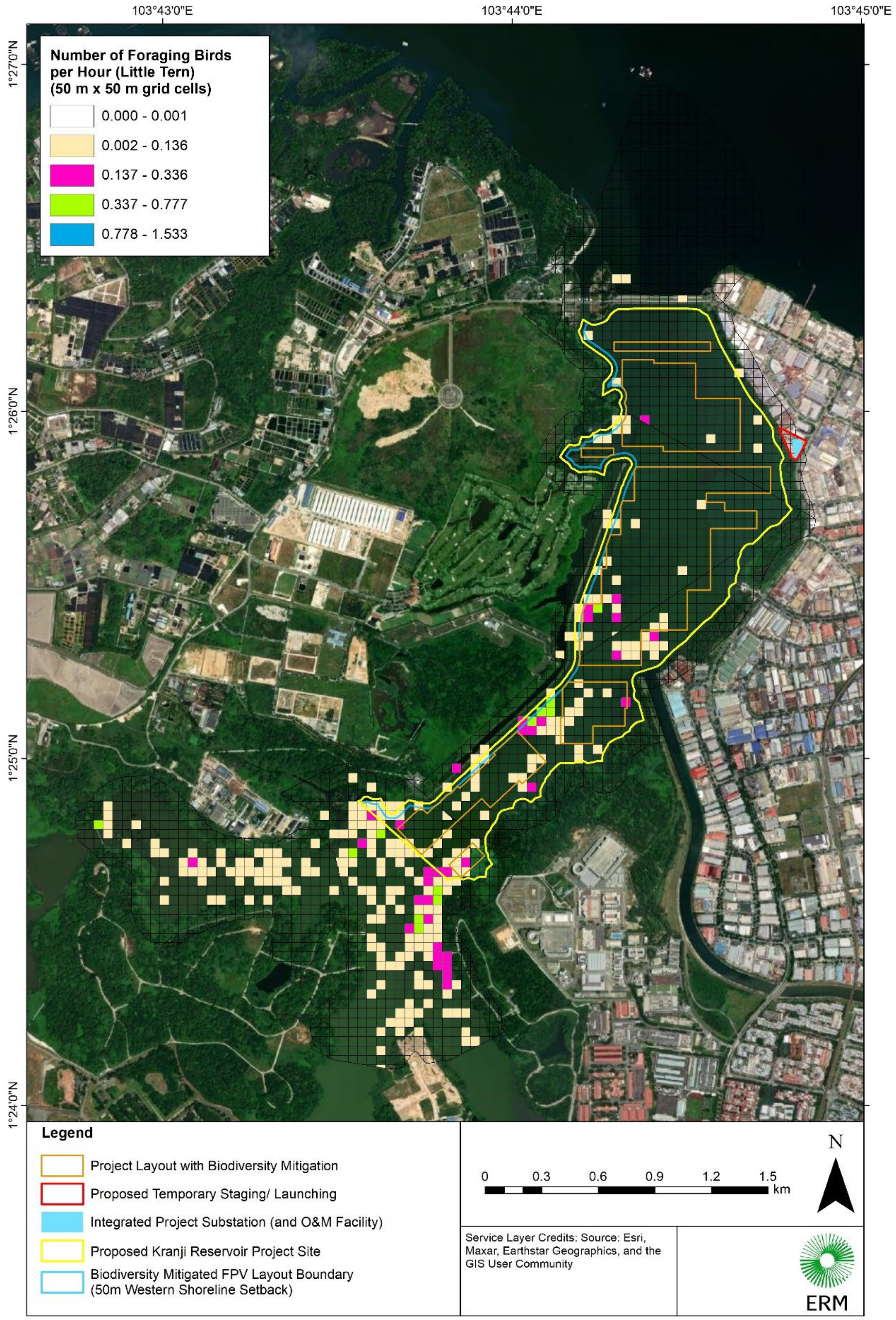


Figure 15: Number of Foraging Events per Hour of Little Tern (Mitigated Biodiversity FPV Layout)

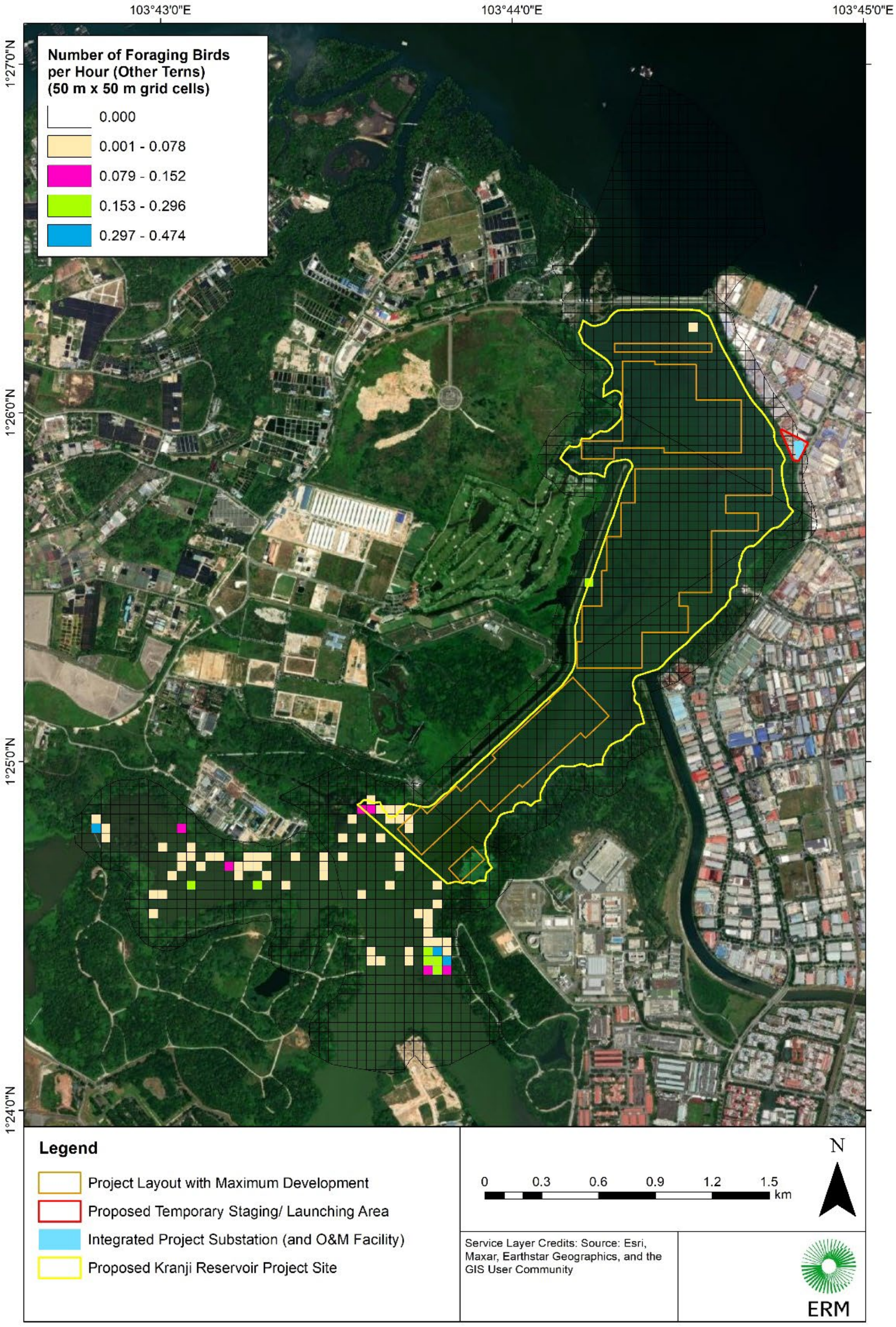


Figure 16: Number of Foraging Events per Hour of Other Terns (Unmitigated Maximum FPV Layout)

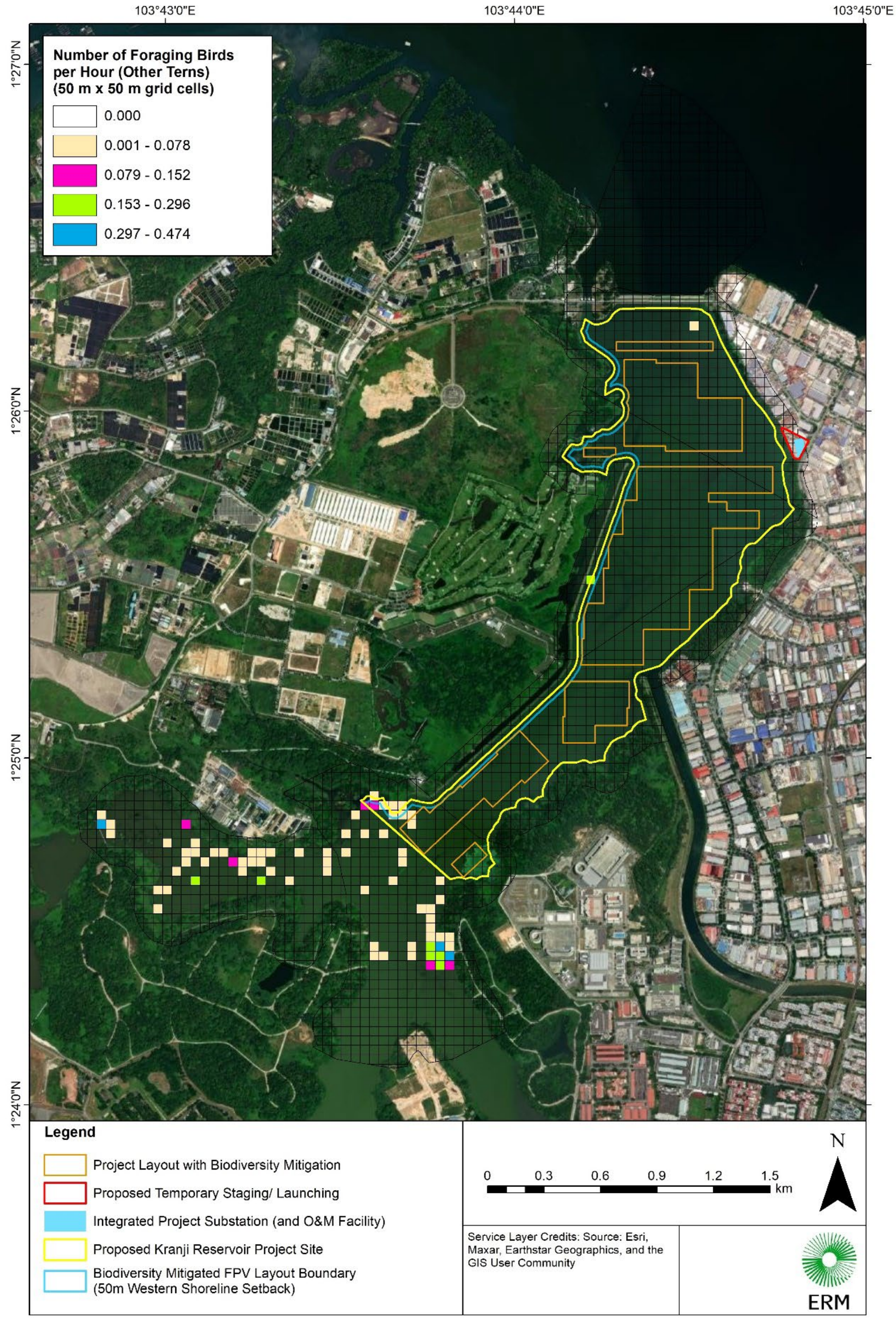


Figure 17: Number of Foraging Events per Hour of Other Terns (Mitigated Biodiversity FPV Layout)

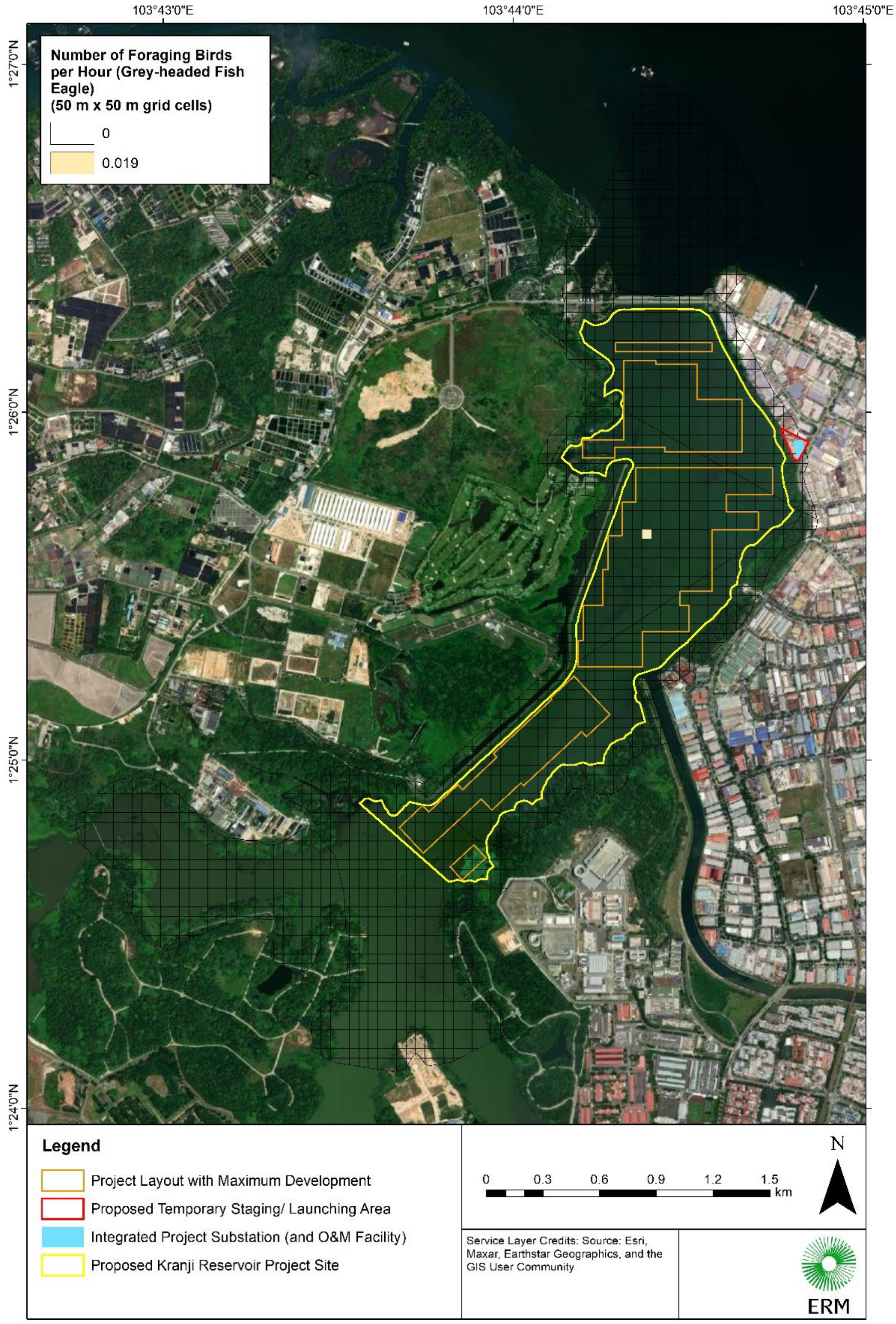


Figure 18: Number of Foraging Events per Hour of Grey-headed Fish Eagle (Unmitigated Maximum FPV Layout)

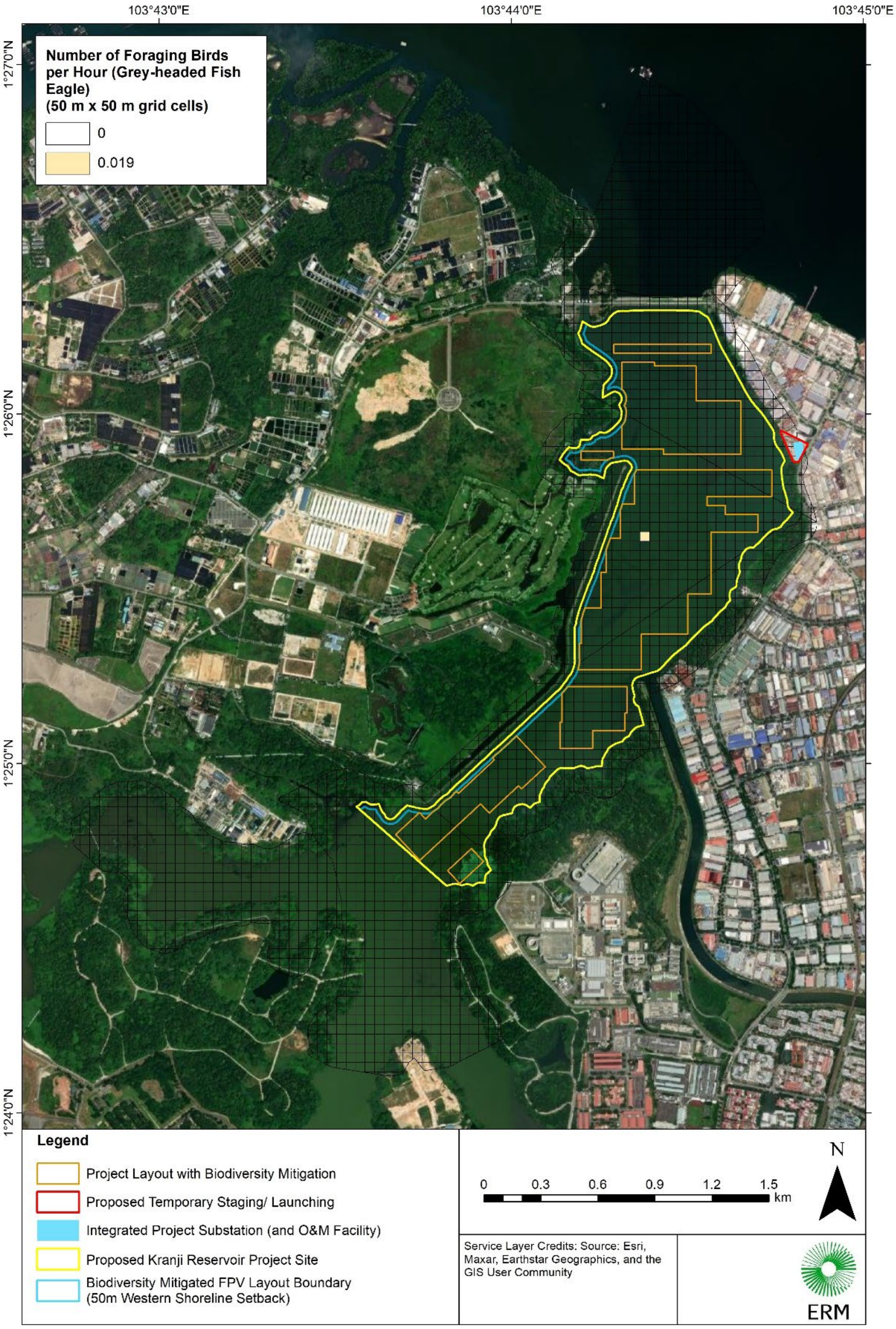


Figure 19: Number of Foraging Events per Hour of Grey-headed Fish Eagle (Mitigated Biodiversity FPV Layout)

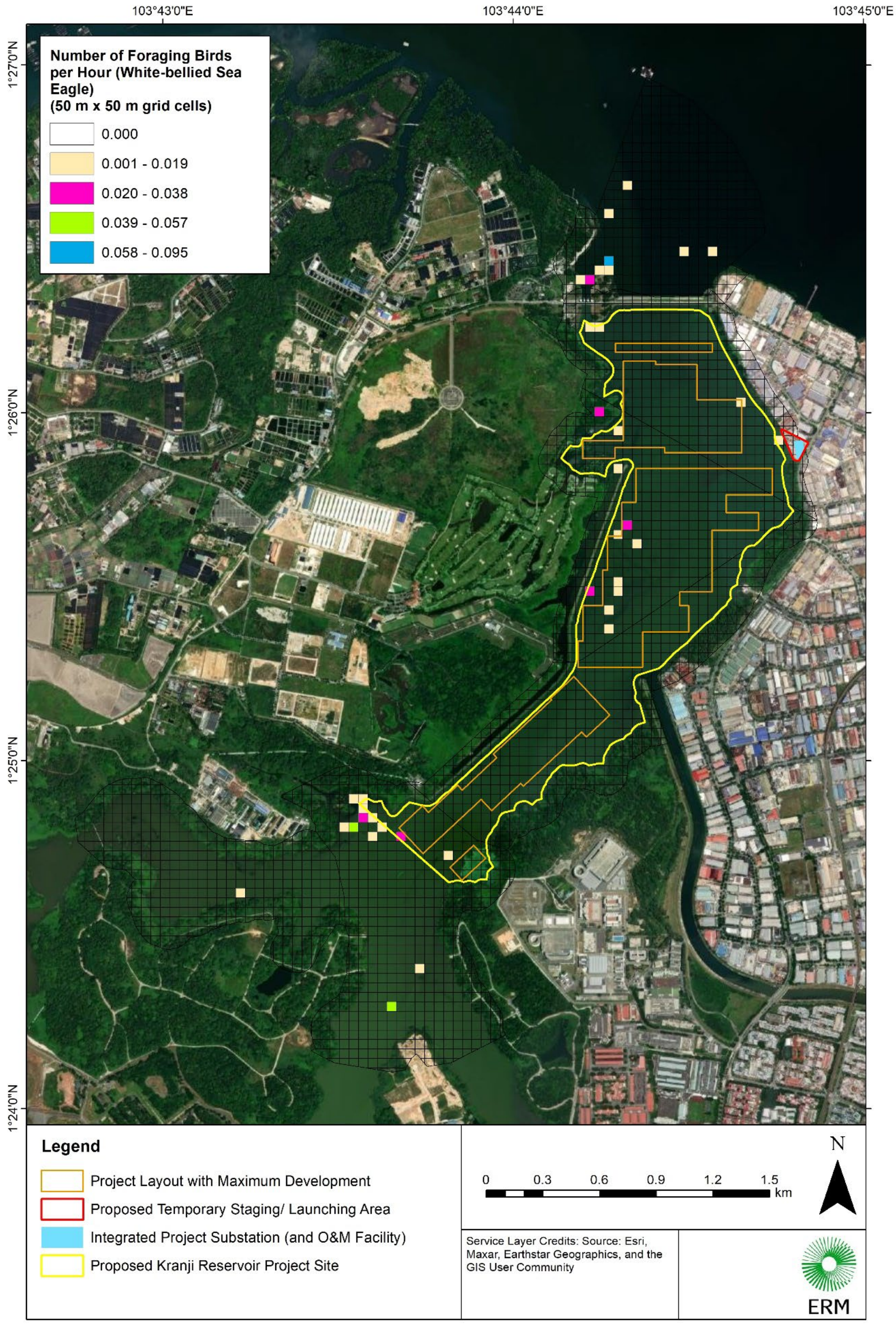


Figure 20: Number of Foraging Events per Hour of White-bellied Sea Eagle (Unmitigated Maximum FPV Layout)

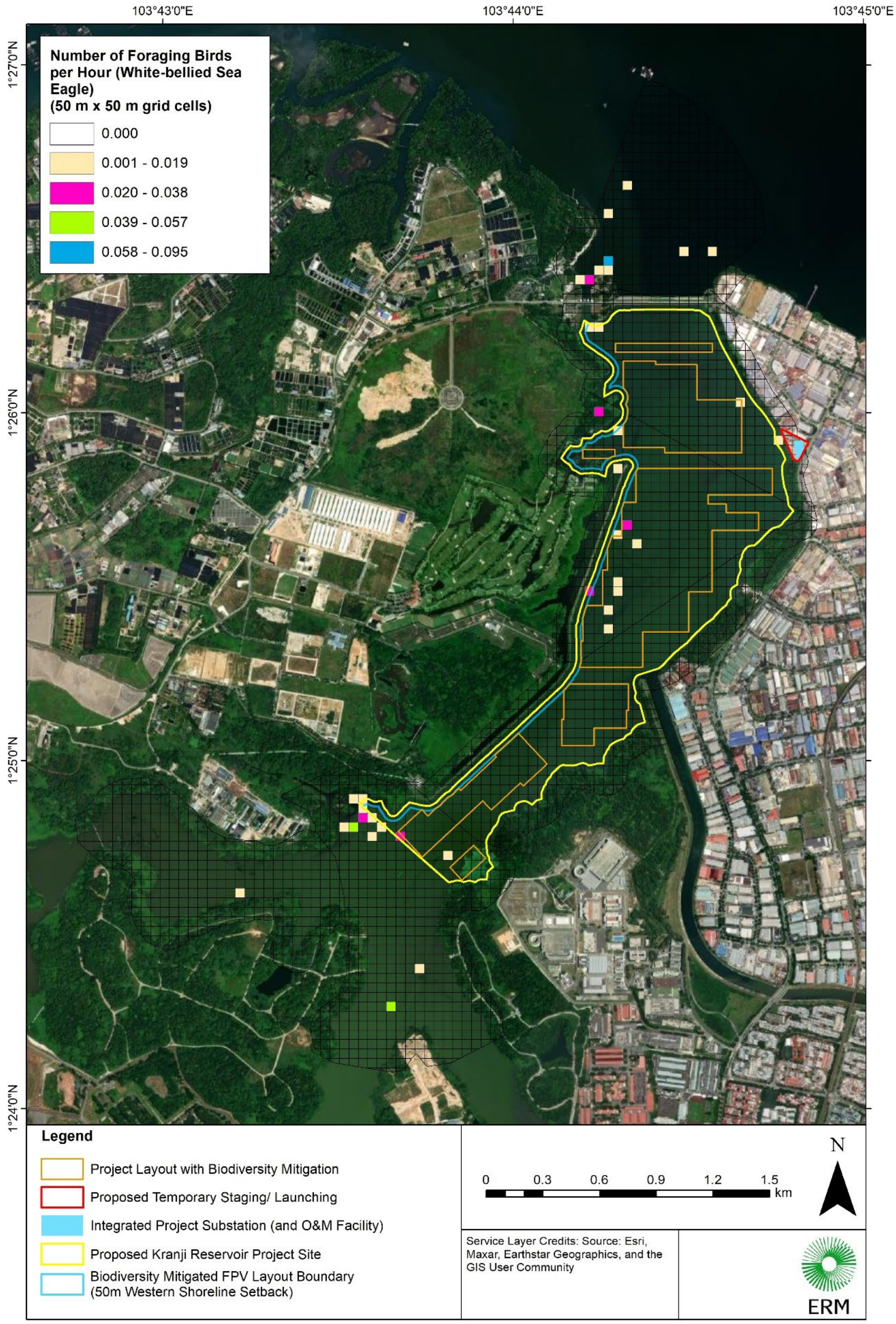


Figure 21: Number of Foraging Events per Hour of White-bellied Sea Eagle (Mitigated Biodiversity FPV Layout)

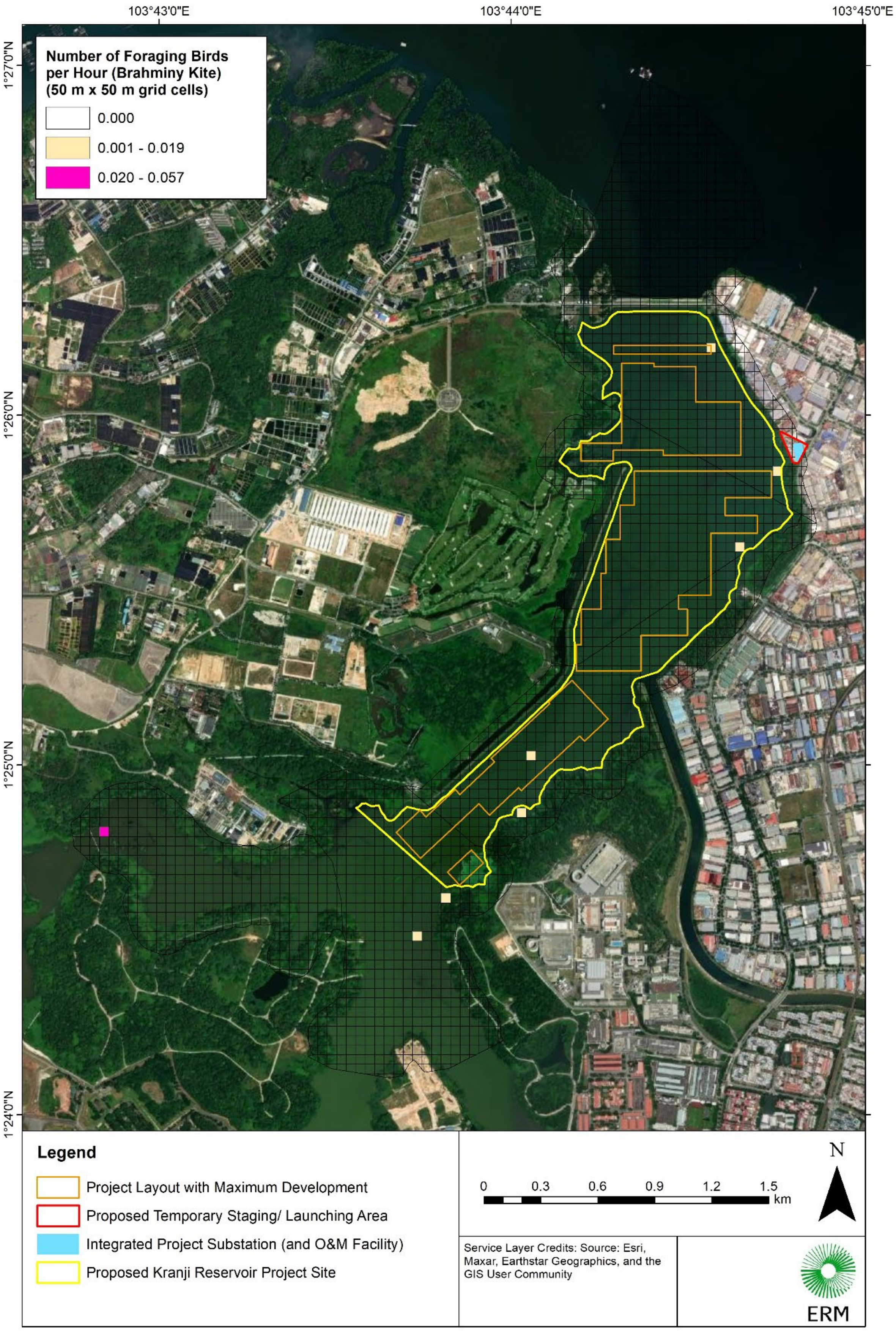


Figure 22: Number of Foraging Events per Hour of Brahminy Kite (Unmitigated Maximum FPV Layout)

Figure 23: Number of Foraging Events per Hour of Brahminy Kite (Mitigated Biodiversity FPV Layout)

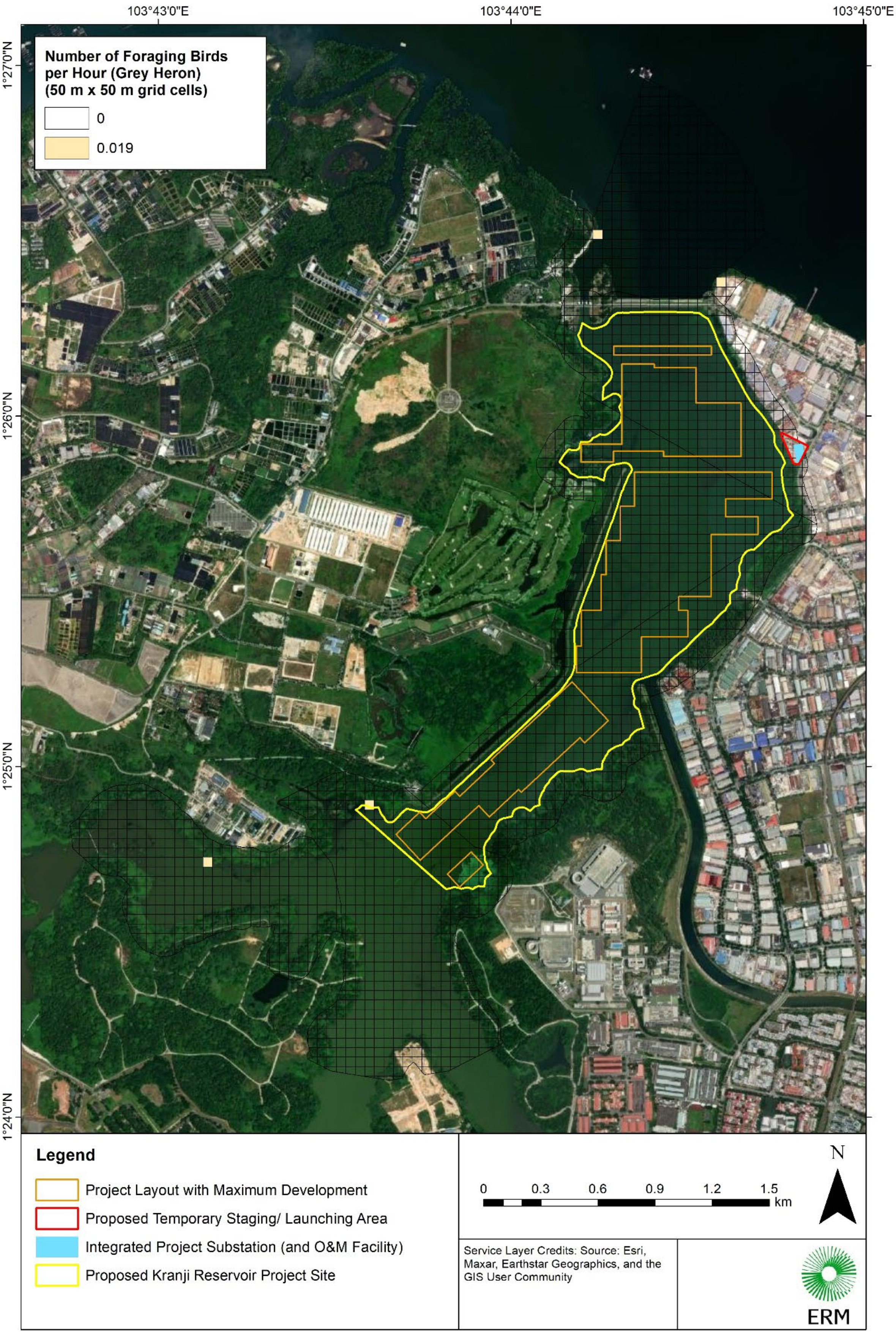


Figure 24: Number of Foraging Events per Hour of Grey Heron (Unmitigated Maximum FPV Layout)

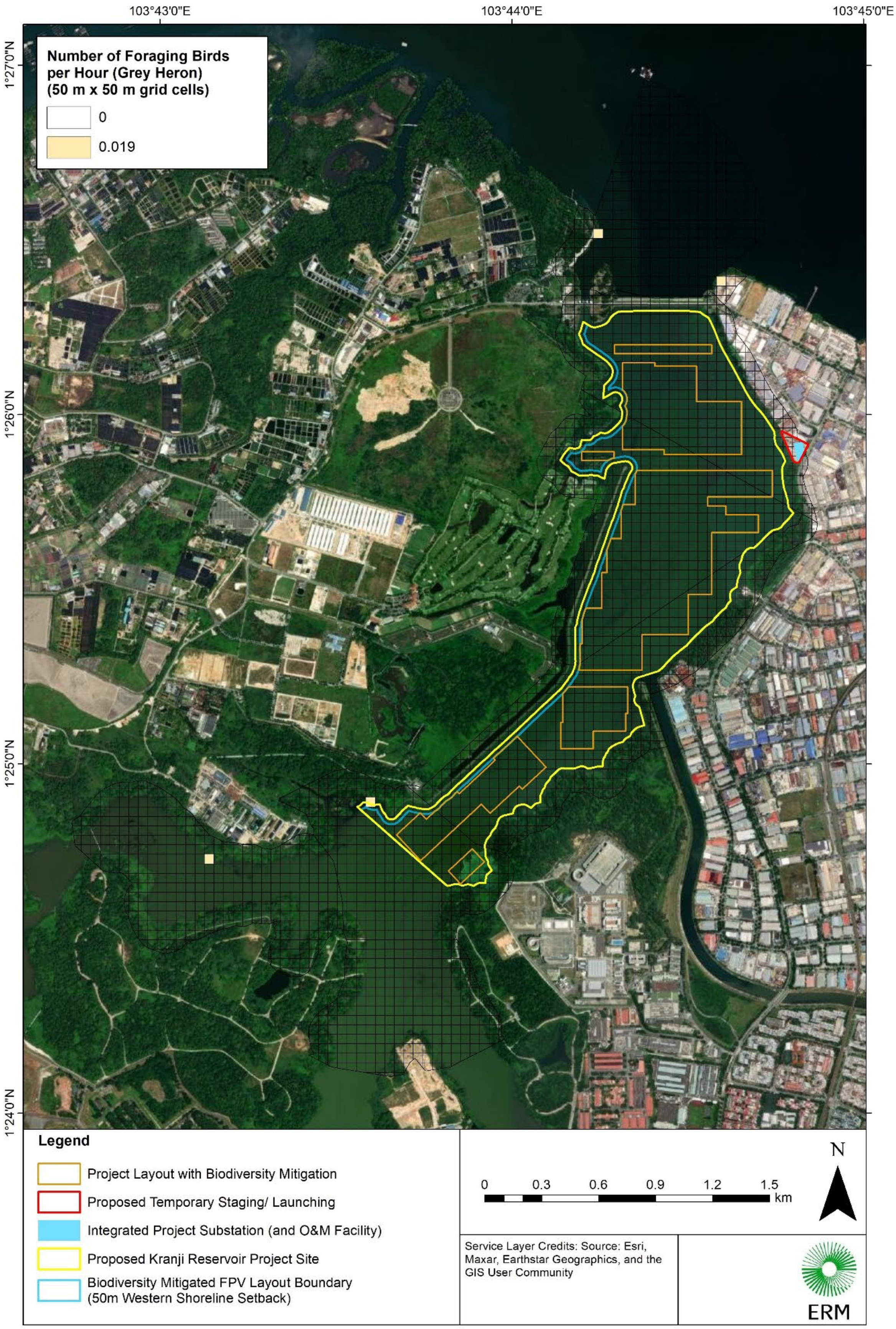


Figure 25: Number of Foraging Events per Hour of Grey Heron (Mitigated Biodiversity FPV Layout)

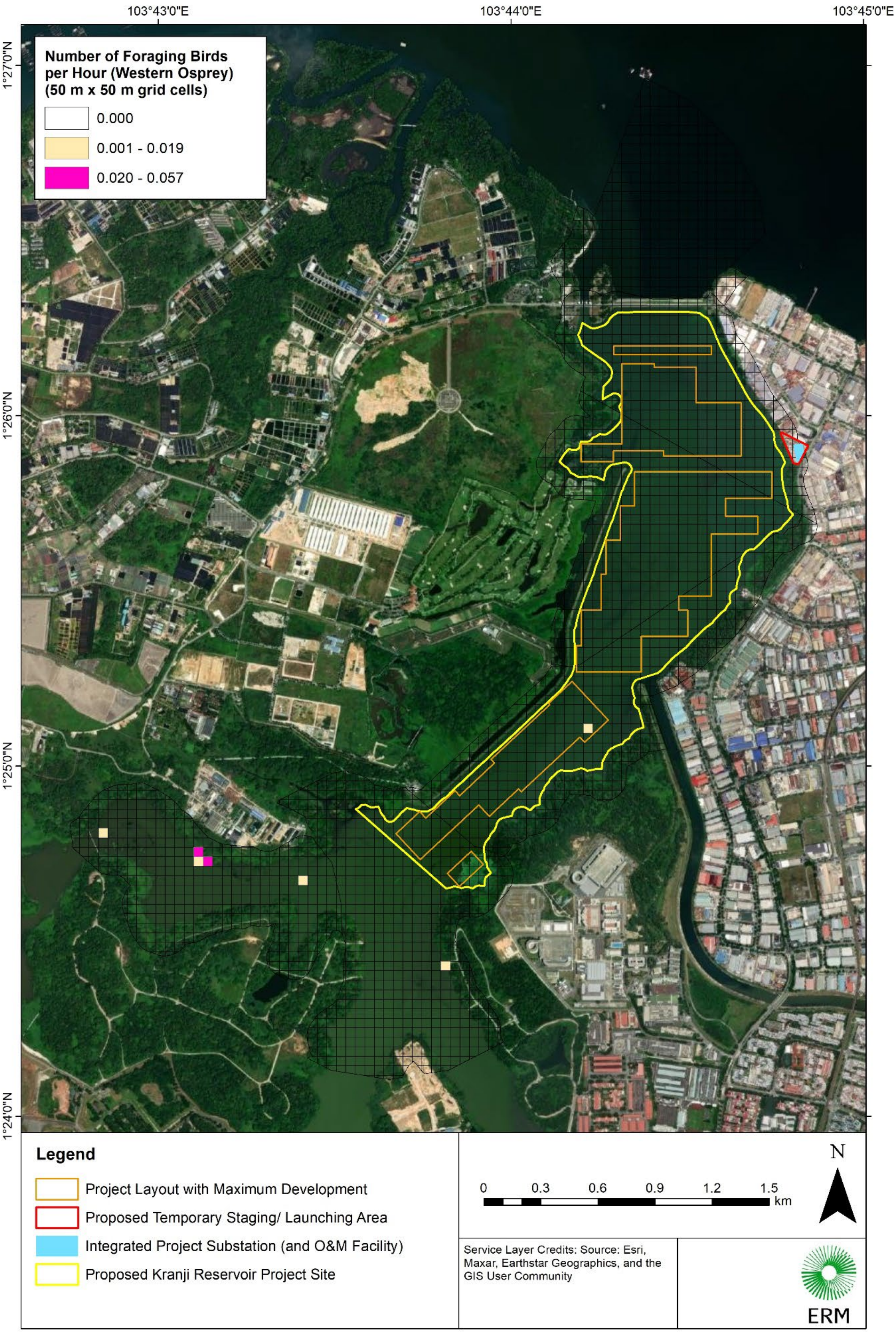


Figure 26: Number of Foraging Events per Hour of Western Osprey (Unmitigated Maximum FPV Layout)

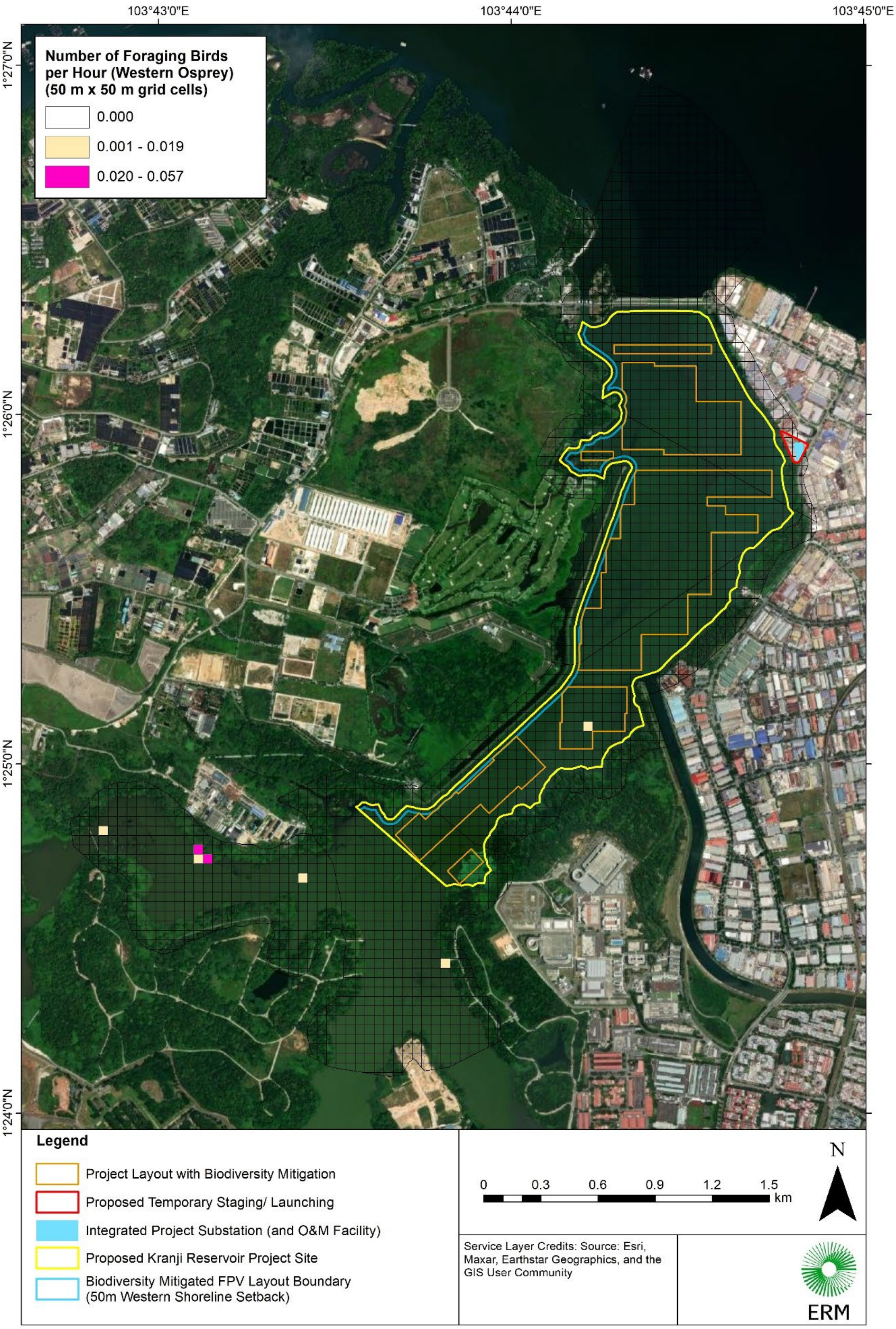


Figure 27: Number of Foraging Events per Hour of Western Osprey (Mitigated Biodiversity FPV Layout)

1.3 Black-crowned Night Heron Roosting Sites

Figure 28: Black-crowned Night Heron Roosting Sites (Unmitigated Maximum FPV Layout)

Figure 29: Black-crowned Night Heron Roosting Sites (Biodiversity Mitigation FPV Layout)

APPENDIX 7.6 PILING NOISE - ECOLOGICAL DISTURBANCE MATRIX

APPENDIX 7.6: PILING NOISE – ECOLOGICAL DISTURBANCE MARTIX

Table 1: Assessment of Disturbance by in-reservoir Piling Noise for Sensitive Receptors (for unmitigated FPV layout)[1]

Sensitive Receptor	Sensitivity	Nearest Distance from piling (unmitigated FPV layout)	Construction (Piling) noise level at receptor (dB(A))	Representative Average Background Noise Levels (dB(A))[2]	Literature Guideline values for impacts on Wildlife (dB(A)) [3]	Potential Impact/ Disturbance	Magnitude of Impact	Significance of Impact (sensitivity x magnitude)
Areas of High Sensitivity								
SBWR	High	> 500 m	0		70	No	Negligible	Negligible
Kranji Marshes	High	25 m	81	62 (western shoreline)	70	Yes. 5,550m^2 of Kranji Marshes would be affected by 4 simultaneous unmitigated piling rigs 25m from the shoreline with noise level of 70 dB(A) and 60,780m^2 with noise level of 62 dB(A) Total reserve size 57 ha. <1% of total reserve impacted with noise level at 70 dB(A) and <11% impacted with noise level at 62 dB(A).	Negligible (70 dB)-**Small (62 dB)**	Negligible-**Moderate**
Gemala Nature Area	High	40 m	77		70	Yes. 4,-500m^2 affected by 4 simultaneous unmitigated piling rigs 40 m from the shoreline and 44,700m^2 by noise level of 62 dB(A). Total reserve size 20.1 ha. 2.2% of total reserve impacted with noise level at 70 dB(A) and 22% with noise level at 62 dB(A).	Negligible (70 dB) - **Small (62 dB)**	Negligible- **Moderate**
Mandai Mangroves and Mudflats	High	> 500 m	0	64 (eastern shoreline)	70	No	Negligible	Negligible
High Value Species Nesting / Roosting Site								
Black-crowned night heron (CR) roost	High	50 m west bank roost 25 m east bank roost (north of O&M berthing facility)	75 75	62-64 (western and eastern shorelines)	70	Yes	**Small** **Small**	**Moderate** **Moderate**
Grey headed fish eagle (CR) nest in Sungei Kadut Forest	High	50 m	72		94[4]	No	Negligible	Negligible
White-bellied sea eagle (WBSE) nest	High	> 500 m	0		94	No	Negligible	Negligible
WBSE Perching/Roosting site (telecom tower)	Medium	c. 100 m	c. 69		94	No	Negligible	Negligible
High Value Species								
Forest birds (CR, EN and VU) in particular using Sungei Kadut Forest	High / Medium	50 m	72	62-64 (western and eastern shorelines)	70	Yes	**Small**	**Moderate**

[1] A qualitative approach to determine impact magnitude was applied, taking into consideration mobility of wildlife, mobile construction work fronts and affected proportion of the protected areas.

[2] Per *Section 9, Table 9-13* background noise monitoring considered representative of the western shoreline of the reservoir, i.e. at NSRCC Kranji Sanctuary Golf Course, identified daytime (7am – 7pm) levels to be 62 dB(A). On the eastern shoreline, background noise monitoring (*Section 9, Table 9-11*) indicated average noise levels adjacent to the shoreline forest strip at the proposed temporary Staging/ Launching Area worksite to be approximately 64 dB(A) (ranging from 57-72 LAeq, 12 hours; and 38-89 LAeq, 5 mins) in the daytime (7am – 7pm).

[3] Cutts et al. (2009) Construction and Waterfowl: defining sensitivity, response, impacts and guidance. Report to Humber INCA, Institute of Estuarine and Coastal Studies, University of Hull.

[4] Johnson, NP (1990). Nesting bald eagles (*Haliaeetus leucocephalus*) in urban areas of southeast Alaska: assessing highway construction and disturbance impacts. Transportation Research Record 1279

Sensitive Receptor	Sensitivity	Nearest Distance from piling (unmitigated FPV layout)	Construction (Piling) noise level at receptor (dB(A))	Representative Average Background Noise Levels (dB(A))[2]	Literature Guideline values for impacts on Wildlife (dB(A)) [3]	Potential Impact/ Disturbance	Magnitude of Impact	Significance of Impact (sensitivity x magnitude)
Wetland birds (CR, EN and VU) in particular using foraging areas on west bank and Kranji Marshes along NRSCC	High / Medium	m	81		70	Yes	**Small**	**Moderate**
Smooth coated otter (CR) feeding only, no holts.	High	Mobile animal. No holts along the reservoir detected.	NA		-	Not expected. Incidental monitoring during fauna monitoring.	Negligible	Negligible (monitor during construction)

APPENDIX 7.7 PILING NOISE MODELLING FOR BIODIVERSITY

Table 1: Piling Noise (Western Reservoir) - 4 no. simultaneous piles

No	Activity / Equipment	Sound Power Level per Piling	Sound Power Level per Piling after mitigated scenario (-9dBA)
1	Piling at Reservoir	114	105
2	Piling at Reservoir	114	105
3	Piling at Reservoir	114	105
4	Piling at Reservoir	114	105
	Total Sound Power Level (dBA)	120	111
	Sound Pressure Level at 1m	109	100

Table 1A: Sound Pressure Level from x Distance from source (dBA) Unmitigated Scenario at Western Kranji Reservoir

SPL from x distance from source (dBA)	
5	95.0
10	89.0
15	85.5
20	83.0
25	81.0
30	79.5
35	78.1
40	77.0
45	75.9
50	75.0
55	74.2
60	73.4
65	72.7
70	72.1
75	71.5
80	70.9
85	70.4
90	69.9
95	69.4
100	69.0
105	68.6
110	68.2
115	67.8
120	67.4
125	67.1
130	66.7
135	66.4
140	66.1
145	65.8
150	65.5
155	65.2
160	64.9
165	64.7
170	64.4
175	64.1
180	63.9
185	63.7
190	63.4
195	63.2
200	63.0
205	62.8
210	62.6
215	62.4
220	62.2
225	62.0

Table 1B: Sound Pressure Level from x Distance from source (dBA) Mitigated Scenario (-9dBA) at Western Kranji Reservoir

SPL from x distance from source (dBA)	
5	86.0
10	80.0
15	76.5
20	74.0
25	72.0
30	70.5
35	69.1
40	68.0
45	66.9
50	66.0
55	65.2
60	64.4
65	63.7
70	63.1
75	62.5
80	61.9

(yellow)	= distance required to achieve <70 dB(A), Cutts et. al (2009)
(green)	= distance required to achieve <62 dB(A), western shoreline representative background noise level

Table 2: Piling Noise (Western Reservoir) - 3 no. simultaneous piles

No	Activity / Equipment	Sound Power Level per Piling	Sound Power Level per Piling after mitigated scenario (-9dBA)
1	Piling at Reservoir	114	105
2	Piling at Reservoir	114	105
3	Piling at Reservoir	114	105
	Total Sound Power Level (dBA)	119	110
	Sound Pressure Level at 1m	108	99

Table 2A: Sound Pressure Level from x Distance from source (dBA) Unmitigated Scenario at Western Kranji Reservoir

SPL from x distance from source (dBA)	
5	94.0
10	88.0
15	84.5
20	82.0
25	80.0
30	78.5
35	77.1
40	76.0
45	74.9
50	74.0
55	73.2
60	72.4
65	71.7
70	71.1
75	70.5
80	69.9
85	69.4
90	68.9
95	68.4
100	68.0
105	67.6
110	67.2
115	66.8
120	66.4
125	66.1
130	65.7
135	65.4
140	65.1
145	64.8
150	64.5
155	64.2
160	63.9
165	63.7
170	63.4
175	63.1
180	62.9
185	62.7
190	62.4
195	62.2
200	62.0

Table 2B: Sound Pressure Level from x Distance from source (dBA) Mitigated Scenario (-9dBA) at Western Kranji Reservoir

SPL from x distance from source (dBA)	
5	85.0
10	79.0
15	75.5
20	73.0
25	71.0
30	69.5
35	68.1
40	67.0
45	65.9
50	65.0
55	64.2
60	63.4
65	62.7
70	62.1
75	61.5

(yellow)	= distance required to achieve <70 dB(A), Cutts et. al (2009)
(green)	= distance required to achieve <62 dB(A), western shoreline representative background noise level

Table 3: Piling Noise (Western Reservoir) - 2 no. simultaneous piles

No	Activity / Equipment	Sound Power Level per Piling	Sound Power Level per Piling after mitigated scenario (-9dBA)
1	Piling at Reservoir	114	105
2	Piling at Reservoir	114	105
	Total Sound Power Level (dBA)	117	108
	Sound Pressure Level at 1m	106	97

Table 3A: Sound Pressure Level from x Distance from source (dBA) Unmitigated Scenario at Western Kranji Reservoir

SPL from x distance from source (dBA)	
5	92.0
10	86.0
15	82.5
20	80.0
25	78.0
30	76.5
35	75.1
40	74.0
45	72.9
50	72.0
55	71.2
60	70.4
65	69.7
70	69.1
75	68.5
80	67.9
85	67.4
90	66.9
95	66.4
100	66.0
105	65.6
110	65.2
115	64.8
120	64.4
125	64.1
130	63.7
135	63.4
140	63.1
145	62.8
150	62.5
155	62.2
160	61.9

Table 3B: Sound Pressure Level from x Distance from source (dBA) Mitigated Scenario (-9dBA) at Western Kranji Reservoir

SPL from x distance from source (dBA)	
5	83.0
10	77.0
15	73.5
20	71.0
25	69.0
30	67.5
35	66.1
40	65.0
45	63.9
50	63.0
55	62.2
60	61.4

(yellow) = distance required to achieve <70 dB(A), Cutts et. al (2009)

(green) = distance required to achieve <62 dB(A), western shoreline representative background noise level

Table 4: Piling Noise (Western Reservoir) - 1 no. simultaneous piles

No	Activity / Equipment	Sound Power Level per Piling	Sound Power Level per Piling after mitigated scenario (-9dBA)
1	Piling at Reservoir	114	105
	Total Sound Power Level (dBA)	114	105
	Sound Pressure Level at 1m	103	94

Table 4A: Sound Pressure Level from x Distance from source (dBA) Unmitigated Scenario at Western Kranji Reservoir

SPL from x distance from source (dBA)	
5	89.0
10	83.0
15	79.5
20	77.0
25	75.0
30	73.5
35	72.1
40	71.0
45	69.9
50	69.0
55	68.2
60	67.4
65	66.7
70	66.1
75	65.5
80	64.9
85	64.4
90	63.9
95	63.4
100	63.0
105	62.6
110	62.2
115	61.8

Table 4B: Sound Pressure Level from x Distance from source (dBA) Mitigated Scenario (-9dBA) at Western Kranji Reservoir

SPL from x distance from source (dBA)	
5	80.0
10	74.0
15	70.5
20	68.0
25	66.0
30	64.5
35	63.1
40	62.0

(yellow)	= distance required to achieve <70 dB(A), Cutts et. al (2009)
(green)	= distance required to achieve <62 dB(A), western shoreline representative background noise level

Table 5: Piling Noise (Eastern Reservoir) - 2 no. simultaneous piles

No	Activity / Equipment	Sound Power Level per Piling	Sound Power Level per Piling after mitigated scenario (-9dBA)
1	Piling at Reservoir	114	105
2	Piling at Reservoir	114	105
	Total Sound Power Level (dBA)	117	108
	Sound Pressure Level at 1m	106	97

Table 5A: Sound Pressure Level from x Distance from source (dBA) Unmitigated Scenario at Eastern Kranji Reservoir

SPL from x distance from source (dBA)	
5	92.0
10	86.0
15	82.5
20	80.0
25	78.0
30	76.5
35	75.1
40	74.0
45	72.9
50	72.0
55	71.2
60	70.4
65	69.7
70	69.1
75	68.5
80	67.9
85	67.4
90	66.9
95	66.4
100	66.0
105	65.6
110	65.2
115	64.8
120	64.4
125	64.1
130	63.7

Table 5B: Sound Pressure Level from x Distance from source (dBA) Mitigated Scenario (-9dBA) at Eastern Kranji Reservoir

SPL from x distance from source (dBA)	
5	83.0
10	77.0
15	73.5
20	71.0
25	69.0
30	67.5
35	66.1
40	65.0
45	63.9

(yellow) = distance required to achieve <70 dB(A), Cutts et. al (2009)

(green) = distance required to achieve <64 dB(A), indicative eastern shoreline representative background noise level

Table 6: Piling Noise (Eastern Reservoir) - 1 no. simultaneous piles

No	Activity / Equipment	Sound Power Level per Piling	Sound Power Level per Piling after mitigated scenario (-9dBA)
1	Piling at Reservoir	114	105
	Total Sound Power Level (dBA)	114	105
	Sound Pressure Level at 1m	103	94

Table 6A: Sound Pressure Level from x Distance from source (dBA) Unmitigated Scenario at Eastern Kranji Reservoir

SPL from x distance from source (dBA)	
5	89.0
10	83.0
15	79.5
20	77.0
25	75.0
30	73.5
35	72.1
40	71.0
45	69.9
50	69.0
55	68.2
60	67.4
65	66.7
70	66.1
75	65.5
80	64.9
85	64.4
90	63.9

Table 6B: Sound Pressure Level from x Distance from source (dBA) Mitigated Scenario (-9dBA) at Eastern Kranji Reservoir

SPL from x distance from source (dBA)	
5	80.0
10	74.0
15	70.5
20	68.0
25	66.0
30	64.5
35	63.1

(yellow)	= distance required to achieve <70 dB(A), Cutts et. al (2009)
(green)	= distance required to achieve <64 dB(A), indicative eastern shoreline representative background noise level

ERM has over 160 offices across the following countries and territories worldwide

Argentina	The Netherlands
Australia	New Zealand
Belgium	Norway
Brazil	Panama
Canada	Peru
Chile	Poland
China	Portugal
Colombia	Puerto Rico
France	Romania
Germany	Russia
Ghana	Senegal
Guyana	Singapore
Hong Kong	South Africa
India	South Korea
Indonesia	Spain
Ireland	Sweden
Italy	Switzerland
Japan	Taiwan
Kazakhstan	Tanzania
Kenya	Thailand
Malaysia	UAE
Mexico	UK
Mozambique	US
Myanmar	Vietnam

ERM Singapore

20 Collyer Quay,
#15-01/02
Singapore
049319

T: +65 6324 9636

www.erm.com

Sustainability is our business

ERM