ORIA STAGE II EXPANSION

POST-DEVELOPMENT KEEP RIVER AQUATIC FAUNA & TARGETED SAWFISH SURVEY - 2021

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EXECUTIVE SUMMARY

This report presents the results of the 2021 Keep River Aquatic Fauna and Targeted Sawfish Survey which represents the second of three post-development surveys required to be completed as per the project conditions of the Goomig Irrigation Development. Whilst a limited number of potentially impacted sites were not able to be surveyed in 2021 as a result of i) COVID-19 travel restrictions implemented by the Western Australian Government during the survey and ii) access limitations as a result of rain associated with the wet season due to the late completion of the survey, the data collected and current analyses were considered adequate for identifying potential impacts on the Keep River in line with the project Aquatic Fauna Management Plan.

Current results suggest that the Goomig Development has not had an adverse impact on the water or sediment quality within the lower Keep River and that there has been limited input or accumulation of pollutants originating from the irrigation development. The herbicide atrazine, which was of specific concern to the projects Independent Review Group (IRG), was not detected in water or sediment sampled. Although there were several exceedances of site-specific guideline values in 2021, the majority were considered to be the result of natural processes, such as increased tidal influence, evapoconcentration and/or the first-flush run-off that occurs after the onset of the wet season. In 2020 increased concentrations and exceedances for a number of parameters, particularly metals in sediment, were attributed to either water released down Border Creek from the Goomig Development or major earthworks including the construction of a bridge and the bituminising of the Legune Road. In 2021 it remains unclear which factor was responsible for increased concentrations in 2020, as neither occurred between 2020 and 2021, however, concentrations in 2021 were generally lower and the number of exceedances was far lower, suggesting that elevated analyte concentrations or their potential effects had been reduced.

Consistent with the baseline surveys and historic survey records, no *Glyphis* (River Shark) species were captured during the 2021 survey. However, two *Pristis pristis* (Largetooth Sawfish) were recorded from the freshwater reaches of the Keep River and four *Pristis clavata* (Dwarf Sawfish) from the estuary. The numbers of individuals of these species recorded in 2021 were within the ranges encountered during the baseline surveys, and distributions were also broadly comparable. Additional analysis undertaken during the current study indicated that the number of *P. pristis* recorded in 2020 and 2021 was within the expected range based on the magnitude of the previous wet seasons. Therefore, the numbers of *P. pristis* and *P. clavata* recorded in 2021 suggested that the Goomig Development had not had a detectable negative population-wide effect on these two *Pristis* species.

With respect to fish and macroinvertebrates, lower Keep River pools continue to support high diversity and assemblages continue to be primarily driven by the longitudinal gradient in salinity decreasing with increasing distance from the estuary. Results indicated that there has been no decline in species richness and composition throughout the lower reaches of the Keep River outside of that which could be considered natural variation in response to the ingress of tidal waters upstream, evapoconcentration and climatic events.

As the third and final post-development survey is to be undertaken in 2022, sampling should continue to use the standardised sampling methodologies utilised to date to allow direct comparison with existing pre-development data. Additionally, 2022 sampling should be undertaken well before the onset of the wet season to avoid any influence rainfall run-off may have on the results as was encountered during the current study. This will allow for the better detection of influence in abiotic factors and aquatic fauna and allow the differentiation of naturally occurring drivers as opposed to those resulting from discharge associated with the Goomig Development.

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Appendix 4. Historic edge macroinvertebrate species data (adjusted taxa level of identification) from each site sampled in 2021. X = taxa recorded.

1 INTRODUCTION

1.1 Background

In 2008 the Western Australian state government approved the second stage of the Ord River Irrigation Area (ORIA) scheme to develop land for irrigated agriculture across the Weaber, Keep River and Knox Creek Plains (M2 Area) and construct the main irrigation channel (the 'M2 channel'), that extends from Lake Kununurra. The final period of irrigation design, environmental management and related approval processes for the construction of the M2 supply channel and development of the Weaber Plain section of the M2 Area commenced in 2010. Approximately 7,400 ha, known as Goomig farmlands, was considered suitable for agricultural development, requiring 120 GL irrigation supply from Lake Argyle. The farm design in the Weaber Plains/Goomig Development is based on the use of an irrigation tail-water management system, with irrigation runoff from irrigated land to be reused on farms (GHD 2010).

In June 2010, the Australian Federal Government determined that the project required approval under the *Environment Protection and Biodiversity Conservation Act 199 (*EPBC Act). The proposal was considered to have the potential to impact a number of Matters of National Environmental Significance (MNES). The proposal was assessed and subsequently approved (2010/5491), subject to 20 conditions, issued on 13 September 2011 (the Approval). Condition 10 of the Approval required the preparation of an Aquatic Fauna Management Plan (AFMP) to protect potentially occurring listed threatened aquatic fauna species in the Keep River, specifically the:

- critically endangered Speartooth Shark (*Glyphis glyphis*);
- endangered Northern River Shark (*Glyphis garricki*);
- vulnerable Dwarf Sawfish (*Pristis clavata*); and
- vulnerable Freshwater Sawfish (*Pristis microdon*; now referred to as *P. pristis*, Largetooth Sawfish).

Sub-conditions 10A to 10H detail specific protective and monitoring measures to be implemented for the protection of the listed species, and require approval from the Minister for Sustainability, Environment, Water, Population and Communities (recently renamed to Department of Environment) before the clearance of farm lots. Particular concerns related to the number of listed species potentially present in pools in the lower Keep River, the size of their populations, how the pools are used (i.e. by adults or as nursery habitat for juveniles), and how the proposed development may affect the listed species, both directly (i.e. water quality) and indirectly (i.e. through changes to habitat and the food chain). Condition 10 also specified that a baseline survey program was to be conducted over three years, and developed in consultation with the Independent Review Group (IRG). The IRG oversee hydrological aspects of the project and associated impacts on EPBC Act listed threatened species. The group consists of independent scientific and technical experts appointed under Condition 9 of the Approval.

The AFMP (Strategen 2012) was formulated to meet each requirement of the Approval and required:

- a targeted, non-lethal baseline survey for listed species likely to occur in the Keep River;
- measures to maintain water quality in Keep River pools; and
- a targeted aquatic fauna monitoring program to measure the management's success and an adaptive management approach.

Wetland Research & Management (WRM) were commissioned by LandCorp (the proponent at the time) to design the monitoring program, including the selection of appropriate sampling methods for the baseline surveys of the Keep River for the AFMP and subsequently undertake the three pre-development baseline surveys of the Keep River in 2011 (WRM 2013a), 2012 (WRM 2013b) and 2013 (WRM, 2014). The aim was to survey surface water and sediment quality, macroinvertebrate and fish assemblages and listed species to establish the baseline ecological condition.

Additionally, the baseline macroinvertebrate surveys were used to satisfy Condition 11F of the Stormwater and Groundwater Discharge Management Plan (SEWPAC 2011), which required the development of Australian River Assessment System (AusRivAS) trigger levels for aquatic macroinvertebrates. However, following the development of these AusRivAS Trigger Values, they were deemed inappropriate for assessing adverse changes in brackish, estuarine pools, as these habitats were beyond the bounds of the models. The Approval was subsequently amended with the wording of Condition 11F changed with to removal of reference to AusRivAS trigger values, and replacement with wording to *"Use of best practice multivariate analyses on species level macro-invertebrate and fish assemblage data, within an adequate experimental design (as defined in the Aquatic Fauna Management Plan required under condition 10), using multiple indices of 'ecological condition' and a 'weight of evidence' approach, to assess any change in ecological health of Keep River pools (K1, K2 & K3) relative to baseline and upstream reference sites"*.

In October 2021, Indo-Pacific Environmental (IPE) was awarded the contract by the Department of Primary Industries and Regional Development (DPIRD), acting as the proponent for the development, to undertake the second post-development survey and assessment. This report presents data obtained from the aquatic survey undertaken in November 2021 and its assessment against baseline data.

1.2 Aims and Objectives

The aim of the second post-development survey and assessment in 2021 was to repeat the sampling program conducted for 2011, 2012 and 2013 baseline surveys and the 2020 post-development survey, for comparison against the baseline data to identify any impacts from the ORIA Stage 2 Goomig Development to date. The specific objectives of the survey were to undertake:

- sediment Sampling - in potentially impacted (exposed) pools;
- targeted *Pristis* and *Glyphis* Survey - to ascertain distribution and population within the potentially affected area; and

- macroinvertebrate, fish and water quality sampling in potentially exposed and reference (control) pools.

With respect to the assessment, specific objectives were to:

- Assess sediment and water quality at potentially exposed sites against reference sites and/or trigger values derived from baseline data sets;
- Determine the distribution and population of *Pristis* and *Glyphis* species within the potentially affected area; and
- Statistically compare 2021 fish and macroinvertebrate assemblages against those recorded in baseline years.

1.3 Notable Changes Since the Baseline Surveys

As part of developing the Goomig irrigation area, but also in preparation for the expansion of the current irrigation area and proposed aquaculture development into the Northern Territory, a series of changes and developments have taken place since the last of three baseline surveys were completed in October 2013 that are directly relevant to the study area. These changes have the potential to adversely affect listed species and the ecological health of the Keep River downstream of the project area.

The changes include construction and sealing (bituminising) of the Legune Road associated with the sea farms prawn aquaculture project on Legune station and the construction of a major bridge over the Keep River at the old Legune Road Crossing between the K4 and K3 pools on the Keep River (Figure 1). Although not directly related to the expansion of the ORIA and completed before September 2020, the potential exists for the Keep River to be affected through increased siltation, potential hydrocarbon spills/releases, and run-off of chemicals from the newly laid bitumen, particularly during and potentially a number of years after construction. An additional change was also noted in WRM (2021), with an ongoing challenge of the Goomig Development being that a component of irrigation drainage water from Ord Stage 1 flows through the Goomig Development and is released down Border Creek that enters the Keep River immediately upstream of pool K3. As per the operational requirements of the Goomig Development, and although this tail water is not strictly from the Goomig Development, M2 supply water has been released down Border Creek and into the Keep to provide a flushing/dilution flow. As such, if any individual activity has an adverse effect on the river system, it may not be possible to separate the relative effects of any one activity. However, in 2021 it was indicated that there was no irrigation water released into Border creek as a pumping station installed by Kimberley Agricultural Investment (KAI), who manages farming operations at the Goomig Development, and the water was recycled (Jo-Anne Ellis, DPIRD, pers. Com)

Historically these surveys have been undertaken in September/October. However, as a result of the 2021 contract not being awarded until October, the 2021 survey was not undertaken until November. This resulted in the survey being commenced after the onset of the wet season and significant rainfall in the region. As a result of the delay in sampling, the influence of the first-flush run-off, notable increases in water levels at some locations and variable climatic conditions at the time of the survey was considered likely to influence fauna assemblages and both water and sediment quality results during the current study. It was also considered likely that any influence from these factors could be difficult to discern from any influence the Goomig Development was having on the lower Keep River.

2 METHODS

2.1 Sample Sites

A total of 12 sites or 26 sub-sites that had previously been established are surveyed as part of this program (Table 1; Figure 1). Sampling is undertaken at potentially exposed sites in the Keep River, as well as reference sites to create a classic BACI design (Before/After: Control/Impact). Potentially exposed sites were designated by KBR (2006) and include the four main pools on the lower Keep River in which five replicate locations (sub-sites) are sampled within K1, K2 and K3, whilst only three sub sites are sampled within K4 as this site is much smaller in size. Additional sites established by WRM (2013a) included the three potentially exposed sites within the Keep Estuary (EST01, EST02 and EST03) and the reference sites KE1 (Milligan's Lagoon), KR1 (Alligator Waterhole), KR2 (Policeman's Waterhole), SR4 (Augustus Waterhole), DR1 (Dunham River at Sugarloaf Hill) and KR1 (Alligator Waterhole). However, at each sub site not all components of the program are undertaken (Table 1). In brief, water quality sampling is undertaken at all sub sites, whilst sediment sampling is only conducted at potentially exposed Keep Estuary and lower Keep River locations. The Aquatic Fauna Ecological Health Assessment, which includes the sampling of macroinvertebrates and fish, is undertaken at each of the sub sites within each of the potentially exposed lower Keep River pools, in addition to each reference sub site. Targeted surveys for *Pristis* and *Glyphis* species are undertaken at one sub site within each of the potentially exposed lower Keep River pools and each of the Keep Estuary sites, although, catch records are also supplemented with incidental captures from the Aquatic Fauna Ecological Health surveys undertaken at remaining sub sites.

Despite best efforts, the presence of rainfall, mud and severe gully erosion meant that it was not possible to get close enough to the original DR1 site to launch a survey vessel during the current study. As such, DR1 was moved to an accessible location approximately 10 km upstream during the current survey (Zone 52: 440463E, 8225848S to 433967E, 8216059S). Furthermore, whilst KR2 was accessed it was apparent that a recent deoxygenation/fish kill event had occurred at the site as a result of the first rains of the wet season, which is a relatively common and natural occurrence in the region. Noting that any fauna that may have survived would have been highly stressed under the conditions present, the survey team decided not to undertake gill netting at this site to avoid the high mortality rates that would have resulted.

Whilst attempts were made to undertake the required sampling at all 26 sub sites in 2021, a COVID-19 outbreak in the Northern Territory (NT) in November lead to the Western Australian Government imposing a hard border with the NT on the 16th of November 2021. As the survey team were based in Kununurra an exemption was sought to continue working on the Keep River which is located approximately 10 km from the WA/NT border. However, this was denied by the WA police force. Noting the travel restrictions and isolation requirements for those entering the state and after discussions with DPIRD, it was decided to terminate the survey early. As a result, the two estuary sites EST02 and EST03, the lower Keep River site K3 and the reference sites KE1, KR1 and SR4 were not surveyed during 2021 (Figure 1). While the option to complete the survey as soon as possible after the re-opening of the border (and when climatic conditions favoured access) was discussed with DPIRD, this option was not undertaken.

2.2 Sampling Methods

The current survey followed the methodology of WRM (2013a, 2013b, 2014 and 2021) including the collection of abiotic samples and the deployment of nets at the same locations and for the same duration, to ensure comparability to baseline data.

2.2.1 Water Quality

At each location sampled, undisturbed filtered and unfiltered water samples were collected in a variety of containers provided by the laboratory depending on the analysis required. Retained samples were immediately labelled and placed on ice before being refrigerated or frozen as quickly as practicable. Water samples were delivered within designated holding times to Australian Laboratory Services (ALS), a NATA-accredited laboratory, and analysed for a suite of physiochemical, ionic and nutrient parameters, in addition to Atrazine which was specifically requested by the IRG (Appendix 1). The herbicide Atrazine was added to the suite in 2020 given the discharge of irrigation return water into the Keep via Border Creek. However, due to the cost of the analysis, only one sample for the analysis of Atrazine was collected from each potentially exposed site. Additionally, a variety of In situ water quality parameters were also measured at the time of sampling (Appendix 1), whilst profiles through the water column of dissolved oxygen (DO), electrical conductivity (EC) and temperature were measured at 0.5 m intervals until the bottom.

2.2.2 Sediment

At each location sediment samples were collected from the left bank, mid-channel and right bank using an Ekman-Birge grab sampler before being transferred via a washed glass-nylon trowel directly into high-density polyethylene (HDPE) press-seal bags or glass jar depending on the analysis required. Retained samples were immediately labelled and placed on ice before being refrigerated or frozen as quickly as practicable. Sediment samples were delivered to ALS within designated holding times and analysed for a suite of physiochemical, major ion, metal and nutrient parameters, whilst one sample from each site was analysed for Atrazine (Appendix 2).

2.2.3 Targeted Pristis (Sawfish) and Glyphis (River Shark) Surveys

The sampling and processing of *Pristis* and *Glyphis* species aligned with the Protocols for Surveying and Tagging Sawfishes and River Sharks (Kyne and Pillans 2014). At each location targeted sampling was undertaken, two 6” single mesh gill nets, each 30 m long with a 2 m drop, were deployed perpendicular to the shore and anchored at both ends to prevent the nets from moving for up to eight hours. To minimise the potential for death and injury of aquatic fauna, nets were closely monitored for movement and regularly cleared (at least every hour) to ensure entangled animals could be removed and released alive. For each net set, the number of each species captured, net length and length of time deployed were recorded to derive Catch per Unit of Effort (CPUE) as an indirect measure of the abundance.

Any listed species captured were processed as rapidly as possible, whilst remaining submerged off the side of the vessel, in the following manner:

- Recording total length (TL) in addition to Total rostrum length (TRL) and left and right tooth count for *Pristis* species;
- Sex was determined (based on presence of claspers); and
- A fin clip was taken, placed in 100% ethanol in the field to provide tissue samples for DNA analyses.

Additionally, to align with the Protocols for Surveying and Tagging Sawfishes and River Sharks outlined by Kyne and Pillans (2014) and after discussion with the NT Department of Industry, Tourism and Trade – Fisheries, the current study utilised Passive Integrated Transponder (PIT) tags as opposed the conventional cattle-style tags which were utilised during previous surveys. PIT tags have no external parts and are the preferred tag type to individually identify animals as they circumvent the biofouling and abrasion issues of external conventional tags. Pit tags were applied internally (in the body musculature, just under the skin) via a stainless steel needle attached to an applicator gun. Each PIT tag has a unique serial number that is read with an electronic scanner and will allow for the identification of recaptured specimens.

Other fish species captured whilst netting for *Pristis* and *Glyphis* spp. were identified to species and a total length recorded before being returned to the water alive.

2.2.4 Fish

Sampling for fish as part of Aquatic Fauna Ecological Health Assessment was undertaken using a standardised methodology which has been used extensively in the Northern Territory (Larson 1999) and Kimberley (Storey 2003; WRC 2003). In particular, two 30 m multi-panel gill nets were deployed at each location, with each net consisting of 6 x 5 m panels, with 2 m drop, and panels increasing in size from 1" to 6" stretched mesh size. The nets were set perpendicular to the bank, with the smallest mesh set against and secured to the bank, and the largest mesh positioned mid-channel with a float and weight to keep the net in place for approximately 2.5 hours. To minimise the potential for death and injury of aquatic fauna, nets were closely monitored for movement and regularly cleared to ensure entangled animals could be removed and released alive. Individual fish were identified to species and total length (mm) and weight (g) measured, before being released back into the water alive. For each net set, the number of each species captured, net length and length of time deployed were recorded. Catches from both nets were combined to form one replicate sample from each sampling location.

2.2.5 Aquatic Fauna Pest Monitoring

Within the AFMP there was a requirement for annual surveys for aquatic pest animals introduced to Border Creek and Keep River (e.g. *Cherax quadricarinatus*, Red Claw Crayfish) to be undertaken. As such, a baited opera house trap was deployed near each set of gill nets at each sub-site for up to seven hours.

The entry size into each trap is restricted to exclude larger air-breathing fauna (e.g. turtles) to mitigate the risk of drowning fauna.

2.2.6 *Macroinvertebrates*

At each location the Aquatic Fauna Ecological Health Assessment was undertaken, macroinvertebrates were sampled using a standard methodology used extensively in rivers of northern Australia, including the Ord Stage 2 project (NCTWR 2005; Storey and Lynas 2007; WRM 2010 and 2011) and the WA (van Looij 2009) and NT (Lloyd and Cook 2002) Australian River Assessment System (AusRivAS) programmes. Edge samples were collected from each location sampled, from habitat along the banks of each pool, typically comprising of root mat, leaf litter/detritus, occasionally some submerged macrophytes or floating vegetation. Samples were collected using a cultivator rake to disturb the substrate along a 10 m transect and a standard macroinvertebrate net (250-micron mesh) to collect dislodged material. As riffle habitat was not present at a majority of sites during the current study, riffle samples were only collected from two locations. Riffle samples were collected by ‘kick-sampling’ over a 10 m transect with the macroinvertebrate net (250-micron mesh) retained on the downstream side of the disturbance and flow to collect dislodged material. For both edge and riffle samples, litter and other coarse debris were washed and removed by hand with the remaining material preserved in 70% ethanol and transported to the Indo-Pacific Environmental Perth laboratory for processing.

In the laboratory, macroinvertebrates were removed from samples by sorting under a low power dissecting microscope and then identified to the lowest possible level (genus or species level) using available keys and guides. Specimens were enumerated to log^{10} scale abundance classes (i.e. 1 = 1 individual, 2 = 2-10 individuals, 3 =11 - 100 individuals, 4 = 101- 1000 individuals, 5 = >1000, etc.).

2.3 Data Analysis

While all efforts were made to undertake data comparisons consisted with those of previous surveys, as a number of sites were unable to be surveyed in 2021, comparisons were only made between the estuary site EST01, the lower Keep River sites K1, K2 and K4 and the reference sites KR2 and DR1 that were sampled in 2021 and historical data. Whilst some discrepancy between previous reports and this report in terms of the total species and numbers presented exist, basing comparisons on only those sites that were surveyed was considered the most appropriate way to identify whether differences existed between the current and previous datasets.

2.3.1 *Limitations and Assumptions*

Noting the pronounced longitudinal gradient in the tidal influence that was prominent at K1 and negligible at K4 the comparison of water quality, sediment quality and fauna between sites within years was not considered appropriate as this alone would cause significant variation. As such, statistical analysis and/or comparisons were undertaken and discussed in depth between 2021 and baseline data within the same site. Additionally, there was a requirement to discuss natural variability in ecosystem health whilst having regard to reference site survey results. Whilst this was done and considered appropriate for K4, the results from the tidally influenced K1 and K2 should be treated with caution as all current reference sites are located well upstream of any tidal influence. Therefore, these sites likely experience different degrees of natural variably in terms of both the environment and the fauna present. Furthermore, the results presented in this report represent a snapshot of the environmental conditions and fauna present in 2021 at the time of sampling. As environmental conditions and fauna can vary considerably depending on the time of year and the climatic conditions around the time of sampling, these factors should be considered when interpreting results. This was considered particularly important in 2021 as sampling occurred later in the year and commenced after the onset of the wet season.

Riffle habitats were only sampled for macroinvertebrates at one potentially exposed site and one reference site in 2021, as a limited number of other sites were not accessible. Therefore, statistical analysis on riffle macroinvertebrate diversity was not undertaken in 2021. In addition, the analysis of a limited number of samples (n = 4 in total) was also not considered robust and added little to the monitoring program in comparison to the analysis of edge macroinvertebrates.

While raw data from the 2020 study by WRM was provided by DPIRD, baseline macroinvertebrate, fish and *Pristis* abundance data was not available and such was required to be extracted from tables within previous reports of WRM (2013a, 2013b, 2014) for 2011, 2012 and 2013. For fish data, based on data presented in WRM (2013a, 2013b, 2014) and the summary presented in WRM (2021) it appeared that specimen observations of fish were attributed an abundance value of one, so this was applied to the 2021 data. For the macroinvertebrate data extracted, it was noted that there were discrepancies between the taxa level of identification between years, whilst there were a number of in-house (WRM) names used to depict species for which no formal identification keys are publicly available. As such, to allow for accurate comparisons and statistical analysis to be made between years, the taxa level of identification was adjusted to be consistent across all years. Additionally, as only $\log^{10}$ scale abundance were presented, when taxa were combined the highest $\log^{10}$ abundance value was allocated.

For abiotic data, only water quality data for 2011 and 2012 and no sediment data for individual years was presented in the reports of WRM. As such, no statistical analysis between sediment quality and fauna abundance data could be undertaken with data from the current study, whilst statistical analysis between water quality and fauna abundance data was only undertaken for 2011, 2012, 2020 and 2021. Whilst additional data for 2013 would have been beneficial, results from statistical analyses are still considered valid. Summary statistics for water and sediment baseline data were, however, provided in WRM (2014 and 2021) and extracted for assessing 2021 water and sediment quality data.

As a result of the WA Government imposing a hard border with the NT, only two reference sites were sampled in 2021. Therefore, due to the reduced sample size, results from analyses comparing reference sites with those potentially impacted should be treated with some caution.

2.3.2 Water and Sediment Quality

Whilst the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) (2018) contains guideline values for a number of the water and sediment parameters measured, guideline values do not exist for the majority of parameters. Furthermore, ANZG (2018) indicates that the use of local reference data for the development of site-specific guidelines is preferential. As such, the methodology outlined in ANZG (2018) for the development of site-specific guideline values for water (SS-WQGV) and sediment (SS-SQGV) quality was adopted. Based on the definitions provided in ANZG (2018), the lower Keep River would be considered a slightly to moderately disturbed ecosystem. For such ecosystems, ANZG (2018) indicates the 80th (or 20th for oxygen saturation) percentile values should be adopted as the site-specific guideline values and these values were derived for each site from the baseline survey data sets (2011, 2012, 2013). Median values derived in 2021 for each parameter at each site were then compared to the site-specific guideline values.

Additionally, 2021 median water quality values are also compared to the Interim Local Trigger Values (ILTVs) developed for the Keep River pools by Bennett and George (2014). Comparisons were also made between water concentrations at potentially exposed and natural background (reference) sites to determine if any changes in 2021 occurred throughout the region and resulted from naturogenic processes or if they were unique to the lower Keep River.

Although the statistical analysis on water and sediment data have previously been undertaken, noting the nationally accepted methodology outlined in ANZG (2018) for undertaking water and sediment quality assessments, they were not undertaken in 2021 or considered to be of any benefit.

2.3.3 Pristis (Sawfish) Population Assessment

Considering that *P. pristis* generally occur in comparatively lower abundances compared to other fish species and that they exist in aquatic environments that experience highly variable seasonal and flow conditions, comparison of CPUE alone between years was not considered appropriate for monitoring *P. pristis*. As such, the magnitude of the previous wet season was considered when assessing whether the Goomig Development was having an effect on *P. pristis* number in the lower Keep River.

To assess the relationship between *P. pristis* CPUE data and the previous wet season, correlation analyses between CPUE data and various Legune Road Crossing (G8100225) gauging station parameters were undertaken. Additionally, to assess recruitment of *P. pristis,* individuals <1300 mm TL and less than a year old, or young-of-the-year (YOY) (Morgan *et al.* 2011; Thorburn *et al.* 2007), were examined separately. Regression analyses were undertaken on baseline (2011-2013) data with the post-development data (2020 and 2021) then fitted to see if it fell within the expected range for assessment.

2.3.4 Fish and Macroinvertebrates

Noting that a requirement of the current survey was to assess the results of macroinvertebrate sampling against AusRivAS trigger values identified in the 2013 report, following the development of the AusRivAS Trigger Values, they were deemed inappropriate for assessing adverse changes in brackish, estuarine pools, as these habitats were beyond the bounds of the models. As such, the Approval was amended to change the wording of Condition 11F to remove reference to AusRivAS trigger values, with wording changed to:

"*Use of best practice multivariate analyses on species level macro-invertebrate and fish assemblage data, within an adequate experimental design (as defined in the Aquatic Fauna Management Plan required under condition 10), using multiple indices of 'ecological condition' and a 'weight of evidence' approach, to assess any change in ecological health of Keep River pools (K1, K2 & K3) relative to baseline and upstream reference sites".*

Relationships among the baseline and post-development survey samples were investigated using several routines in PRIMER/PERMANOVA+. Unless specified, default values or procedures recommended in PRIMER-7 (Clarke and Gorley 2006) and PERMANOVA+ (Anderson *et al.* 2008) were used for the analysis routines.

For the analysis of species level macroinvertebrate and fish assemblage data, fish abundance data were transformed (log [x+1]) prior to the analysis, whilst untransformed $\log_{10}$ scale abundance classes were used for macroinvertebrates. Data of water quality variables collected during all years were also transformed (log [x+1] and normalised to account for various measurement scales and to correct asymmetric (positive) distribution (Clarke and Gorley 2006). Additionally, Water quality parameter values below the LOR were allocated a value of half of the LOR before statistical analysis.

Ordination of assemblage data was by non-metric Multi-Dimensional Scaling (nMDS) depicted as two-dimensional (2D) plots based on annual site by site similarity matrices, based on Bray – Curtis similarity matrices (Clarke and Warwick 2001).

Pair-wise comparisons were undertaken using the permutational multivariate analysis of variance (PERMANOVA) routine to test for statistically significant ($p < 0.05$) differences between:

- each potentially exposed site and combined reference sites (DR1 and KR2) in 2021;
- combined 2011-2013 baseline and both 2020 and 2021 post-development data sets for each site; and
- individual baseline years and both 2020 and 2021 post-development data sets for each site.

In some cases, there were low numbers of unique permutations for comparisons in the PERMANOVA analysis due to the limitations associated with the distribution and availability of sites in the design. As a result, Monte-Carlo *p*-values were also generated, as these may provide a more accurate assessment where unique permutation numbers are less than 100 (Anderson *et al.* 2008).

To identify species that are likely to be the major contributors to any difference detected by the PERMANOVA pair-wise test, the similarity percentage analysis (SIMPER) routine was used to calculate the contribution of each species (%) to the dissimilarity between each group.

Relationships between the water quality variables and both fish and macroinvertebrate assemblage data were explored using the distance-based linear models (DistLM) routine (AIC and step-wise comparisons) (Clarke and Gorley 2006; Anderson *et al.* 2008). DistLM was chosen over other models as it takes into account the potential overlap of different predictors and finds linear combinations of the abiotic variables that are best to predict patterns in the biotic data set.

For macroinvertebrates, an additional 'sensitivity analysis' was undertaken as per the Stream Invertebrate Grade Number – Average Level (SIGNAL) 2 biotic indices for river macroinvertebrate methodology (Chessman 2003). However, as indices only exist for macroinvertebrate families, this analysis was not undertaken on species level data. A SIGNAL 2 score provides an indication of water quality at the site from which the sample was collected. Sites with high SIGNAL scores are likely to have low levels of salinity, turbidity and nutrients such as nitrogen and phosphorus. When considered together with macroinvertebrate diversity, this can provide indications of the types of pollution and other physical and chemical factors that are affecting the macroinvertebrate community.

3 RESULTS AND DISCUSSION

3.1 Water quality

Water quality parameters measured during the 2021 survey at individual sub-sites are presented in Appendix 1, whilst median values derived for each site along with ANZG (2018) default water quality guidelines, SS-WQGVs and ILTVs are presented in Table 2. As noted in Section 2.3.3, ANZG (2018) indicates there is a preference for the use of site-specific water quality guidelines when undertaking an assessment. As such, whilst ANZG (2018) default water quality guidelines are provided in Table 2, they are not discussed further and median values are only assessed against SS-WQGVs and ILTVs.

Vertical profiles of temperature, electrical conductivity and dissolved oxygen are presented in Figure 2 and indicate some level of stratification was present at all Keep River sites. Consistent with previous surveys, stratification was strongest in the most downstream Keep River pools (K1 and K2) with evidence of a halocline and thermocline formation around 1 m below the surface level. Oxygen levels decreased with depth with hypoxia (≤25% DO) occurring in bottom waters at around 4 m. Concerning the estuary site EST01, the relatively shallow waters appeared to be well mixed.

3.1.1 General Parameters

In 2021, median temperatures at the majority of sites, including reference sites, were above their respective SS-WQGV and/or ILTV and this is likely the result of the survey being undertaken later in the year than baseline surveys when ambient air temperatures are higher. At all lower keep river sites (K1, K2 and K4) median turbidity, pH and DO% values were below or within their respective SS-WQGV and/or ILTV, whilst at EST01, and in some instances at reference sites, were above.

For TDS, the SS-WQGV was only exceeded at K2 and this was attributed to an increase in tidal influence and evapoconcentration as discussed further below. Whilst median TSS values exceeded respective SS-WQGV at all lower keep river sites, the LOR of the analysis undertaken for TSS in 2021 was above that what has previously been used (5 mg/L *c.f.* 1 mg/L) not allowing for an accurate comparison to be made. However, all values were below their respective ILTV.

3.1.2 Salinity and Ionic Composition

Median conductivity values at the majority of sites were below their respective SS-WQGV and ILTV. The exception was K2, which marginally exceeded the SS-WQGV and ILTV. This is likely the result of the survey being undertaken later in the year when the effects of tidal influence and evapoconcentration would have been more prominent. Whilst this did not occur at K1 and EST01, where the surface water had a lower conductivity, from Figure 2 it can be seen that below one meter conductivity was higher within K1. This suggests that K1 and EST01 likely had considerable freshwater input from Oakes Creek (Figure 1) during recent rainfall events, which did not significantly feed into K2. This, in turn, also resulted in the majority of ionic composition parameters within K2 being above their respective SS-WQGV. Whilst alkalinity and acidity within K4 and K1, respectively, were slightly in exceedance, it is suspected that this resulted from the recent input of alkaline soils or organic matter during the recent rainfall and run-off event.

3.1.3 Nutrients

The majority of nutrient parameter values at lower Keep River sites were below their respective SS-WQGV and ILTV, whilst at all reference sites they were above. Exceptions at lower Keep River sites included total soluble phosphate, total phosphate and DOC. Increased water temperatures are known to accelerate the release processes at the sediment and water interface for phosphate (Li *et al.* 2013) and DOC (Winterdahl *et al.* 2016), increasing concentrations of these parameters within the water column. Furthermore, the first-flush run-off in the wet/dry tropics can have very high concentrations of suspended particulate matter, nutrients, and some heavy metals (Sinclair Knight Merz 2013). Noting that exceedances of these parameters also occurred at reference sites, where concentrations were also higher (Figure 3), it was considered likely that these exceedances resulted from the survey being undertaken later in the year than previous baseline surveys when water temperatures were higher and flows associated with the wet season had begun.

3.1.4 Atrazine

Consistent with the findings of 2020, all values for atrazine were below the Limit of Reporting (LOR) (i.e. >0.5 µg/L) during the current study. This suggested that atrazine was not entering the environment, or that it was present in negligible concentrations. Furthermore, the high surrogate recoveries indicate matrix compatibility for the method of analysis, as matrix interference is not suppressing the recovery of the analyte of interest, and that results are not biased low.

3.2 Sediment quality

Results from the analysis of each sediment sample collected in 2021 are presented in Appendix 2, whilst median values derived for each site along with SS-SQGVs are presented in Table 3. Although ANZG (2018) default sediment quality guidelines are also provided in Table 3, and none were exceeded, as noted in Section 2.3.3, ANZG (2018) indicates there is a preference for the use of site-specific sediment quality guidelines when undertaking an assessment. As such, ANZG (2018) default sediment quality guidelines are not discussed further and median values are only assessed against SS-SQGVs.

3.2.1 Ionic Composition

From Table 3 it can be seen that a limited number of ions were above their respective SS-SQGV at EST01 and K1. This is likely the result of the survey being undertaken later in the year when the effects of tidal influence and evapoconcentration would have been more prominent, resulting in both the precipitation and absorption of these ions into the sediment increasing.

3.2.2 Metals

Median concentrations in 2021 for the majority of metals at each site were below their respective SS-SQGV. Whilst antimony, beryllium, boron, cadmium, molybdenum and silver median concentrations at all sites may be above their respective SS-SQGV, they were all below the LOR for the current analysis, which was higher than the LOR during the analysis of baseline samples. The difference between the current and previous LOR for these analytes is, however, considered trivial as the LOR for each of these analytes used in 2021 is well below concentrations that are known to have detrimental effects. Furthermore, as the LOR in most instances was only marginally higher in 2021, it is considered likely that comparable concentrations to baseline data would have been obtained with a lower LOR. Titanium was the only metal to be in exceedance across all sites, however, comparable relative increases occurred over all sites, including K4 upstream of the Border Creek confluence, and likely represents natural background levels associated with surrounding geology. Individual exceedances included selenium, bismuth and tin at K1 and vanadium at K2, although median values were only marginally higher than their respective SS-SQGV. These and the majority of other metals at EST01, K1 and K2 in 2020 were above their respective SS-SQGV and at notably higher concentrations. WRM (2021) noted that the distinct increase in metal levels between the pools K3 and K1 could be attributed to releases down Border Creek, although the source of these metals is unknown, or major earthworks including the construction of a bridge and the bituminising of the Legune Road. As the number of metals in exceedance and concentrations was far lower in 2021 compared to 2020, it could be assumed that the effects resulting from major earthworks, completed before the September 2020 survey, had subsided. However, as noted in section 1.1.1, there was no water released down Border Creek between the 2020 and 2021 surveys. Therefore, it cannot be said with certainty which of these events were responsible for the increased metal concentrations observed in 2020, although this could be determined in subsequent surveys following the release of water down Border Creek.

3.2.3 Nutrients

With respect to nutrients, the majority of values measured in 2021 were below their respective SS-SQGV. The exception to this was the far higher concentrations of ammonium recorded from EST01, K1 and K2, in comparison to baseline and 2020 survey concentrations. However, the median value at K4 was well below the comparatively higher SS-SQGV for this site. Although this may suggest nutrient enrichment and potential build-up from the release of water down Border Creek, it should be noted that no water was released down Border Creek between the 2020 and 2021 surveys. Furthermore, total nitrogen values were all below their respective SS-SQGV and mean concentrations were comparable, indicating that there has been limited or no additional input of nitrogen into the lower Keep River (Figure 4). Increased concentrations of ammonium in 2021 may have occurred as a result of processes such as ammonification of decomposing particulate organic nitrogen, remineralisation from dissolved organic nitrogen and dissimilatory nitrate reduction to ammonium by anaerobic bacteria in sediments (Dagg *et al.* 2004; Howley *et al.* 2018) being influenced by the onset of the wet season. Furthermore, based on previous results it is suspected that the seven-day holding time of sediment samples for the analysis of nutrients was exceeded during previous surveys, which would have resulted in ammonium breaking down into other compounds and thus lower ammonium concentrations being reported. As such, increase ammonium concentrations in 2021 are not suspected of being associated with the release of water down Border creek. Furthermore, total phosphorus and total organic carbon in sediments were also below their respective SS-SQGV and mean concentrations were comparable between baseline data and 2021 (Figure 4). This, in turn, suggests that there had been limited or no additional input of nutrients (i.e. as fertilisers) into the lower keep river as a result of water being released down Border Creek.

3.2.4 Atrazine

During the current study, all values for Atrazine in sediments were below the limit of detection (i.e. <0.05 mg/kg). This suggested that it is not entering the environment, or that if present, it only occurred in negligible concentrations. Furthermore, the high surrogate recoveries indicate matrix compatibility for the method of analysis, as matrix interference is not suppressing the recovery of the analyte of interest, and that results are not biased low.

3.3 *Pristis* (Sawfish) and *Glyph*is (River Shark) Populations

Five sawfish were captured during the current survey, comprising of one *P. pristis* from the freshwater reaches of the Keep River (K4) and four *P. clavata* from the estuary site EST01. Additionally, a *P. pristis* that had succumbed to the fish kill/deoxygenation event at KR2, approximately 60 km upstream from the Keep Estuary, was also recorded (Plate 1). All *Pristis* recorded were considered sub-adults (<2,500 mm), ranging in size from 1,800 – 1,950 mm TL for *P. pristis*, and 1,960 – 2,200 mm TL for *P. clavata*, with all individuals considered to be at least 2+ years old (>1,600 mm) (Thorburn *et al.* 2007, 2008).

Plate 1. *Pristis pristis* captured and released at K4 (left), dead *P. pristis* observed at KR2 (centre) and *P. clavata* captured and released at EST01 (right).

Within the Keep River catchment, all historic records of *P. clavata* have been from the estuary, whilst all records of *P. pristis* have been from the upper freshwater reaches (Larson 1999; WRC 2003; WRM 2011, 2013a, 2013b, 2014 and 2021). *Pristis clavata* is restricted to brackish and saltwater habitats (Thorburn *et al*. 2007) and likely retreat out of the estuary during periods of increased flow. Whist conditions in the lower Keep River pools at the time of the survey may have been suitable for this species, the rock bar between the Estuary and K1 likely acts as a physical barrier to upstream movement when water levels decrease and salinities increase to suitable levels for this species. For *P. pristis*, Young of the Year (YoY) and juveniles penetrate freshwater drainages during flood periods and the upper reaches of estuaries to take advantage of waters with fewer large predators and favourable feeding conditions before returning to the sea to mature and breed (Whitty *et al.* 2008, 2009a and 2009b). As such, the spatial separation of these two species was not considered unusual. Whilst *Pristis zijsron* (Green Sawfish) was not recorded during the current survey, this species has not been regularly recorded in the survey area, with only one individual being recorded from the estuary (EST01) in 2011. Furthermore, this species is typically recorded from nearshore, rather than salt-freshwater interface, environments (Morgan *et al*. 2017). As such, the individual recorded at EST01 in 2011 was likely to have been a vagrant. Consistent with the baseline surveys (WRM 2013a, 2013b, 2014) and historic survey records (Larson; 1999; NCTWR 2005; WRC 2003), no *Glyphis* species were captured during the 2021 survey. The regular capture of *Carcharhinus leucas* (Bull Shark) indicates that current methods catch sharks of equivalent size and dimensions to *Glyphis* species, and so would catch these species if they were present. Whilst this may suggest that they do not occur at sampling locations, it may be that they seldom occur, are present in undetectable numbers or occur further downstream in the Keep River catchment.

The capture of a single *P. pristis* and four *P. clavata* in 2021, was within the ranges of 1-5 individuals for *P. pristis* and 0-12 individuals for *P. clavata* recorded during the baseline surveys from the same sample sites (Figure 5). However, considering only one estuary site could be surveyed in 2021, it is possible that the overall numbers encountered would have been higher. As the estuary and nearshore habitats in which *P. clavata* is restricted to remain relatively connected throughout the year and water quality, particularly salinity, was consistent between years, comparisons of capture rates between years could be considered appropriate. However, when navigating into freshwater reaches *P. pristis* experience highly variable seasonal and flow conditions that are known to influence recruitment and success of dispersion (IPE 2020, 2021a and 2021b; Lear *et al*. 2019). Therefore, comparison of annual capture data alone between years was not considered appropriate when assessing populations of *P. pristis*.

Noting that the baseline data set is very small and could be considered too small to draw any practical statistical conclusion, results from the correlation analysis between CPUE data and various gauging station parameters should be interpreted with caution. However, despite the very small data set, the results appeared to align with the finding of IPE (2020, 2021a and 2021b) and Lear *et al*. (2019), in that CPUE of YOY increased in years where the magnitude of the previous wet season increased. Specifically, the number of days the water level at Keep River gauging at the Legune Road Crossing (G8100225) was above 5.5 m was found to have the strongest relationship with YOY CPUE data (Figure 6). Whilst the relationship was less defined for total numbers captured, based on the cohort data presented in Figure 7 it can be seen that after a high magnitude wet season and notable recruitment the age class of individuals increased in subsequent years after low magnitude wet seasons and limited recruitment. As such, based on the regression lines fitted in Figure 6, it can be seen that the CPUE of YOY and total numbers obtained in both 2020 and 2021 fitted the models and could be considered within the expected range based on the magnitude of the previous wet season. Therefore, the numbers of *P. pristis* and *P. clavata* recorded in

2021 suggests that the Goomig Development has not had a detectable negative population-wide effect on these two Pristis species.

With respect to recaptured specimens, one male *P. clavata* (tag# 026) was recaptured in 2021 at EST01. This specimen was initially caught and tagged at the same location in 2020 and increased in size from 1,920 to ~ 2200 mm TL; a total of 280 mm in 14 months. Whilst it is unlikely that this individual remained at this location over the year, this result and the consistent presence of both species within the lower Keep River suggests that environmental conditions are favourable for the growth and survival of these species.

3.4 Fish Assemblages

3.4.1 Species Richness and Abundance

In 2021, 31 species of fish were recorded (Table 4), with 20 being recorded from K1, 17 from K2, 13 from K4, and 13 from the reference sites DR1 and KR2. Including sites not sampled in 2021, this resulted in a total of 47 species being recorded within the Keep River catchment upstream of the estuary throughout the Keep River surveys of riverine pools. The total number of species increased in 2021, from 42 in 2020, as a result of five additional species including *Glossogobius* sp. (Goby), *Melanotaenia australis* (Western Rainbowfish), *Pomadasys kaakan* (Barred Javelinfish), *Scatophagus argus* (Spotted Scat) and *Zenarchopterus* sp. (Viviparous Halfbeak) first being recorded in 2021 (Appendix 3). Within pools, total species richness ranged from five at K2-2 and K4-3 to 16 at K1-1, with the highest mean species richness of 10 being recorded at K1, followed by 7.8 at K2 then 7.0 at K4, whilst 11 species were recorded from DR1 (Figure 8). The tendency for greater species richness in the lower system likely reflects proximity to the Estuary (Figure 1), higher salinities (Table 2) and presence of estuarine-marine vagrants (Table 4). Most of the species recorded to date are considered common and known to permanently reside within rivers throughout northern Australia, or utilise them at some stage during their life-cycle (Table 4). The exception to this is *P. pristis* (K4-3 and KR2), which has already been discussed in Section 3.3.

Of the 607 fish recorded in 2021, *Nematalosa erebi* (Bony Bream) was by far the most abundant species with 336 individuals recorded, followed by *Planiliza ordensis* (Diamond Mullet), *Moolgarda buchanani* (Bluetail Mullet), *Neoarius graeffei* (Blue Catfish), *Lates calcarifer* (Barramundi), *Ellochelon vaigiensis* (Diamondscale Mullet) and *Eleutheronema tetradactylum* (Blue Threadfin) which accounted for 40 to 20 of individuals recorded (Table 4). Between pools, mean abundance varied and was greatest at K1 (72), followed by K2 (34.4) then K4 (17.3), whilst an abundance of 21 was recorded from DR1 (Figure 8). There was also a high variability within-pools with the lowest abundance of nine recorded at K4-3 and the highest abundance of 131 recorded at K1-1 (Table 4). *Nematalosa erebi* was the most widespread species, being recorded from all of the 14 sub-sites sampled. Other widespread but less abundant species were *Toxotes chatareus* (Seven-spot Archerfish) (11 sites), *N. graeffei* (10 sites) and *P. ordensis* (10 sites). Several species were, however, only captured or observed on single occasions from the riverine pools, and represented by single individuals at a single site.

3.4.2 Statistical Analysis of Fish Assemblages

Within the MDS ordination presented in Figure 9, it can be seen that fish species richness and composition (assemblages) at sub-sites within Keep River sites or the reference site were generally grouped with some overlap occurring between sites. 2021 assemblages at sub-sites within K1 and K2 and, although to a lesser extent, the reference site DR1 were somewhat separate from baseline assemblages, indicating some degree of dissimilarity, whilst those from K4 were amongst baseline assemblages, indicating a degree of similarity.

Results of PERMANOVA pair-wise tests confirmed these similarities and dissimilarities (Table 5). There was a significant difference between baseline and 2021 assemblages within K1 (p = 0.001) and K2 (p = 0.002), whilst there was no significant difference within K4 (p = 0.176) and DR1 (pMC = 0.199).

From Figure 8 it can be seen that both species richness and abundance at K1 were notably higher in 2021, in comparison to baseline data, whilst species richness was generally higher at K2, potentially explaining why there was a significant difference between baseline and 2021 assemblages within these pools. Further analysis with SIMPER (results not presented) indicated that the significant difference for K1 was mostly driven by notably higher numbers of *M. buchanani*, *E. tetradactylum* and *N. erebi* being recorded in 2021, in addition to lower numbers of *P. ordensis*, compared to baseline surveys, with each explaining 8% to 13% of the total variation. Additionally, small shifts in the abundance of several other species also contributed (< 6% of the total variation) to the significant difference for K1. Results of the DistLM (stepwise AIC) sequential test (Figure 10) indicated that alkalinity, pH and a limited number of nutrient parameters were considered the best subset of water quality variables explaining 43% of the variation of fish assemblages between years. As discussed in section 3.1, the reduced alkalinity and slightly increased concentrations of a limited number of nutrient parameters were attributed to the first-flush run-off event that occurred before and during the survey. As such, the fact that K1 assemblages in 2021 were significantly different from those during baseline surveys is considered to be the result of increased abundances occurring in 2021, rather than a decrease in diversity and abundance or anthropogenic impacts on water quality.

With respect to K2, SIMPER indicated that the significant difference was largely the result of *Carcharhinus leucas* (Bull Shark) being recorded for the first time, and in numbers, in 2021 and both *E. vaigiensis* and *L. calcarifer*, which were not recorded during each baseline survey, being recorded in 2021 (8% to 12% of the total variation). Additionally, a limited number of species also contributed slightly (< 6% of the total variation) to the significant difference by either not being recorded in 2021, despite being recorded previously or being recorded for the first time in 2021. As such, the significant difference between 2021 and baseline data at K2 is considered to be the result of increased diversity occurring in 2021 and, to a lesser extent, a slight shift in composition.

As discussed in Section 3.1, in 2021 the salinity within K2 was more akin to that which had typically been encountered in K1 during the baseline surveys (Figure 3). This, in turn, may explain the presence of or increases in abundance of species such as *C. leucas*, *E. tetradactylum*, *E. vaigiensis* and *L.calcarifer* which have typically been encountered or more common within K1. Results of the DistLM (stepwise AIC) sequential test (Figure 10) indicated that total nitrogen, alkalinity and calcium were considered the best subset of water quality variables explaining 35% of the variation of fish assemblages between years. Whilst increased calcium concentrations in 2021 likely resulted from evapoconcentration of estuarine waters, increased total nitrogen may be attributed to the previously mentioned recent rainfall and runoff event. However, it should be noted that water quality variables alone explained a relatively small portion of the variation of fish assemblages between years. Therefore, it is considered likely that other factors not related to water quality were influencing fish assemblages in 2021.

With respect to comparisons between upstream reference and Keep River sites, within the MDS ordination presented in Figure 9, it can be seen that fish assemblages in 2021 at DR1 were separate from Keep River assemblages, indicating they are dissimilar. However, results of the PERMANOVA pair-wise tests indicated that only assemblages at K1 (pMC = 0.046) and K2 (pMC = 0.05) were significantly different from those at the reference site (Table 5). Analysis with SIMPER indicated that these significant differences were driven by the assemblages in the lower system primarily consisting of estuarine-marine vagrant species, which is not unexpected noting the proximity to the Estuary and far higher salinities, and upstream sites primarily consisting of freshwater species. Results of the DistLM (stepwise AIC) sequential test confirmed this (Figure 11), with magnesium and alkalinity, both of which increased concentrations are associated with estuarine waters, considered the best subset of water quality variables explaining 50% of the variation of fish assemblages between sites.

3.5 Aquatic Fauna Pest Monitoring

No C. quadricarinatus were recorded from any of the 13 opera house traps set in K1, K2 or K4. The absence of this species from K1 and K2 was expected as the conductivities at these locations were above the value of 2900 mS/m known to cause significant mortalities in this species (Jones 1995). With respect to K4, this result suggests that C. quadricarinatus has not established a population within the Keep River, as a result of the extended irrigation channels providing a pathway or being inadvertently or intentionally introduced to the Keep River via recreational fishers who collect red claw from the Ord system.

3.6 Macroinvertebrates Assemblages

3.6.1 Species Richness and Abundance

A total of 109 macroinvertebrate taxa were originally recorded from edge habitats across all sites sampled in 2021. This list includes several taxa that could not be identified to species level due to life phase (e.g. larvae, early instars), sex (some taxonomic determinations are based on males only) and/or lack of suitable taxonomic keys. As noted in Section 2.3.1, to allow for accurate comparisons and statistical analysis to be made between years, the taxa level of identification was adjusted to be consistent across all years. As such, in 2021 106 macroinvertebrate taxa were identified (Table 6). Including taxa recorded from the same sites sampled in 2021, during baseline surveys and 2020, this makes a combined total of 316 macroinvertebrate taxa collected from edge habitats in Keep River pools and reference sites

(Appendix 4). The total number of taxa recorded in 2021 was comparable to previous years when 124 to 140 taxa have been recorded (Table 7). As in baseline years and 2020, no species listed under State or Commonwealth legislation were recorded in 2021 with the majority of macroinvertebrates collected considered common, ubiquitous species, with distributions extending throughout Australia, northern Australia or Australasia. Consistent with baseline data, insects comprised the highest portion of taxa collected (81%) followed by malacostracans (8.5%) then gastropods (4.7%), with the majority of remaining classes accounting for less than 1% (Table 7).

3.6.2 Statistical Analysis of Macroinvertebrate Assemblages

Within the MDS ordination presented in Figure 12, it can be seen that during each sampling event (year) macroinvertebrate assemblages at sub-sites within each site were generally grouped. However, between years there was negligible overlap of assemblages within the sites K1 and K2 which were also quite dispersed, whilst there was limited overlap of assemblages within K4 and some overlap at reference sites which were somewhat grouped. As such, 2021 assemblages at sub-sites within K1 and K2 were somewhat separate from respective baseline assemblages, indicating some degree of dissimilarity, whilst those from K4 and reference sites were amongst baseline assemblages to some extent, indicating some degree of similarity.

Results of the PERMANOVA pair-wise tests confirmed these similarities and dissimilarities (Table 8). There was a significant difference between baseline and 2021 assemblages within K1 ($p = 0.003$), K2 ($p = 0.001$) and K4 ($p = 0.022$), whilst there was no significant difference within reference sites ($pMC = 0.091$). However, results from additional PERMANOVA pair-wise tests undertaken between baseline years within a site indicated that assemblages were significantly different between baseline years, in addition to 2021, for both K1 and K2 (Table 9). Additionally, in most instances, assemblages at K1 and K2 during baseline years were significantly different from reference sites in the same year. This, in turn, suggests that macroinvertebrate assemblages naturally experience a high degree of temporal variation at these sites. With respect to K4, assemblages were not significantly different between baseline years or individual baseline years and 2021, suggesting that macroinvertebrate assemblages naturally experience little temporal variation and that assemblages in 2021 were not significantly different.

Analysis with SIMPER on species-level data indicated that differences in macroinvertebrate assemblages between baseline and 2021 data sets within all sites was due to small changes in abundance of a large number of species, with the vast majority contributing $\lessapprox$ 3%, and a limited number contributing ≈ 5%, to the total variation. Further analysis with SIMPER on family-level data indicated that the significant differences in macroinvertebrate assemblages between baseline and 2021 data sets at K1 and K2 were driven by an increase in estuarine species or those tolerant of such conditions (e.g. Corophiidae, Hymenosomatidae, Clenchiellidae, Corophiidae Polychaeta and Bithyniidae) and a decrease in freshwater species which are generally more diverse (Figure 13, nMDS with correlations > 0.7 of taxa are shown). As such, in comparison to baseline years, the species richness recorded in 2021 was lower within K2 and at the lower end of what had been recorded within K1 (Figure 14). However, in 2021, species richness followed the historic trend of increasing in an upstream direction, indicating that species richness increases with reduced salinities.

Results of the DistLM (stepwise AIC) sequential test (Figure 15) indicated that turbidity and total phosphate within K1 were considered the best subset of water quality variables explaining 51% of the variation of assemblages between years. With respect to total phosphate, as discussed in Section 3.1, higher concentrations in 2021 were considered to be the result of increased temperatures and the recent rainfall and runoff event. Furthermore, increased concentrations of total phosphate at reference sites, along with other nutrient parameters, were identified in the best subset of water quality variables explaining 54% of the variation of assemblages between years at reference sites. As such, the influence of these variables in 2021 is not considered to be resulting from the Goomig Development.

Within K2, DistLM (stepwise AIC) sequential test results indicated that dissolved oxygen, magnesium, chloride and pH were the best subset of water quality variables explaining 69% of the variation of assemblages between years, with magnesium and chloride alone accounting for 56% and separating 2021 from baseline assemblages. As discussed in Section 3.1, in 2021 the salinity within K2 was more akin to that which had typically been encountered in K1 during the baseline surveys and the increased magnesium and chloride concentrations in 2021 likely results from evapoconcentration of estuarine waters.

With respect to comparisons between upstream reference and lower Keep River sites, within the MDS ordination presented in Figure 16, it can be seen that assemblages in 2021 at reference site were separate from K1 and K2 (both estuarine) assemblages, indicating they are dissimilar, whilst those from K4 (freshwater) were amongst baseline assemblages, indicating a degree of similarity. Results of the PERMANOVA pair-wise tests confirmed these similarities and dissimilarities, with assemblages at K1 (*pMC* = 0.007) and K2 (*pMC* = 0.003) being significantly different from those at reference sites, whilst those at K4 (*pMC* = 0.395) were not significantly different. As expected, SIMPER indicated that significant differences in macroinvertebrate assemblages between both K1 and K2 with those reference sites were driven by an increased number of estuarine taxa or those tolerant of such conditions being present at K1 and K2 (Figure 16 nMDS with correlations > 0.5 of taxa are shown). Furthermore, the DistLM (stepwise AIC) sequential test indicated that water quality parameters mostly related to the increased salinity of estuarine waters were considered the best subset of water quality variables explaining the variation of assemblages between sites (Figure 16). As such, noting the proximity of K1 and K2 to the estuary and the far higher salinities present, the significantly different assemblages is not unexpected and considered natural.

From the SIGNAL 2 Score analysis presented in Figure 17, it can be seen that when compared to baseline data, all K1 and K4 sub-sites in 2021 fell within quadrant one, indicating physical conditions are benign and pollutants are not present in large amounts. The reference site DR1 was the only one to fall within quadrant four which generally indicates it is heavily impacted by human activity as the SIGNAL 2 score and diversity is reduced. However, DR1 falling within quadrant four in 2021 was attributed to the flow event occurring at the site at the time of sampling. This would have resulted in macroinvertebrates being washed away without having had time to recolonise, markedly reducing diversity.

The majority of K2 sub-sites and the reference site KR2 fell within quadrant three, as a result of high SIGNAL 2 values and few macro-invertebrate types, which often indicates toxic pollution, unusual forms of pollution or harsh physical conditions. For KR2 this was attributed to the recent deoxygenation/fish kill event at the site, resulting from the first rains of the wet season, which is considered a natural occurrence. This event would have had a similar effect to the presence of toxic pollution, reducing diversity and shifting this site into quadrant three. With respect to K2, whilst this result may indicate pollution is present, sites fall within this quadrant as a result of species richness decreasing when the tolerances of macroinvertebrate types differ, which is typical of estuarine assemblages. Whilst the SIGNAL 2 Score analysis indicates that sites with higher salinity should fall within quadrant two, this analysis is typically done on freshwater systems. Therefore the marked increase in salinity at this estuarine site in 2021, although natural, may be considered unusual “pollution” or water quality in comparison to baseline data.

Similarly, for the SIGNAL 2 Score analysis undertaken on 2021 data, all K4 sub-sites in 2021 fell within quadrant one, whilst all K1 and K2 sub-sites fell within quadrant three as a result of the estuarine assemblages present at these sites.

4 CONCLUSION

Analyses presented in this report compared 2021 data to that collected during the baseline surveys (2011, 2012 and 2013) and represents the second of three post-development surveys required to be completed as per project approval conditions. Whilst a limited number of potentially impacted sites were not surveyed in 2021 as a result of COVID-19 travel restrictions implemented during the survey, current results are considered adequate for identifying potential impacts on the lower Keep River from the Goomig development. Furthermore, it is acknowledged that each survey only provides a single snapshot of the abiotic conditions and faunal assemblages within the Keep River which are naturally variable. Whilst the river is highly dynamic with large variability in the magnitude of wet season rains and flows occurring between years, standardising sampling to the late dry season can minimise seasonal effects on the data to some degree, thus allowing inter-annual comparisons and detection of any impacts of the Goomig Development to be made.

Current results suggest that the Goomig Development has not had an adverse impact on the water or sediment quality within the lower Keep River. In all instances, the herbicide atrazine was below the LOR. While there were several exceedances of site-specific guideline concentration values in 2021, the majority were considered to be the result of natural processes and at this stage do not appear to be having any direct adverse effects on the biota present. This was supported by fact that water from the Goomig Development was not been released into Border Creek (and subsequently into the Keep River) since the 2020 survey. Exceedance of ionic composition parameters were attributed to increased tidal influence and evapoconcentration that commonly occurs in rivers later in the year. Furthermore, elevated nutrient parameters associated with the first-flush run-off in the wet/dry tropics can have high concentrations of suspended particulate matter, nutrients and heavy metals. This, in turn, suggests that there has been limited input or accumulation of pollutants into the lower Keep River as a result of water previously being released down Border Creek and that these parameters can naturally be highly variable depending on the time of year and the weather around the time of sampling. In comparison, in 2020 WRM (2021) observed increased concentrations and exceedances of a number of parameters, particularly metals in sediment. These exceedances were attributed by those authors to water releases down Border Creek or major earthworks associated with the construction of a bridge and the bituminising of the Legune Road. In 2021 it remains unclear which factors were responsible for increased concentrations in 2020 as neither occurred between 2020 and 2021, however, concentrations in 2021 were generally lower and the number of exceedances was far lower, particularly for metals, suggesting that effects had subsided and/or that various analytes had dispersed, diluted or decomposed. WRM (2021) also noted that thunderstorms and rainfall occurred prior to and during the 2020 survey. As such, it is suspected that rainfall run-off may have contributed to those exceedances. In order to identify whether the release of water into Border Creek is specifically influencing the Keep River, future sampling should be undertaken well before the onset of the wet season to avoid any influence the rainfall run-off may have on the results.

Consistent with the baseline surveys and historic survey records, no *Glyphis* species were captured during the 2021 survey. However, one *P. pristis* from the freshwater reaches of the Keep River and four *P. clavata* from the estuary site EST01 were captured. An additional *P. pristis* that had succumbed to the fish kill/deoxygenation event at the reference site KR2 was also recorded. These numbers were within the ranges recorded from the same sample sites during the baseline surveys, whilst the distribution was comparable to historic records within the Keep River catchment. Additional analyses comparing *P. pristis* baseline capture data and the magnitude of the previous wet season indicated that the numbers obtained in both 2020 and 2021 were within the expected range based on the magnitude of the previous wet season. Therefore, the numbers of *P. pristis* and *P. clavata* recorded in 2021 suggests that the Goomig Development has not had a detectable negative population-wide effect on these two *Pristis* species. Furthermore, the presence of both species within the lower Keep River in all years and the recapture of a *P. clavata* in 2021 from the same location it was tagged at in 2020 suggests that environmental conditions are favourable for the growth and survival of these species.

With respect to fish and macroinvertebrates, Keep River pools continue to support a high species diversity. Current results indicate that assemblages and diversity within the lower Keep River continue to be primarily driven by the longitudinal gradient in salinity decreasing from K1 to K4 with increasing distance from the estuary. Furthermore, concerning the slightly increased concentrations of a limited number of nutrients that were considered potential drivers of assemblages, whilst it was considered likely to be the result of first-flush run-off, it did not appear to result in a decline in species richness or a significant shift in composition throughout the lower reaches of the Keep River. This result suggests that there has been no decline in species richness and composition throughout the lower reaches of the Keep River outside of that which could be considered natural variation and in response to the ingress of tidal waters upstream, evapoconcentration in pools and climatic events.

In light of the requirement for a third and final post-development survey, sampling should continue to use the standardised methodologies and conduct sampling in the latter part of the dry season to allow direct comparison with existing pre-development data. As noted, sampling in the 2022 dry season should be undertaken well before the onset of the wet season to avoid any influence rainfall run-off may have on the results. This will allow for the far better detection of any future changes in abiotic factors and aquatic fauna and differentiate natural changes from any effects from the Goomig Development. Additionally, whilst current reference sites may not be the most appropriate for assessing the potentially impacted sites that are tidally influenced, there may be limited benefit in relocating these sites at this late stage of the longitudinal study as which are written into the project approval documents. Noting that the usefulness of current reference sites is limited, future comparisons between these and potentially impacted sites should be interpreted with caution and the limitations highlighted. If the post-development monitoring is to continue beyond 2022, however, consideration should be given to identify more appropriate reference sites and/or the removal of those references sites which are not located on the Keep River catchment.

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TABLES

Table 1. List and location of the monitoring programs sampling sites and sub-sites. Type refers to whether the site is a potentially exposed (PE) or reference (R) site. Y = sampled in 2021, NA = not accessible in 2021 and blank = not a component of the sampling program undertaken at the site or sub-site.

Site Information				Sediment	water quality				Macroinvertebrates		Elasmobranchs	Small fish	Crayfish
Code	Easting	Northing	Type		In situ water quality	Do + T profiles 0.5 m intervals	water samples	Atrazine	Edge habitats	Riffle habitats	6" & 7" x 30 m up to 8 hrs	x2 30 m multi-pane for 2.5 hours	Opera house Trap
EST01	512679	8305571	PE	Y	Y	Y	Y	Y			Y		
EST02	512545	8313129	PE	NA	NA	NA	NA	NA			NA		
EST03	513091	8316246	PE	NA	NA	NA	NA	NA			NA		
K1-1	509484	8305651	PE	Y	Y	Y	Y		Y			Y	Y
K1-2	510312	8304733	PE	Y	Y	Y	Y		Y			Y	Y
K1-3	508853	8303530	PE	Y	Y	Y	Y	Y	Y		Y	Y	Y
K1-4	509064	8302722	PE	Y	Y	Y	Y		Y			Y	Y
K1-5	508988	8301745	PE	Y	Y	Y	Y		Y			Y	Y
K2-1	509147	8300892	PE	Y	Y	Y	Y		Y			Y	Y
K2-2	509256	8300705	PE	Y	Y	Y	Y		Y			Y	Y
K2-3	509276	8300457	PE	Y	Y	Y	Y	Y	Y		Y	Y	Y
K2-4	509141	8300123	PE	Y	Y	Y	Y		Y			Y	Y
K2-5	509004	8300012	PE	Y	Y	Y	Y		Y			Y	Y
K3-1	508553	8299522	PE	NA	NA	NA	NA		×			NA	NA
K3-2	508512	8298897	PE	NA	NA	NA	NA		×			NA	NA
K3-3	508377	8298346	PE	NA	NA	NA	NA		×	NA	NA	NA	NA
K3-4	508350	8297859	PE	NA	NA	NA	NA		×			NA	NA
K3-5	508132	8297681	PE	NA	NA	NA	NA		×			NA	NA
K4-1	506892	8296907	PE	Y	Y	Y	Y		Y			Y	Y
K4-2	506816	8296830	PE	Y	Y	Y	Y	NA	Y	Y	Y	Y	Y
K4-3	506977	8296457	PE	Y	Y	Y	Y		Y			Y	Y
KE1	500794	8272943	Ref		NA	NA	NA		NA			NA	
KR1	504078	8265707	Ref		NA	NA	NA		NA			NA	
KR2	507481	8260867	Ref		Y	Y	Y	Y	Y			NA	
SR4	534621	8283769	Ref		NA	NA	NA		NA	NA		NA	
DR1	433967	8216059	Ref		Y	Y	Y		Y	Y		Y	

Table 2. Median water quality values (mg/L unless indicated), obtained from reference sites and potentially impacted lower Keep River and estuary sites in 2021. Median values highlighted purple = SS-WQGV exceedance, yellow = ILTV and SS-WQGV exceedance, green = > SS-WQGV and < ILTV. ANZG (2018) default trigger values for tropical Australian lowland rivers (LR) and estuaries (E) are also displayed.

	Analyte	LOR	ANZG (2018)		Keep River									Estuary		Reference sites			
					K4			K2			K1			EST01		DR		KR	
			LR	E	SS-WQGV	ILTV	Median	SS-WQGV	ILTVs	Median	SS-WQGV	ILTVs	Median	SS-WQGV	Median	SS-WQGV	Median	SS-WQGV	Median
Miscellaneous	TDS-calc	1			2416		478	12200		17400	27000		20100	31600	20500	200	73	110	91
	TSS	5			1.5	62	<5	1.5	21	5	1.5	27	9	66.8	27	0.9	<5	6.6	13
	Temp (oC)				28	31	33	32.5	32	36	30.4	33	32	31.4	31	31.2	33	29.1	31
	Turbid (NTU)		15	20	13.2	120	3	10	15	7.6	9.7	15	10	34.8	38	5.3	14	6	174
	pH (units)		6-8	6-8.5	8	6.0–8.0	7.2	8.4	6.0–8.4	8.3	8.4	6.0–8.4	8.3	8.2	8.3	8.2	8.3	8.2	7.8
	DO (%)		90	80	52	23	59	91	35	109	85	28	105	88	60	84	92	88	31
	Econd (mS/m)	1	250		121	85	74	2176	2158	2680	4566	4166	3090	5444	3160	42.5	11	35.4	14
Ionic composition	Alkalinity	1			145		150	160		155	174		111	187	88	207	50	135	51
	Acidity	1			11.8		5	16.4		2	1.6		3	15.4	3	4.8	1	3.8	6
	Hardness	1			328		208	2400		3420	5300		4100	6400	3740	156	40	75	50
	CO3	1			<1		<1	<1		<1	9		<1	11	<1	3	<1	<1	<1
	Cl	1			251		142	7152		8020	15440		10400	19960	11200	16	5	18	5
	F	0.1			0.21		0.1	0.48		0.5	0.74		0.5	0.8	0.4	0.29	0.1	0.07	<0.1
	SO4-S	1			105		42	1002		1060	2340		1300	2740	1460	21	<5	2.5	8
	HCO3	1			175		150	185		155	200		111	228	88	218	50	114	51
	Ca	1			45		39	189		271	361		315	439	275	28	8	26	10
	Mg	1			36		27	456		666	1030		806	1294	741	26	5	18	6
	Na	1			366		71	3518		4850	8816		5980	11400	5880	17	8	30	6
	K	1			12		4	117		230	296		292	397	274	12	3	8	3
Nutrients	DOC	1			2.8		3	4.3		6	4.7		6	4.3	7	3.1	7	4.2	12
	N-NH3	0.005			0.007	0.32	0.015	0.006	0.32	<0.005	0.022	0.32	0.005	0.07	0.044	<0.01	0.034	<0.01	0.081
	N-NOx	0.002	0.01	0.03	<0.01	0.17	0.009	<0.01	0.17	0.003	<0.01	0.17	0.006	<0.01	0.004	<0.01	0.14	0.014	0.024
	N-org.	0.025/0.01*			0.27		0.12	0.35		0.28	0.47		0.33	0.57	0.36	0.31	0.34	0.38	0.56
	N-tot.sol.	0.025/0.01*			0.22		0.14	0.32		0.33	0.48		0.35	0.57	0.17	0.21	0.59	0.3	0.58
	N-total	0.05/0.01*	0.3	0.25	0.24	0.44	0.14	0.35	0.35	0.28	0.5	0.4	0.34	0.66	0.4	0.29	0.51	0.37	0.67
	P-tot.sol	0.005			<0.005		0.016	<0.005		0.014	<0.005		0.014	<0.005	<0.005	<0.005	0.021	<0.005	0.012
	P-total	0.005	0.01	0.02	0.01	0.04	0.019	<0.01	0.01	0.013	<0.01	0.01	0.024	0.03	0.037	0.016	0.036	<0.005	0.056
Herbicide	Atrazine (µg/L)	0.5								<0.5			<0.5		<0.5				<0.5
	Dibromo-DDE (%)*	0.5								69			69		76				68
	DEF (%)*	0.5								73			74		93				71

*Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018), Site-Specific Water Quality Guideline Values (SS-WQGV) as the 80th, or 20th for oxygen saturation, percentile value of baseline data and Bennett and George (2014) lower Keep River Interim Local Trigger Values (ILTV) for aquatic environmental stressors and toxicants.

Table 3. Median sediment quality values (mg/kg unless indicated), obtained from potentially impacted lower Keep River and estuary sites in 2021. Median values highlighted purple = SS-SQGV exceedance. ANZG (2018) sediment default guideline values (DVG) and default guideline values-High (GV-H) are also displayed. N.B. For red values, the limit of reporting (LOR) was greater than the SS-SQGV.

					Estuary			Keep River								
	Analyte	LOR	ANZG (2018)		EST01			K1			K2			K4		
			DGV	GV-H	SQGV	2020	2021	SQGV	2020	2021	SQGV	2020	2021	SQGV	2020	2021
Major Ions	Si	1			154	180	10	190	130	8	160	160	7	190	190	13
	Cl	10			8800	3230	10200	10400	2600	8640	5840	85	4910	850	15	20
	SO4	10			1580	2000	1610	1820	2000	950	812	30	780	384	200	15
	Na	50			6560	10000	7520	8080	8100	7560	5160	590	3980	936	230	90
	K	50			2900	4100	2290	2640	3200	2900	2200	1700	1560	1300	1200	500
	Ca	50			48600	31000	47000	11200	7000	4200	4720	2900	2350	4140	2600	1370
	Mg	50			7980	9600	7820	6520	7900	5810	6720	3700	4000	5900	3100	1280
Nutrients	NO3-N	0.1			1	<1	<0.1	1	1	<0.1	1	1	<0.1	<1	<1	<0.1
	N-Total	20			344	300	240	460	590	410	522	360	430	732	440	150
	P-Total	2			210	200	201	150	130	143	160	90	95	150	76	40
	NH4-N	0.2			2	2	23.2	4.2	5	14.4	7.2	4	18.4	35	6	10.2
	TOC%	0.02			0.71	0.38	0.13	0.7	0.65	0.26	0.7	0.46	0.5	1	0.59	0.24
Total Metals	Al	50			10520	21900	7780	17000	26200	12200	17300	24500	6850	16620	16400	4440
	Sb	0.5	2	25	0.06	0.07	<0.5	0.09	0.09	<0.5	0.12	0.08	<0.5	0.13	0.08	<0.5
	As	1	20	70	3.6	4.4	3.31	2.5	2.9	2.06	2.3	2.2	1.61	2.1	1.7	0.5
	Ba	10			17	23	10	114	80	100	172	150	80	170	140	90
	Be	1			0.34	0.44	<1	0.75	0.57	<1	0.76	0.51	<1	0.73	0.53	<1
	Bi	0.1			<0.05	0.14	<0.1	0.14	0.16	0.2	0.16	0.12	0.1	0.16	0.13	<0.1
	B	50			23	36	<50	13.2	21	<50	6.2	6	<50	2.5	5	<50
	Cd	0.1	1.5	10	<0.05	<0.05	<0.1	<0.05	0.05	<0.1	<0.05	0.05	<0.1	<0.05	<0.05	<0.1
	Cr	1	80	370	18	27	16	27	32	23	29	26	17	29	21	10
	Co	1			10	11	8	21	18	19	23	20	18	23	20	12
	Cu	1	65	270	9	11	7	15	18	13	19	16	13	18	15	6
	Ga	0.1			4.3	6.9	2.6	7.7	7.4	4	8.3	8.9	2.6	8.2	6	1.6
	Fe	50			18000	23000	14400	29400	31000	24400	33200	25000	17400	32000	27000	11100
	La	0			12	14	10	18	17	14	20	19	15	20	15	8
	Pb	1	50	220	6	7.6	4.7	10	11	9.2	11	12	9.4	11	9.8	5.2
	Li	0.1			8	18	6.7	7	16	4.9	7	9.8	2.7	6	6.1	1.3
	Mn	10			290	310	249	630	590	504	1100	620	619	748	630	522
	Mo	2			0.23	0.19	<2	0.32	0.28	<2	0.28	0.13	<2	0.22	0.14	<2
	Hg	0.01	0.15	1	0.21	<0.02	<0.01	0.45	<0.02	<0.01	0.49	<0.02	<0.01	0.286	<0.02	<0.01
	Ni	1	21	52	10	14	8.8	17	18	13.9	19	22	14.4	18	14	6.8
	Se	0.1			0.06	0.09	0.05	0.11	0.12	0.2	0.11	0.12	0.1	0.11	0.11	0.05
	Ag	0.1	1	4	<0.05	<0.05	<0.1	<0.05	<0.05	<0.1	<0.05	<0.05	<0.1	<0.05	<0.05	<0.1
	Sn	0.1			<0.5	1	0.5	0.6	1.1	0.8	0.7	1	0.5	0.8	0.8	0.4
	Ti	10			220	460	360	112	280	210	100	280	150	73.4	130	80
	U	0.1			0.5	0.72	0.5	0.8	0.94	0.7	1	0.99	0.7	1	0.75	0.3
	V	2			29	43	27	56	65	54	66	87	68	66	62	36
	Zn	1	200	410	18	24	15.6	25	26	20.7	31	20	13.4	29	19	7.4
Herbicide	Atrazine	0.05				<0.01	<0.05		<0.01	<0.05		<0.01	<0.05		<0.01	<0.05
	Dibromo -DDE	0.05					114			94.3			108			113
	DEF	0.05					74.6			95.2			111			111

*Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018), Site-Specific Sediment Quality Guideline Values (SS-SQGV) as the 80th percentile value of baseline data.

Table 4. Fish species and numbers recorded from each sub-site and site sampled in 2021.

Species	Common Name	Life-cycle Category	Keep River																Reference		Total
			K1-1	K1-2	K1-3	K1-4	K1-5	**K1**	K2-1	K2-2	K2-3	K2-4	K2-5	**K2**	K4-1	K4-2	K4-3	**K4**	DR1	KR2	**Total**
Ambassis sp.	Glassfish	EV/P							1					**1**							**1**
Amniataba percoides	Barred Grunter	P																	1		**1**
Arrhamphus sclerolepis	Snub-nosed Garfish	MV/EV/P		1		1		**2**				1		**1**							**3**
Carcharhinus leucas	Bull Shark	EE	3	1	1		1	**6**	1			6	2	**9**						1	**16**
Eleutheronema tetradactylum	Blue Threadfin	MM	1	5	6		4	**16**			7			**7**							**23**
Ellochelon vaigiensis	Diamondscale Mullet	MM	4	1	3	1		**9**	2	2	4	1	6	**15**							**24**
Elops hawaiensis	Herring	MV	1					**1**													**1**
Glossamia aprion	Mouth Almighty	P							1					**1**	1			**1**			**2**
Glossogobius spp.	Goby	EV/P							1					**1**	1			**1**			**2**
Hephaestus jenkinsi	Western Sooty Grunter	P															1	**1**	1		**2**
Lates calcarifer	Barramundi	Sc	3		3		4	**10**	2	4		5		**11**	2	3		**5**			**26**
Leiognathus equula	Common Ponyfish	MV	2					**2**													**2**
Leiopotherapon unicolor	Spangled Perch	P																	1		**1**
Lutjanus argentimaculatus	Mangrove Jack	MM					1	**1**													**1**
Marilyna meraukensis	Merauke Toadfish	MV/EV			1	1	1	**3**	1		1			**2**							**5**
Megalops cyprinoides	Oxeye Herring	MM	1					**1**			1			**1**	2	1		**3**	4		**9**
Melanotaenia australis	Western Rainbowfish	P													1			**1**	1		**2**
Moolgarda buchanani	Bluetail Mullet	MM	10	3	9	11		**33**													**33**
Nematalosa erebi	Bony Bream	P	85	58	38	39	22	**242**	22	20	7	13	14	**76**	3	7	1	**11**	7		**336**
Neoarius graeffei	Blue Catfish	MV/EV/P	2		1	1		**4**			9	6	1	**16**	3	3	4	**10**	1		**31**
Neoarius midgleyi	Shovel-nosed Catfish	P	1			1		**2**			3			**3**		1		**1**	1		**7**
Neosilurus ater	Narrow-fronted Tandan	P																	1		**1**
Planiliza ordensis	Diamond Mullet	MM	4				3	**7**	4	4	5	4	1	**18**	5	8	2	**15**			**40**
Polydactylus macrochir	Giant Threadfin	MM	1	1				**2**													**2**
Pomadasys kaakan	Barred Javelinfish	MM	1					**1**													**1**
Pristis pristis	Largetooth Sawfish	EE															1	**1**		1	**2**
Scatophagus argus	Spotted Scat	MV								4				**4**							**4**
Strongylura krefftii	Freshwater Longtom	P		1				**1**							1			**1**	2		**4**
Thryssa sp.	Anchovy	MM	7					**7**													**7**
Toxotes chatareus	Seven-spot Archerfish	P	5	1	1	1	2	**10**	1		1	2	1	**5**	1			**1**	1		**17**
Zenarchopterus sp.	Viviparous Halfbeaks	MV							1					**1**							**1**
	Species Richness		16	9	9	8	8	**20**	11	5	9	8	6	**17**	10	6	5	**13**	11	2	**31**
	Total Number		131	72	63	56	38	**360**	37	34	38	38	25	**172**	20	23	9	**52**	21	2	**607**

*Life-cycle category: EE = euryhaline elasmobranch, MM = marine migrants, MV = marine vagrants, EV = estuarine vagrants, Sc = semi-catadromous, and P = potamodromous fishes (but includes those freshwater obligatory species where migratory information is unavailable).

Table 5. Results of the PERMANOVA (permutational multivariate analysis of variance, Type 1 sequential) pair-wise test undertaken on fish abundance data (Bray-Curtis similarity) recorded during baseline surveys (2011-2013) and post-development at potentially impacted and reference sites in 2021 and 2020. N.B. Significant values ($p < 0.05$) are highlighted orange and in instances when the number of permutations was below 100 (highlighted yellow) the Monte Carlo p-value should be referred to.

Pair	t	P(perm)	Unique perms	P(MC)
K1 Baseline, K1 2021	1.9476	0.001	965	0.005
K2 Baseline, K2 2021	1.7873	0.002	977	0.009
K4 Baseline, K4 2021	1.2521	0.176	218	0.195
Reference Baseline, Reference 2021	1.5644	0.255	4	0.199
K1 2021, Reference 2021	1.961	0.178	6	0.046
K2 2021, Reference 2021	1.8689	0.174	6	0.05
K4 2021, Reference 2021	1.3376	0.49	4	0.253
K1 Baseline, K1 2020	1.0268	0.393	962	0.378
K2 Baseline, K2 2020	1.6197	0.009	961	0.027
K4 Baseline, K4 2020	1.0752	0.383	219	0.341
Reference Baseline, Reference 2020	0.99893	0.752	4	0.46
K1 2020, Reference 2020	1.3783	0.177	6	0.164
K2 2020, Reference 2020	1.8717	0.173	6	0.075
K4 2020, Reference 2020	1.2447	0.248	4	0.3

Table 6. Edge macroinvertebrate species abundance data from each sub-site sampled in 2021. N.B. Data are log^{10} abundance classes; 1 = 1 - 10 individuals, 2 = 11 - 100 individuals, 3 = 101-1000 individuals, 4 = >1000.

PHYLUM CLASS order	Lowest Taxon	Keep River													Reference	
		K1					K2					K4				
		1	2	3	4	5	1	2	3	4	5	1	2	3	KR2	DR1
ANNELIDA																
OLIGOCHAETA	Oligochaeta spp.	1				1						4	4	4	3	2
POLYCHAETA	Polychaeta spp.	2		3	3	3	3	3	4	4	3					
ARTHROPODA																
ACARINA	Acarina			1		1						2		1	4	3
INSECTA																
Coleoptera	Curculionidae spp.							1								
	Clypeodytes feryi											1		1		1
	Clypeodytes larsoni															1
	Clypeodytes weiri															1
	Copelatus nigrolineatus											1				2
	Hydaticus consanguineus															1
	Hydroglyphus basalis											2	1			2
	Hydroglyphus grammopterus													2		
	Hydroglyphus leai													2		
	Hydrovatus ovalis						1					1		1		2
	Hyphydrus spp.															1
	Laccophilus clarki												2	2		
	Laccophilus spp.											1				
	Laccophilus unifasciatus															1
	Laccophilus walkeri															2
	Limbodessus compactus													1		
	Megaporus ruficeps											1				
	Neobidessodes flavosignatus															1
	Neobidessodes mjobergi															1
	Tiporus josepheni												1		2	
	Heteroceridae spp.															2
	Hydraena spp.											2	1	2		2
	Limnebius spp.															1
	Ochthebius spp.													1		
	Hydrochus spp.										1	2	2	2	1	1
	Berosus dallasae															1
	Berosus pulchellus											1				
	Helochares marreensis											1				
	Helochares spp.											1				
	Paracymus pygmaeus						2					2	2	3		2
	Regimbartia attenuata						3	3		1	2		2	2		
	Limnichidae spp.												1	1		1
	Hydrocanthus micans											1				
	Neohydrocoptus subfasciatus											1		1		
	Notomicrus tenellus													2		2
	Scirtidae spp.															1
	Staphylinidae spp.					1		1					1			
Diptera	Cecidomyiidae spp.															3
	Ceratopogonidae spp.															1
	Ceratopogoninae spp.			2	1			1	2	1	2	4	4	4	1	4
	Dasyheleinae spp.											2	2	2		
	Forcipomyiinae spp.													1		
	Chironomidae spp.										1	4	2	3		3
	Chironominae spp.						2	1	1	2	2	4	3	3	2	4
	Orthocladiinae spp.											2		1		
	Tanypodinae spp.											3	3	3	3	4
	Aedes spp.															1
	Anopheles spp.									2	2			1		2
	Culicidae spp.															1

PHYLUM / CLASS / order	Lowest Taxon	Keep River K1 1	K1 2	K1 3	K1 4	K1 5	K2 1	K2 2	K2 3	K2 4	K2 5	K4 1	K4 2	K4 3	Reference KR2	Reference DR1
	Muscidae spp.															2
	Stratiomyidae spp.												1	1		
	Tabanidae spp.												1	2		
Ephemeroptera	Baetidae spp.											3	3	3	3	3
	Cloeon fluviatile											3			2	3
	Cloeon sp. Red Stripe											2	2		2	3
	Caenidae spp.											4	2	3	2	4
	Tasmanocoenis sp. E														1	
	Tasmanocoenis sp. M											3				3
	Tasmanocoenis sp. P/arcuata											3		2	1	
	Wundacaenis dostini											3			1	3
Hemiptera	Diplonychus spp.															1
	Mesovelia spp.													2		
	Mesovelia vittigera													1		
	Austronecta micra											2				3
	Micronecta lansburyi															2
	Micronecta paragoga											3	1			
	Micronecta spp.											2		2		3
	Micronecta virgata												1			
	Micronectidae spp.											3				3
	Ranatra diminuta						1	1	2							
	Notonectidae spp.											2	2	2	1	2
	Nychia sappho												1			2
	Paraplea spp.						1	1		2	1	4	4	3		3
	Veliidae spp.													1		
Odonata	Argiocnemis rubescens									2						
	Pseudagrion aureofrons									2			1			1
	Pseudagrion microcephalum						2		2		1	1				
	Antipodogomphus neophytus											1			1	
	Diplacodes haematodes											1				
	Anisoptera spp.											2	1	2		2
	Zygoptera spp.						1	2	2	2	1	1	2	2	1	2
Trichoptera	Ecnomus spp.											1		1		1
	Leptoceridae spp.											1	1	1		
	Oecetis spp.											1				
	Triplectides ciuskus seductus											1				
	Triplectides spp.															2
MALACOSTRACA																
Amphipoda	Corophiidae spp.	3	2	3	2	3	4	4	4	4	4					
	Melitidae spp.	1														
Decapoda	Caridina nilotica											3	1			
	Caridina serratirostris											2	2			
	Caridina spp.		2	2	2	3	2	1				3	2		3	1
	Amarinus lacustris	1	2	2	2	3			1							
	Macrobrachium bullatum				2									1		
	Macrobrachium rosenbergii	2	2	2				1	2	2	1				2	
	Macrobrachium spp.	3	3	2	3	3		2			1			2	3	
MOLLUSCA																
BIVALVIA																
Cardiida	Corbicula spp.													1		
Unionida	Hyriidae spp.						3	4	4	3	4					
GASTROPODA																
Hygrophila	Gyraulus spp.															2
Hypsogastropoda	Bithyniidae spp.			2	2		2	3	3		1					
	Coleglabra spp.			2	2	1	4	4	4	2	2					
	Tateidae spp.	1														
	Notopala spp.														2	
NEMATODA	Nematoda spp.												2		2	

Table 7. The total number of macroinvertebrate taxa and the composition recorded within edge samples collected during baseline (2011-2013) and post-development (2020 and 2021) surveys from sites sampled in 20201 (K1, K2, K4, KR2 and DR1).

Phylum	Class	2011	2012	2013	2020	2021
ANNELIDA	OLIGOCHAETA	0.81	0.74	0.71	0.80	0.94
	POLYCHAETA	0.81	0.74	0.71	0.80	0.94
ARTHROPODA	ACARINA	0.81	0.74	0.71	0.80	0.94
	ENTOGNATHA	0.81	0.00	0.71	0.80	0.00
	INSECTA	82.2	80.8	83.5	84.8	81.1
	MALACOSTRACA	8.87	8.09	5.71	5.60	8.49
CNIDARIA	HYDROZOA	0.00	0.74	0.71	0.80	0.00
MOLLUSCA	BIVALVIA	1.61	2.21	1.43	1.60	1.89
	GASTROPODA	3.23	5.15	4.29	3.20	4.70
NEMATODA		0.81	0.00	0.00	0.80	0.94
NEMERTEA		0.00	0.00	0.71	0.00	0.00
PLATYHELMINTHES	TURBELLARIA	0.00	0.74	0.71	0.00	0.00
	Grand Total	**124**	**136**	**140**	**125**	**106**

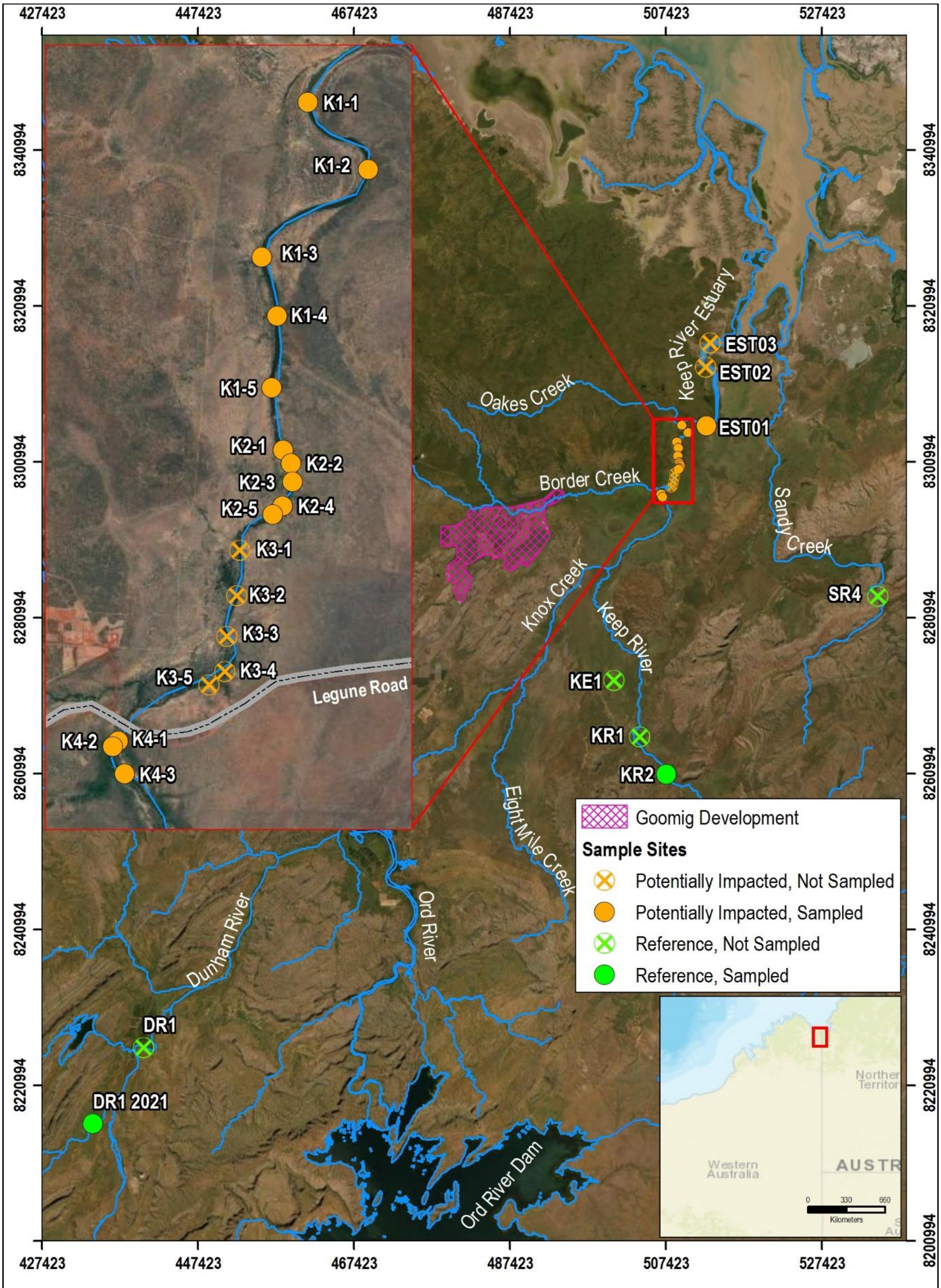
Table 8. Results of the PERMANOVA (permutational multivariate analysis of variance, Type 1 sequential) pair-wise test undertaken on edge macroinvertebrate abundance data (Bray-Curtis similarity) recorded during baseline surveys (2011-2013) and post-development at potentially impacted and reference sites in 2021 and 2020. N.B. Significant values ($p < 0.05$) are highlighted orange and in instances when the number of permutations was below 100 (highlighted yellow) the Monte Carlo p-value should be referred to.

Pair	t	P(perm)	Unique perms	P(MC)
K1 Baseline, K1 2021	2.3297	0.001	965	0.003
K2 Baseline, K2 2021	2.977	0.001	967	0.001
K4 Baseline, K4 2021	1.3614	0.022	220	0.074
Reference Baseline, Reference 2021	1.5005	0.043	28	0.091
K1 2021, Reference 2021	2.9022	0.049	21	0.007
K2 2021, Reference 2021	3.1128	0.051	21	0.003
K4 2021, Reference 2021	1.1315	0.301	10	0.395
K1 Baseline, K1 2020	2.0471	0.003	959	0.005
K2 Baseline, K2 2020	1.9893	0.004	963	0.006
K4 Baseline, K4 2020	1.3045	0.038	215	0.109
Reference Baseline, Reference 2020	1.2088	0.156	28	0.255
K1 2020, Reference 2020	2.74	0.045	21	0.01
K2 2020, Reference 2020	1.7329	0.058	21	0.059
K4 2020, Reference 2020	1.3775	0.111	10	0.21

Table 9. Results of the PERMANOVA (permutational multivariate analysis of variance, Type 1 sequential) pair-wise test undertaken on edge macroinvertebrate abundance data (Bray-Curtis similarity) recorded in individual years during baseline surveys (2011-2013) and post-development (2021 and 2020). N.B. Significant values ($p < 0.05$) are highlighted orange and in instances when the number of permutations was below 100 (highlighted yellow) the Monte Carlo p-value should be referred to.

Site	Pair	Year	t	P(perm)	Unique perms	P(MC)
K1	Baseline, Baseline	2011, 2012	1.8959	0.009	126	0.008
		2011, 2013	3.4702	0.006	126	0.002
		2012, 2013	2.6869	0.007	126	0.003
	Baseline, Post-Development	2011, 2020	2.3548	0.007	125	0.005
		2011, 2021	3.9511	0.011	126	0.001
		2012, 2020	2.5815	0.009	126	0.003
		2012, 2021	3.3789	0.007	126	0.002
		2013, 2020	3.3456	0.014	126	0.001
		2013, 2021	2.1361	0.009	126	0.008
	Post-Development, Post-Development	2020, 2021	4.0424	0.01	126	0.001
	Baseline, Reference	2011, Ref 2011	2.0689	0.047	21	0.031
		2012, Ref 2012	2.4087	0.039	21	0.011
		2013, Ref 2013	3.2445	0.056	21	0.003
K2	Baseline, Baseline	2011, 2012	1.8948	0.007	126	0.012
		2011, 2013	3.6928	0.012	126	0.001
		2012, 2013	3.0975	0.009	126	0.002
	Baseline, Post-Development	2011, 2020	2.3894	0.006	126	0.003
		2011, 2021	4.5215	0.004	126	0.001
		2012, 2020	2.1195	0.004	126	0.001
		2012, 2021	4.1821	0.006	126	0.002
		2013, 2020	3.586	0.011	126	0.001
		2013, 2021	3.2153	0.016	126	0.001
	Post-Development, Post-Development	2020, 2021	4.2577	0.01	126	0.001
	Baseline, Reference	2011, Ref 2011	1.5055	0.05	21	0.095
		2012, Ref 2012	1.81	0.052	21	0.024
		2013, Ref 2013	3.2253	0.051	21	0.003
K4	Baseline, Baseline	2011, 2012	1.5727	0.092	10	0.087
		2011, 2013	1.6563	0.102	10	0.081
		2012, 2013	1.2061	0.096	10	0.252
	Baseline, Post-Development	2011, 2020	1.7657	0.12	10	0.054
		2011, 2021	1.6846	0.094	10	0.065
		2012, 2020	1.4591	0.094	10	0.134
		2012, 2021	1.63	0.096	10	0.082
		2013, 2020	1.2854	0.108	10	0.188
		2013, 2021	1.4247	0.101	10	0.123
	Post-Development, Post-Development	2020, 2021	1.6116	0.091	10	0.084
	Baseline, Reference	2011, Ref 2011	1.3575	0.099	10	0.196
		2012, Ref 2012	1.2029	0.093	10	0.285
		2013, Ref 2013	1.0057	0.616	10	0.433
Reference (KR1, DR1)	Baseline, Baseline	2011, 2012	1.0625	0.69	3	0.399
		2011, 2013	1.2879	0.357	3	0.274
		2012, 2013	1.1733	0.331	3	0.327
	Baseline, Post-Development	2011, 2020	1.4296	0.342	3	0.22
		2011, 2021	1.2624	0.345	3	0.293
		2012, 2020	1.3797	0.341	3	0.231
		2012, 2021	1.3111	0.327	3	0.28
		2013, 2020	1.2237	0.334	3	0.318
		2013, 2021	1.2405	0.327	3	0.31
	Post-Development, Post-Development	2020, 2021	1.2338	0.339	3	0.326

FIGURES



INDOPACIFIC Environmental

Figure 1. Keep River Aquatic Fauna and Targeted Sawfish Post-development Survey sampling sites and sites sampled or not sampled due to access issues in 2021.

0 10 20
Kilometers

Project: 21030 Keep River
Client: DPIRD
Coordinate System: GDA 1994 MGA Zone 52
Scale: 750,000
Author: J. Keleher

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

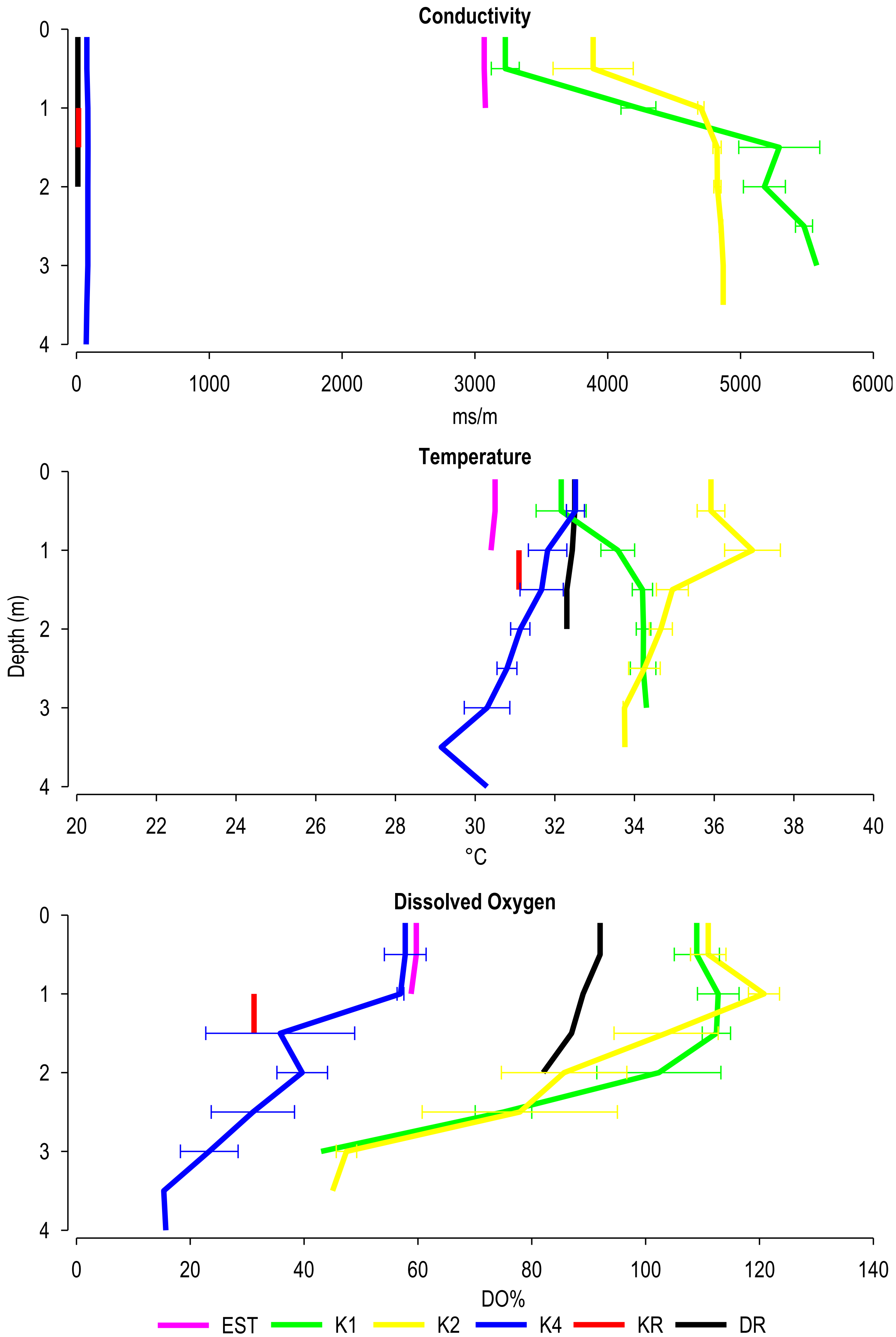


Figure 2. Mean (±SE) conductivity, temperature and dissolved oxygen (saturation) depth profiles recorded from each site sampled in 2021.

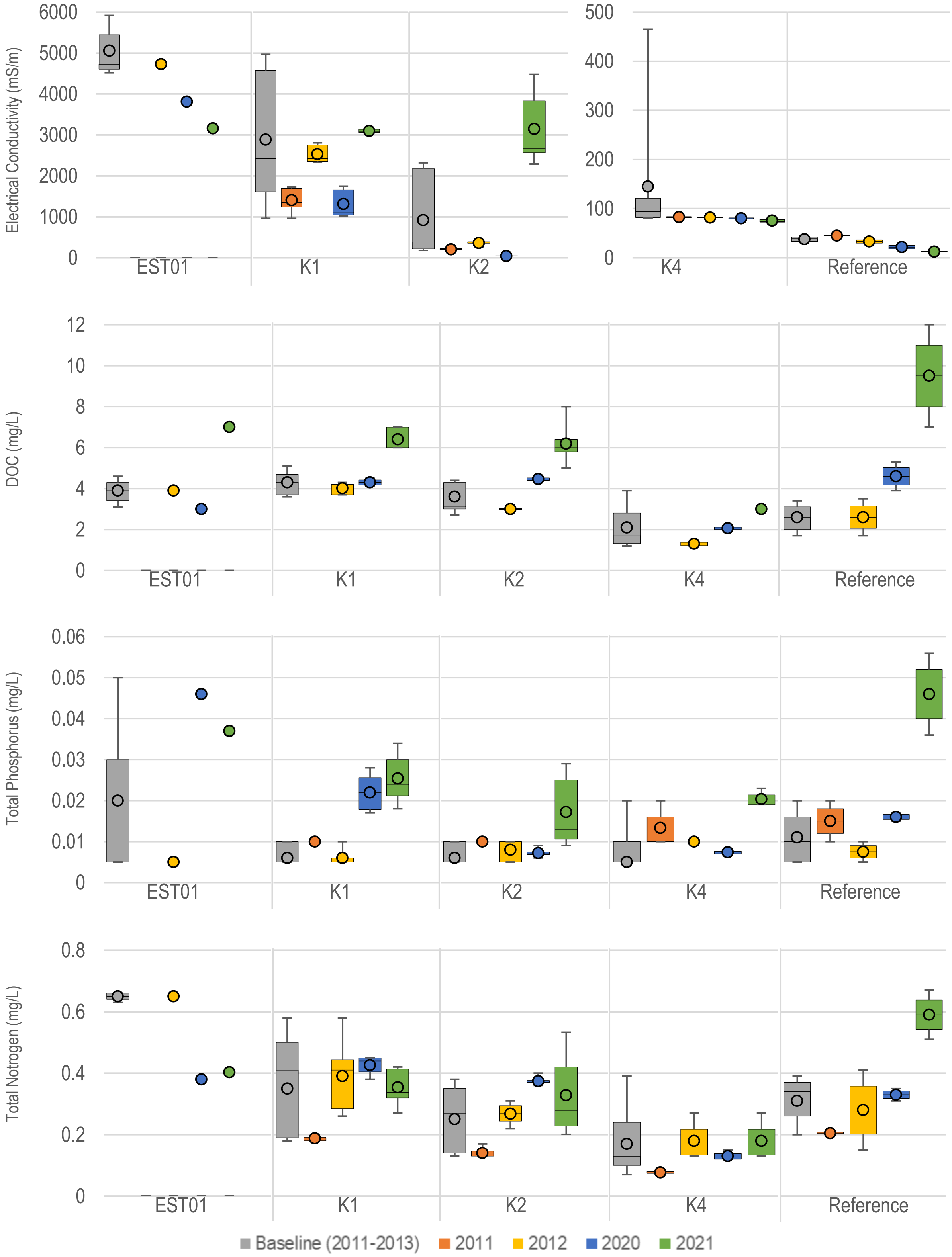


Figure 3. Box plots displaying minimum, 20%ile, median, 80%ile, maximum and mean (circle) of select water quality parameters within the Keep River (K1, K2 and K4), Keep River Estuary (EST01) and reference (KR2 and DR1) sites recorded during combined baseline surveys (2011-2013), individual baseline survey years (2011 and 2012) and post-development surveys (2021 and 2021).

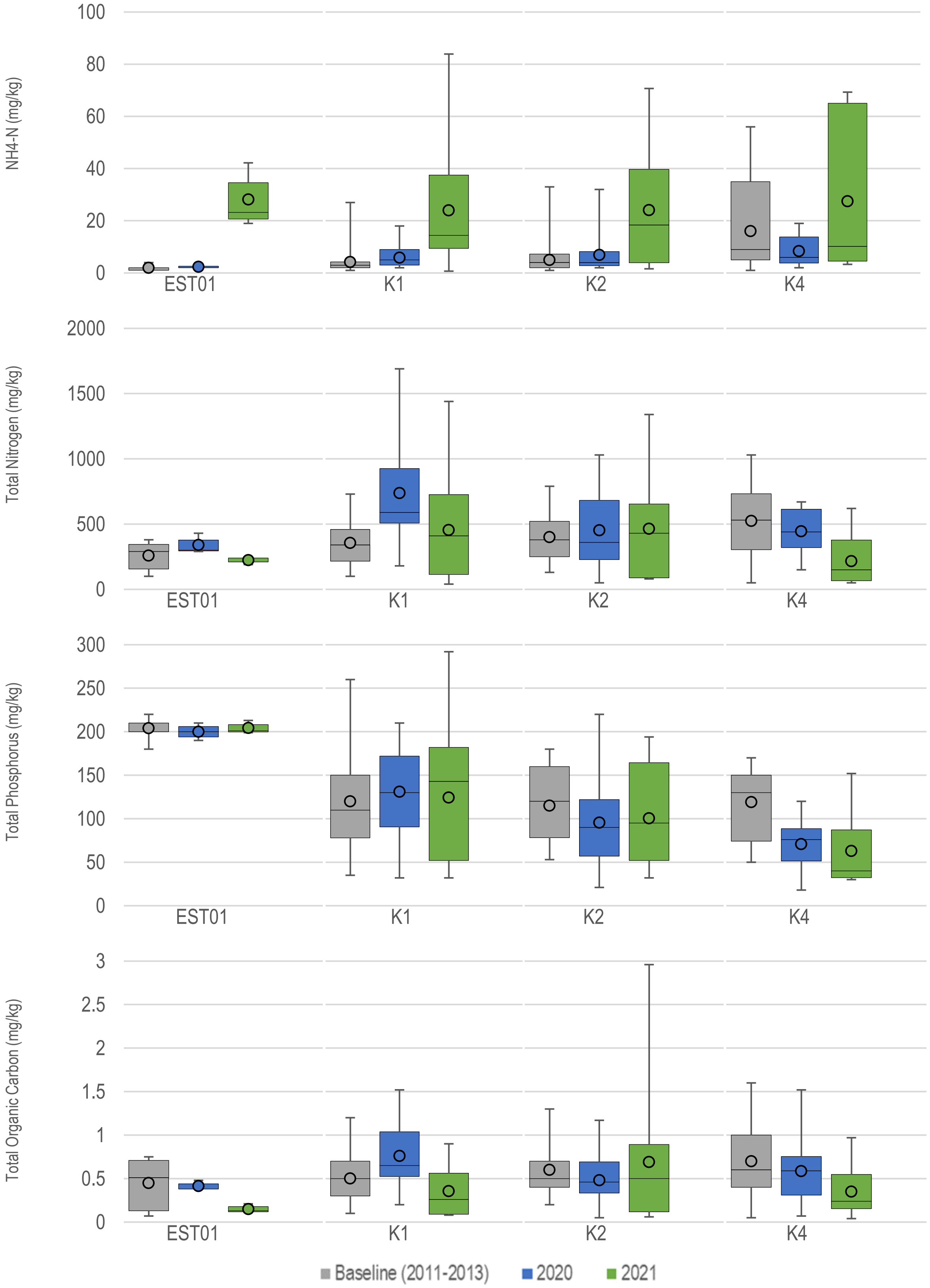


Figure 4. Box plots displaying minimum, 20%ile, median, 80%ile, maximum and mean (circle) of select sediment quality parameters within the Keep River (K1, K2 and K4) and Keep River Estuary (EST01) sites recorded during combined baseline surveys (2011-2013) and post-development surveys (2021 and 2021).

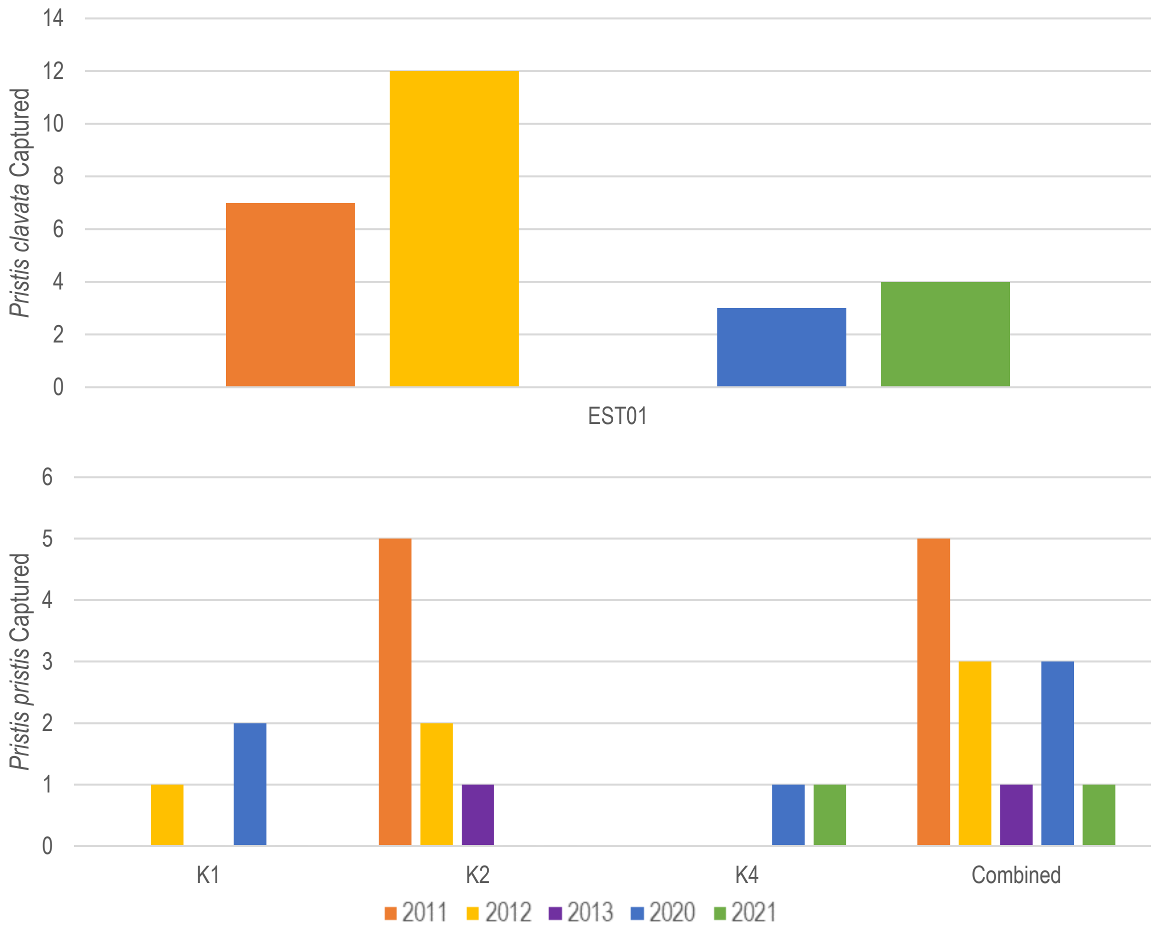


Figure 5. The total number of *Pristis clavata* (top) and *Pristis pristis* (bottom) captured from sites sampled in 2021 during baseline (2011-2013) and post-development (2020 and 2021) surveys.

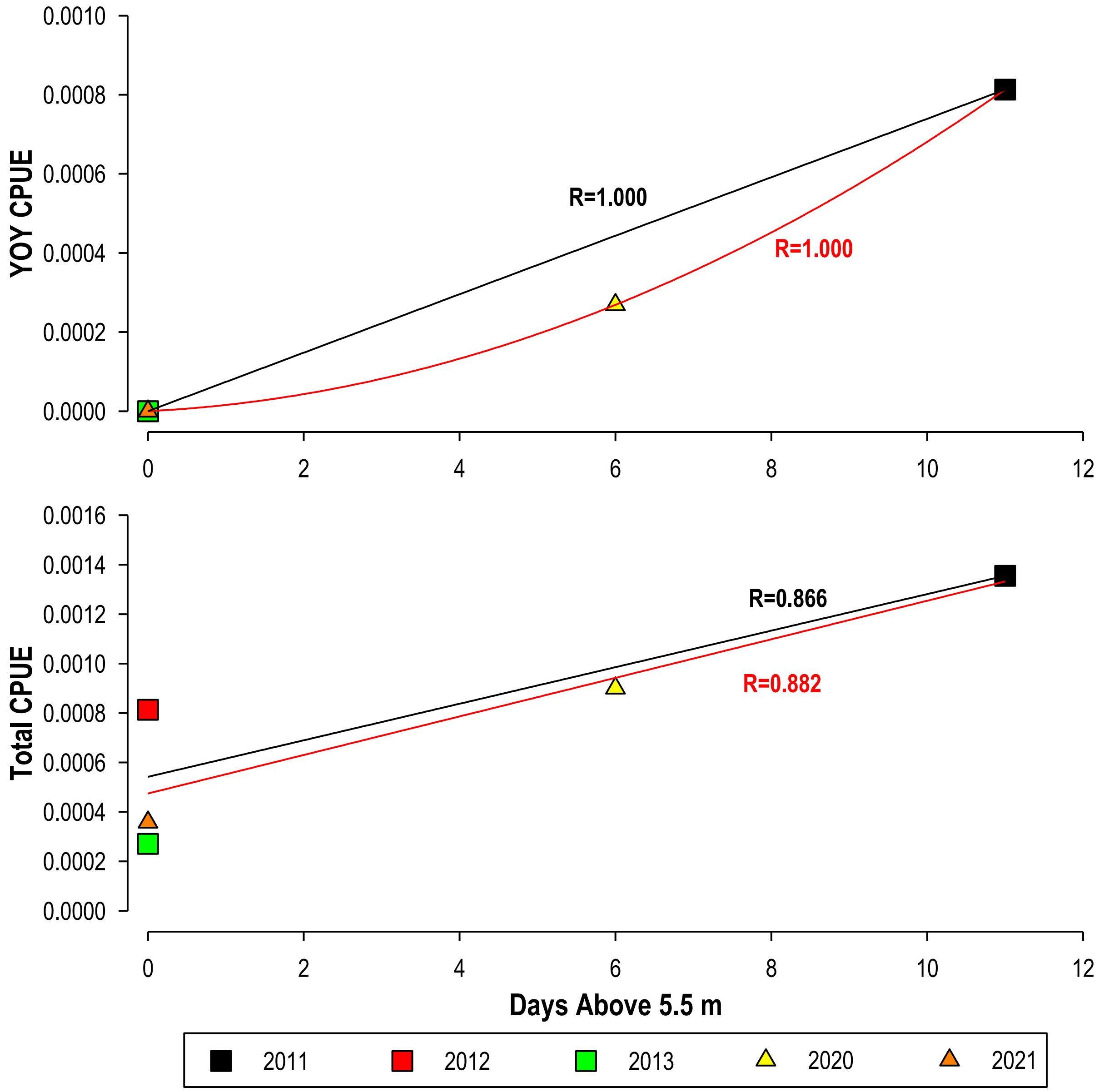


Figure 6. Regression analysis results produced from 2011 to 2013 (black) and 2011 to 2021 (red) mean survey Catch Per Unit of Effort (CPUE) data of young-of-the-year (YOY) (top) and total (bottom) *Pristis pristis* captured with the number of days the water level at Keep River gauging at the Legune Road Crossing (G8100225) was above 5.5 m during the previous wet season.

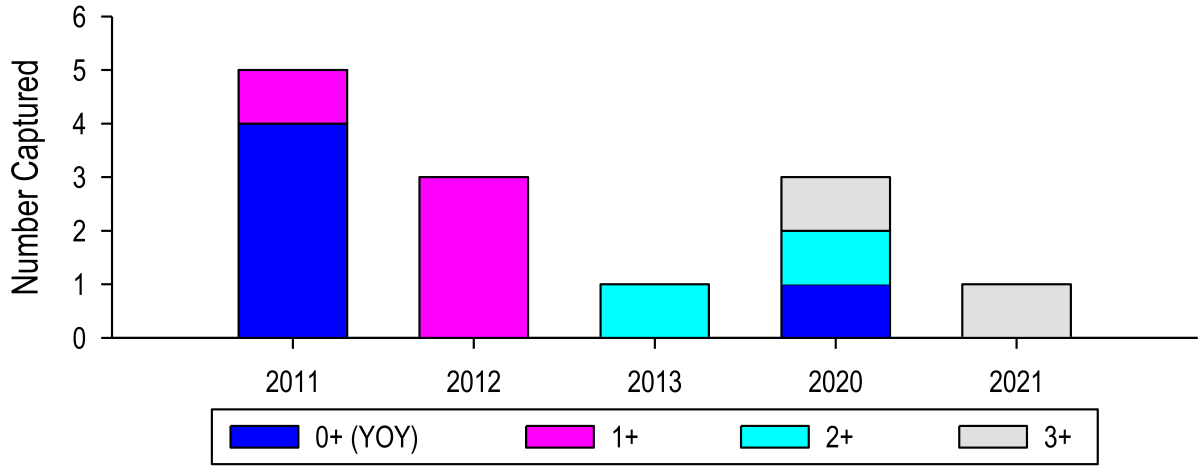


Figure 7. Age class (cohort data) of *Pristis pristis* captured from sites sampled in 2021 (K1, K2 and K4) during each survey event.

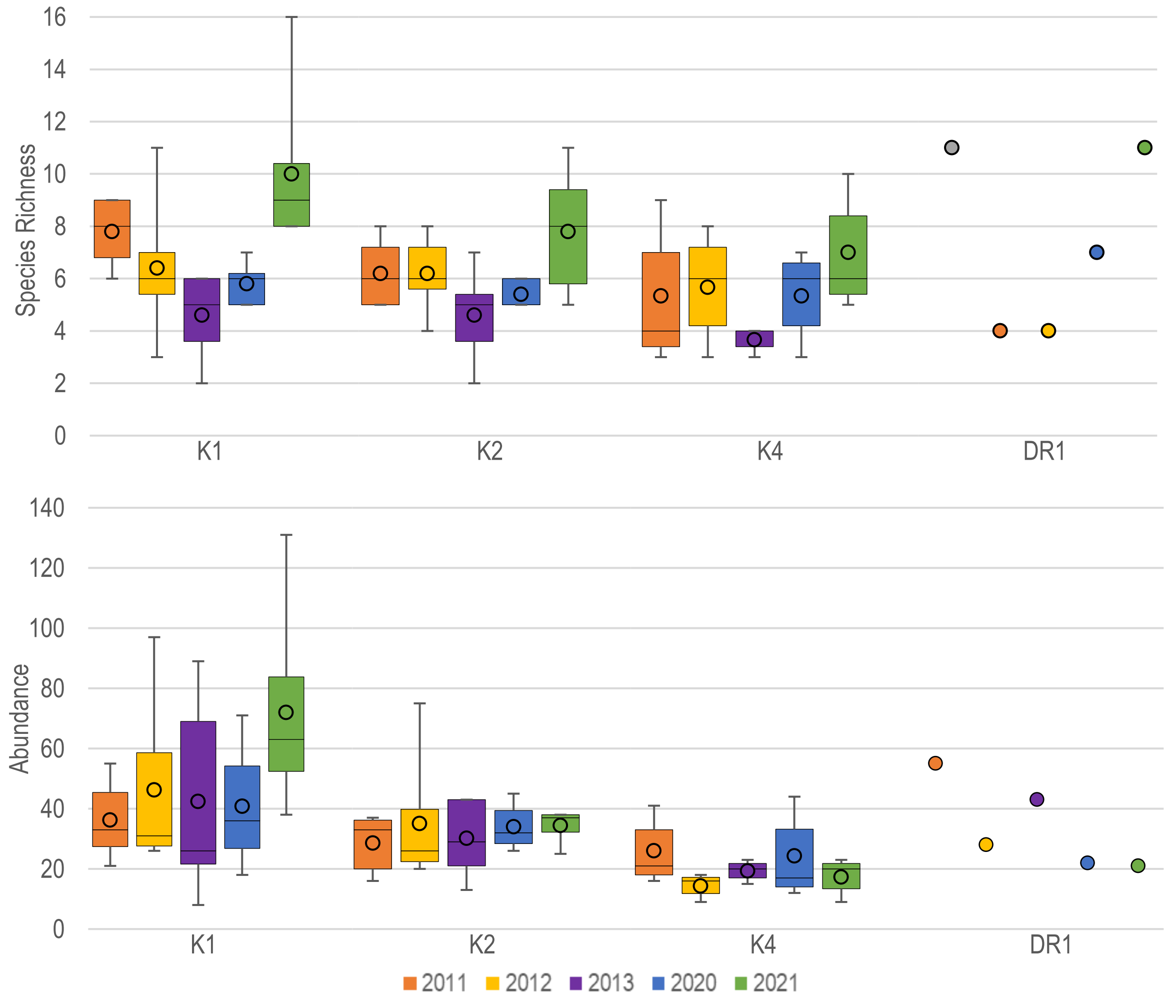


Figure 8. Box plots displaying minimum, 20%ile, median, 80%ile, maximum and mean (circle) of fish species richness and abundance within Keep River (K1, K2 and K4) and reference (DR1) sites recorded during individual baseline survey years (2011-2013) and post-development surveys (2021 and 2021).

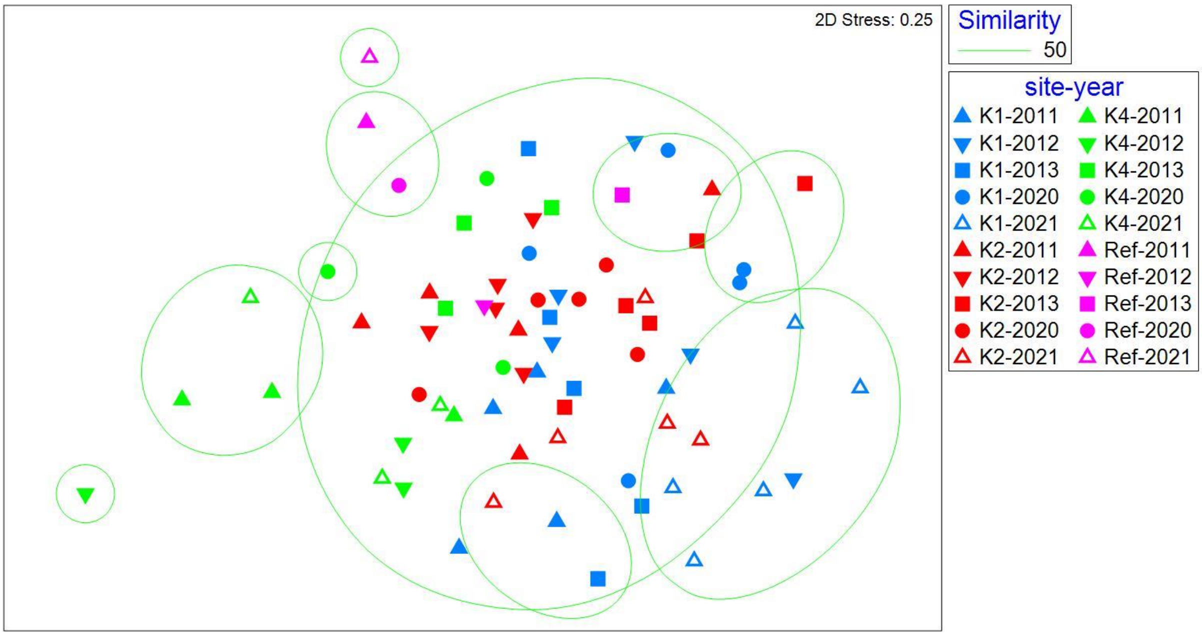


Figure 9. Non-metric MDS plots of fish assemblage data (transformed) within Keep River (K1, K2 and K4) and reference (DR1) sites sampled in 2021 during baseline (2011-2013) and post-development (2020 and 2021) surveys separated by year and site.

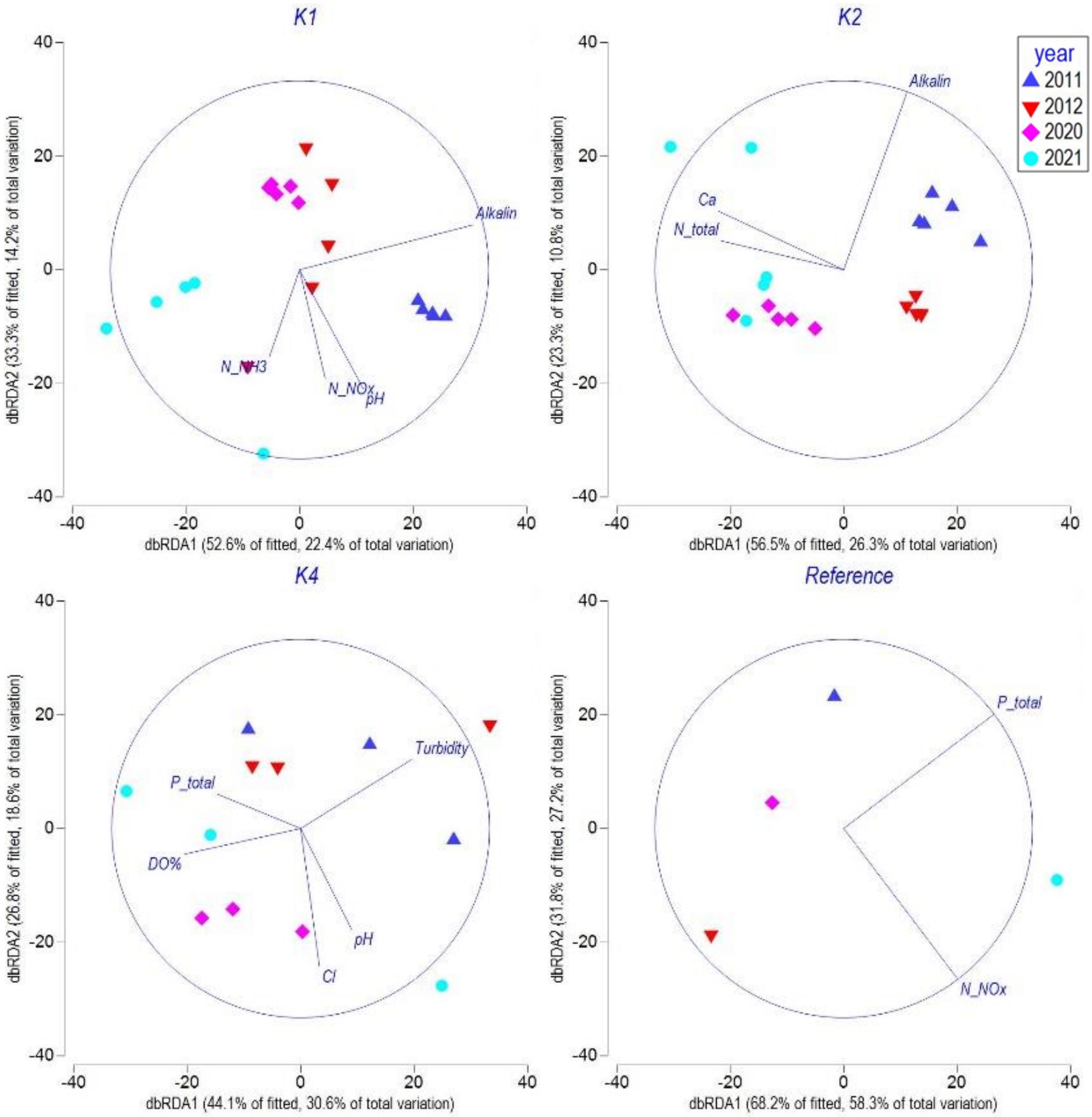


Figure 10. Distance-based redundancy analysis (dbRDA) plots of fish assemblage data for Keep River (K1, K2 and K4) and reference (DR1) sites sampled during baseline (only 2011 and 2012 available for water quality data) and post-development (2020 and 2021) surveys overlaid with transformed and normalised predictor water quality variables (based on distLM analysis). Vectors indicate the direction and strength of the parameter effect in the ordination plot.

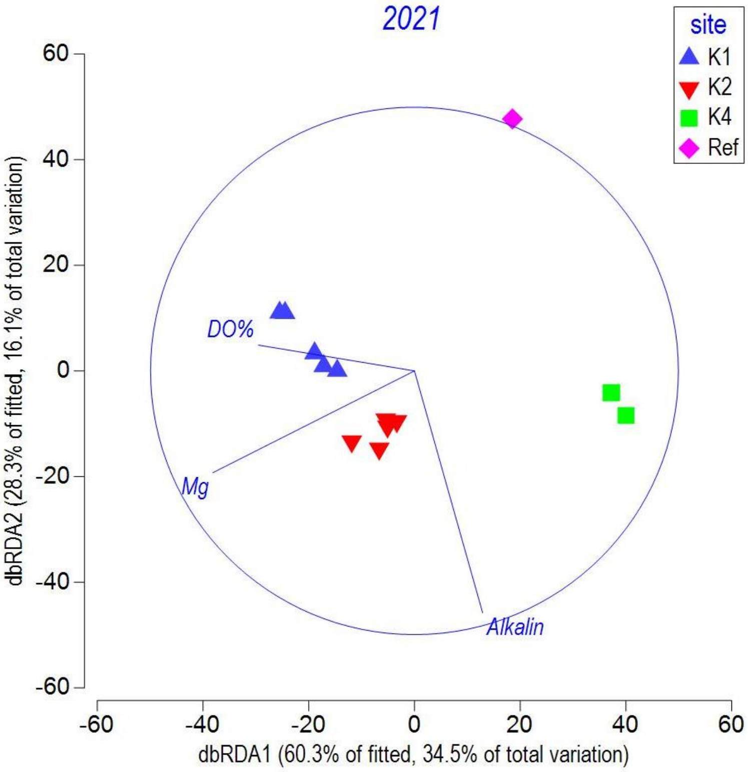


Figure 11. Distance-based redundancy analysis (dbRDA) plots of fish assemblage data for Keep River (K1, K2 and K4) and reference (DR1) sites sampled in 2021 overlaid with transformed and normalised predictor water quality variables (based on distLM analysis). Vectors indicate the direction and strength of the parameter effect in the ordination plot.

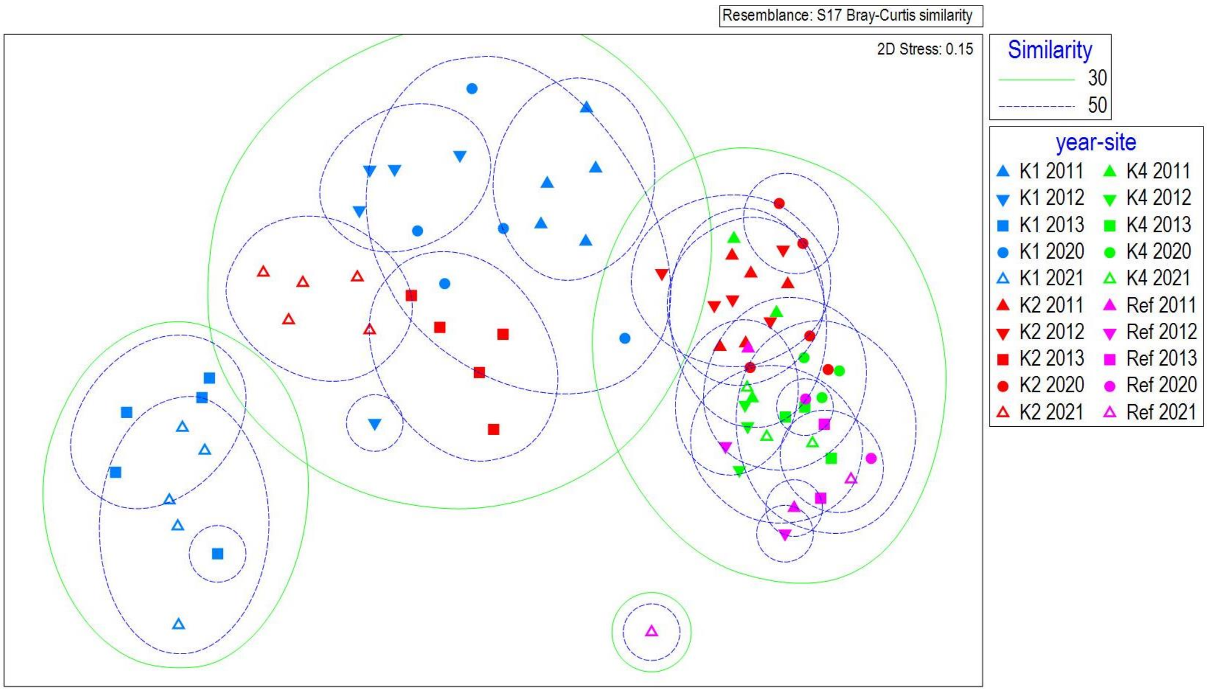


Figure 12 Non-metric MDS plots of edge macroinvertebrate assemblage data (log10 scale) within Keep River (K1, K2 and K4) and reference (KR2 and DR1) sites sampled in 2021 during baseline (2011-2013) and post-development (2020 and 2021) surveys separated by year and site.

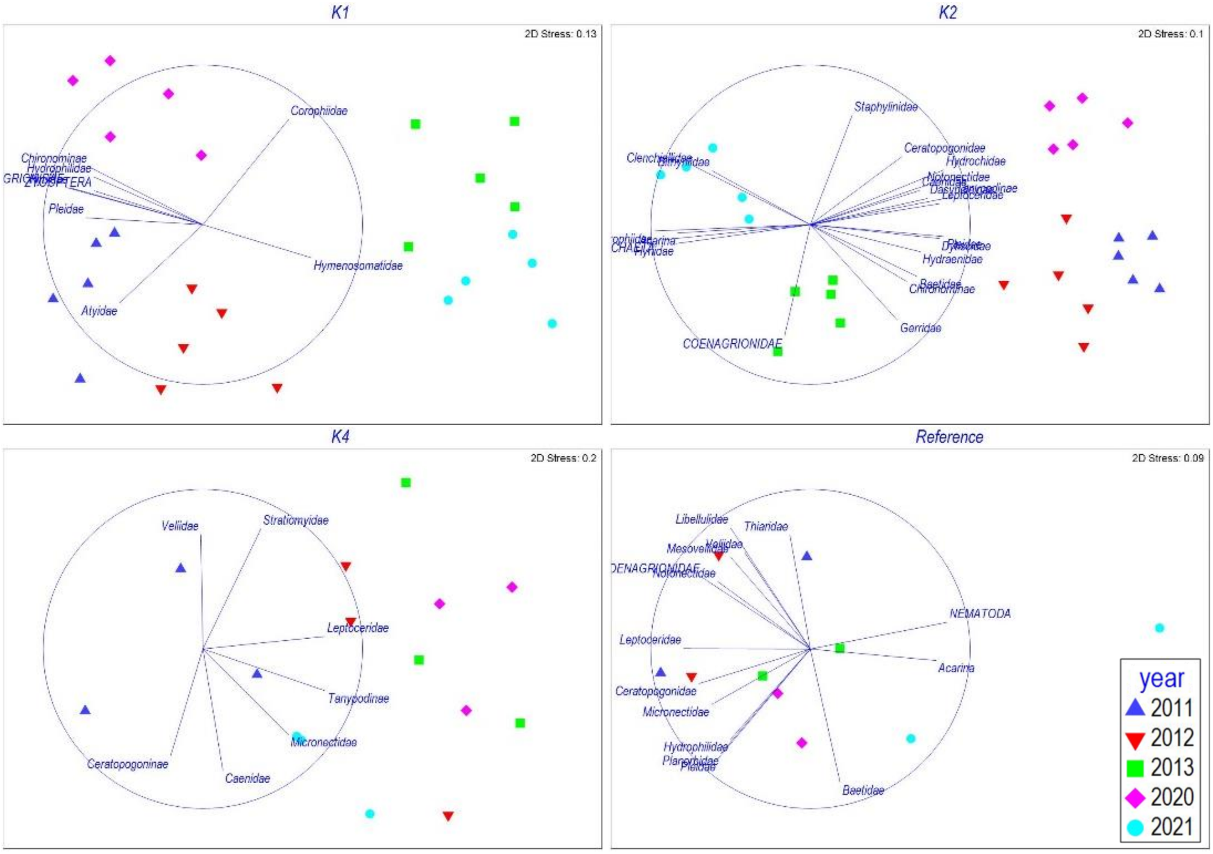


Figure 13. Non-metric MDS plots of edge macroinvertebrate assemblage data (log10 scale) within Keep River (K1, K2 and K4) and reference (KR2 and DR1) sites sampled in 2021 during baseline (2011-2013) and post-development (2020 and 2021) surveys separated by year and site, with overlaid correlation (>0.7) vectors displaying the macroinvertebrate families that best distinguish the distribution sub-site samples within sites and between years.

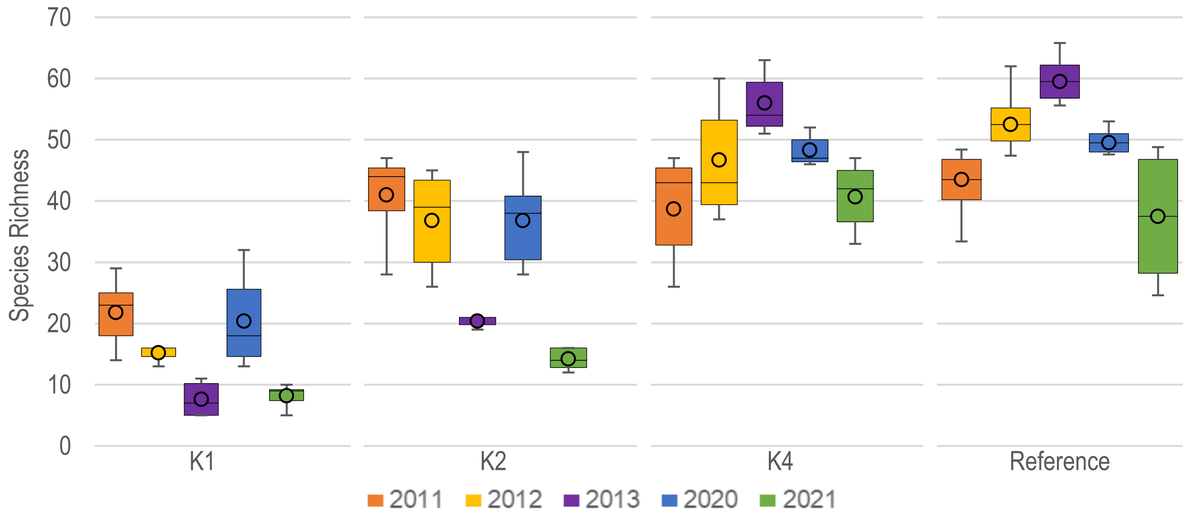


Figure 14. Box plots displaying minimum, 20%ile, median, 80%ile, maximum and mean (circle) of macroinvertebrate species richness within Keep River (K1, K2 and K4) and reference (KR2 and DR1) sites recorded during individual baseline survey years (2011-2013) and post-development surveys (2021 and 2021).

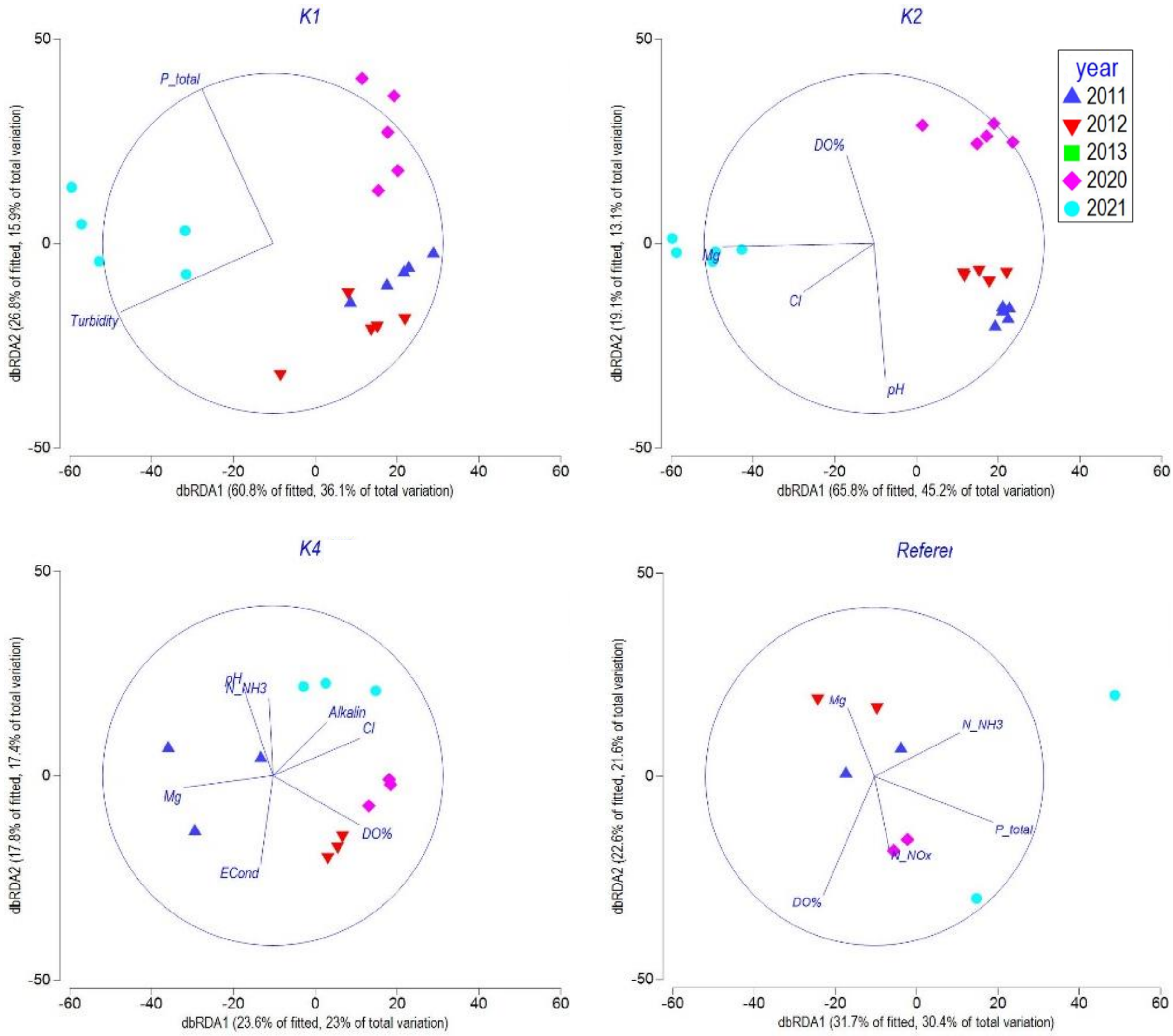
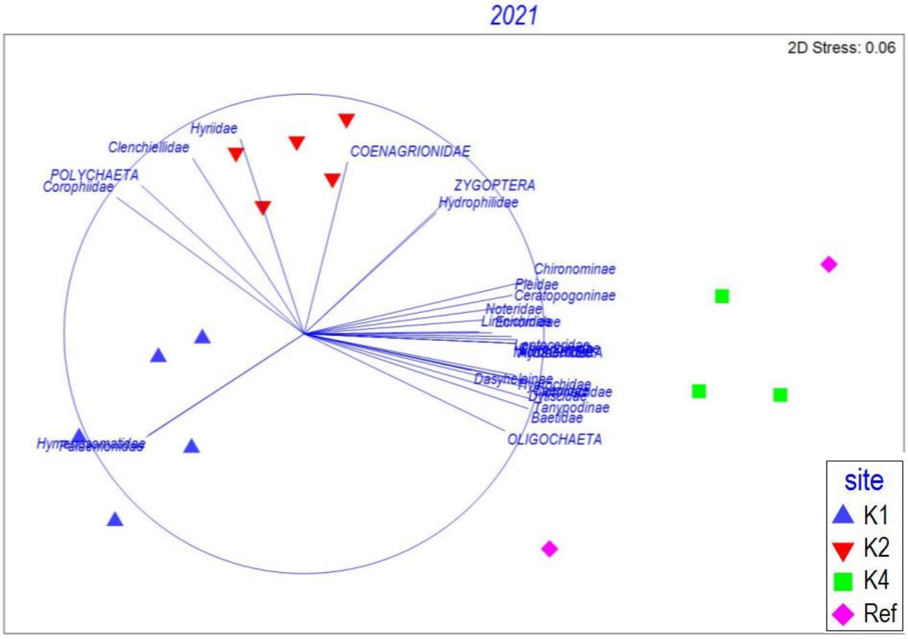


Figure 15. Distance-based redundancy analysis (dbRDA) plots of macroinvertebrate species assemblage data for Keep River (K1, K2 and K4) and reference (KR2 and DR1) sites sampled during baseline (only 2011 and 2012 available for water quality data) and post-development (2020 and 2021) surveys overlaid with transformed and normalised predictor water quality variables (based on distLM analysis). Vectors indicate the direction and strength of the parameter effect in the ordination plot.



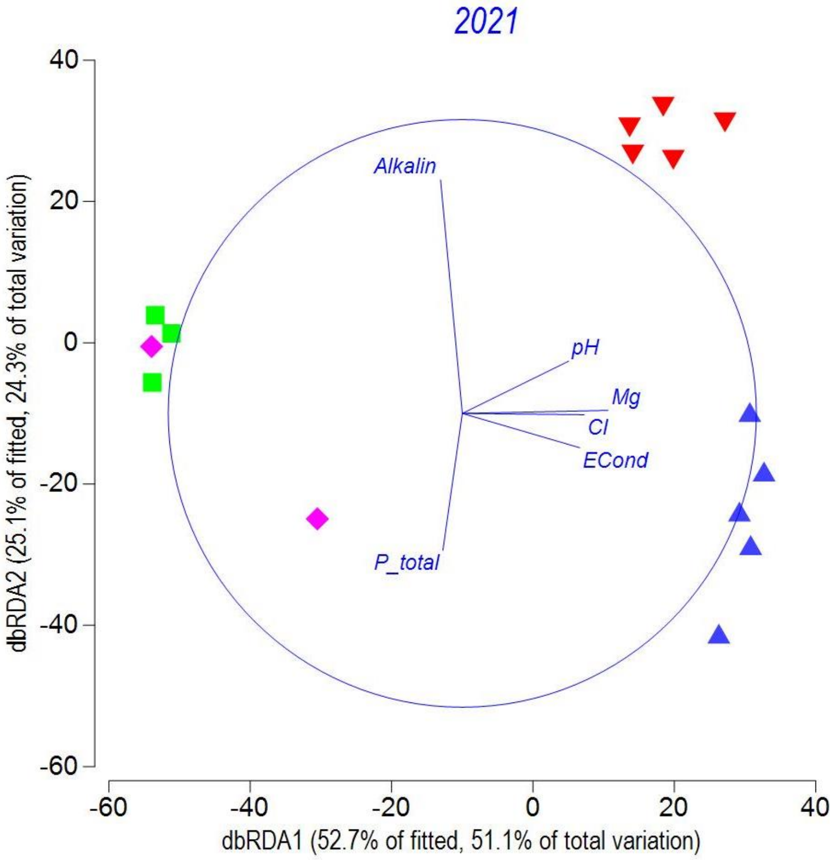


Figure 16. Top - Non-metric MDS plots of edge macroinvertebrate assemblage data ($\log^{10}$ scale) within Keep River and reference (KR2 and DR1) sites sampled in 2021 separated by site with overlaid correlation (>0.7) vectors displaying the macroinvertebrate families that best distinguish the distribution sub-site samples within sites and between years. Bottom - Distance-based redundancy analysis (dbRDA) plots of macroinvertebrate species assemblage data for Keep River and reference (KR2 and DR1) sites sampled in 2021 overlaid with transformed and normalised predictor water quality variables (based on distLM analysis). Vectors indicate the direction and strength of the parameter effect in the ordination plot.

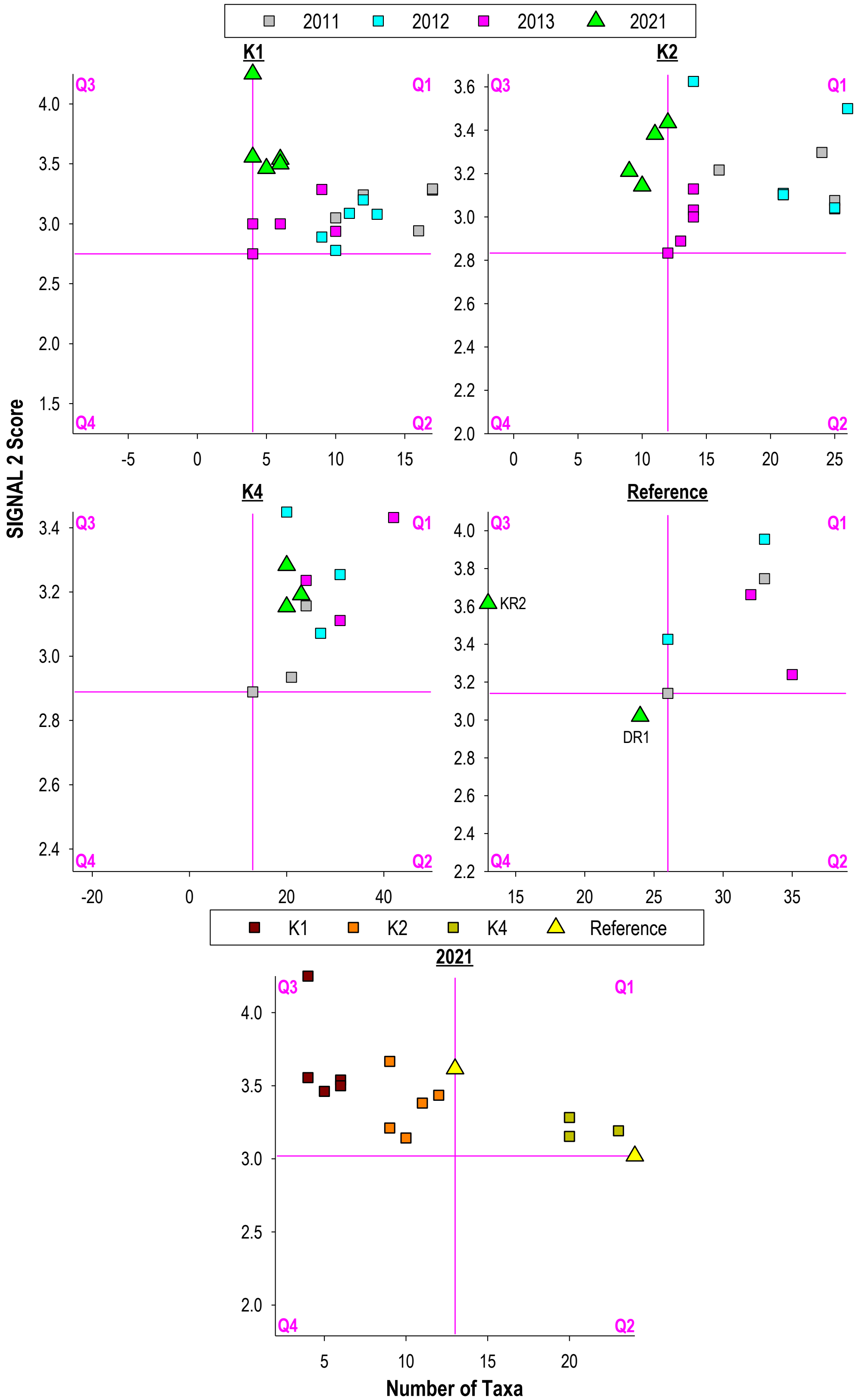


Figure 17. Bi-plots of SIGNAL2 (family) scores from Keep River (K1, K2 and K4) and reference (KR2 and DR1) sites for 2021 and respective baseline (2011-2013) edge macroinvertebrate assemblages. The pink lines represent quadrant boundaries based on baseline (2011-2013) or reference site values.

APPENDICES

Appendix 1. Water quality values (mg/L unless indicated), obtained from reference sites and potentially impacted lower Keep River and estuary sub-sites in 2021. Values highlighted purple = SS-WQGV exceedance, yellow = ILTV and SS-WQGV exceedance, green = > SS-WQGV and < ILTV. ANZG (2018) default trigger values for tropical Australian lowland rivers (LR) and estuaries (E) are also displayed.

					Keep River																				Estuary		Reference sites			
	Analyte	LOR	ANZG (2018)		K4					K2							K1								EST01		DR		KR	
			LR	E	SS-WQGV	ILTV	1	2	3	SS-WQGV	ILTVs	1	2	3	4	5	SS-WQGV	ILTVs	1	2	3	4	5	SS-WQGV	1	SS-WQGV	1	SS-WQGV	2
Miscellaneous	TDS-calc	1			2416		478	468	526	12200		29100	23800	17100	17400	14900	27000		20100	20300	19600	20600	20000	31600	20500	200	73	110	91
	TSS	5			1.5	62	<5	<5	<5	1.5	21	6	10	<5	<5	<5	1.5	27	19	8	9	7	10	66.8	27	0.9		6.6	13
	Temp (oC)				28	31	33	33	32	32.5	32	36	36	36	35	37	30.4	33	31	35	33	32	31	31.4	31	31.2	33	29.1	31
	Turbid (NTU)		15	20	13.2	120	4.3	2.7	3	10	15	4.4	7.6	9.2	3.5	8.4	9.7	15	12	11	10	6.4	6.7	34.8	38	5.3	14	6	17.4
	pH (units)		6-8	6-8.5	8	6.0-8.0	7.2	7.1	7.6	8.4	6.0-8.4	8.3	8.3	8.2	8.3	8.2	8.4	6.0-8.4	8.1	8.2	8.3	8.3	8.3	8.2	8.3	8.2	8.3	8.2	7.8
	DO (%)		90	80	52	23	65	59	50	91	35	124	110	103	109	109	85	28	103	120	119	105	98	88	60	84	92	88	31
	Econd (mS/m)	1	250		121	85	74	72	81	2176	2158	4480	3670	2630	2680	2290	4566	4166	3090	3130	3020	3170	3070	5444	3160	42.5	11	35.4	14
Ionic composition	Alkalinity	1			145		150	147	158	160		163	168	149	155	153	174		90	92	111	115	117	187	88	207	50	135	51
	Acidity	1			11.8		4	5	5	16.4		1	2	2	1	3	1.6		5	5	3	2	2	15.4	3	4.8	1	3.8	6
	Hardness	1			328		206	208	222	2400		6070	4680	3280	3420	2900	5300		4060	4260	4100	4210	3750	6400	3740	156	40	75	50
	CO3	1			<1		<1	<1	<1	<1		<1	<1	<1	<1	<1	9		<1	<1	<1	<1	<1	11	<1	3	<1	<1	<1
	Cl	1			251		142	138	160	7152		16000	11700	7970	8020	6820	15440		10100	10400	10400	10500	10100	19960	11200	16	5	18	5
	F	0.1			0.21		0.1	0.1	0.1	0.48		0.6	0.6	0.5	0.4	0.4	0.74		0.5	0.5	0.5	0.5	0.5	0.8	0.4	0.29	0.1	0.07	<0.1
	SO4-S	1			105		42	41	46	1002		2150	1550	1020	1060	968	2340		1300	1300	1320	1320	1280	2740	1460	21	<5	2.5	8
	HCO3	1			175		150	147	158	185		163	168	149	155	153	200		90	92	111	115	117	228	88	218	50	114	51
	Ca	1			45		38	39	41	189		437	348	261	271	239	361		303	321	315	322	288	439	275	28	8	26	10
	Mg	1			36		27	27	29	456		1210	926	639	666	559	1030		801	840	806	828	736	1294	741	26	5	18	6
	Na	1			366		71	71	76	3518		9260	6910	4640	4850	4000	8816		5960	6290	5980	6180	5490	11400	5880	17	8	30	6
	K	1			12		4	4	4	117		422	343	218	230	185	296		292	306	288	300	262	397	274	12	3	8	3
Nutrients	DOC	1			2.8		3	3	3	4.3		5	6	6	8	6	4.7		6	7	7	6	6	4.3	7	3.1	7	4.2	12
	N-NH3	0.005			0.007	0.32	0.015	0.02	0.014	0.006	0.32	<0.005	<0.005	<0.005	<0.005	<0.005	0.022	0.32	0.006	0.005	0.006	<0.005	<0.005	0.07	0.044	<0.01	0.034	<0.01	0.081
	N-NOx	0.002	0.01	0.03	<0.01	0.17	0.006	0.009	0.01	<0.01	0.17	0.003	<0.002	0.003	0.002	0.004	<0.01	0.17	0.043	0.015	0.003	0.004	0.006	<0.01	0.004	<0.01	0.14	0.014	0.024
	N-org.	0.025/0.01*			0.27		0.12	0.24	0.11	0.35		0.53	0.39	0.23	0.2	0.28	0.47		0.36	0.4	0.33	0.33	0.26	0.57	0.36	0.31	0.34	0.38	0.56
	N-tot.sol.	0.025/0.01*			0.22		0.14	0.18	0.13	0.32		0.37	0.3	0.33	0.27	0.36	0.48		0.35	0.36	0.32	0.28	0.36	0.57	0.17	0.21	0.59	0.3	0.58
	N-total	0.05/0.01*	0.3	0.25	0.24	0.44	0.14	0.27	0.13	0.35	0.35	0.53	0.39	0.24	0.2	0.28	0.5	0.4	0.41	0.42	0.34	0.33	0.27	0.66	0.4	0.29	0.51	0.37	0.67
	P-tot.sol	0.005			<0.005		0.022	0.016	0.01	<0.005		0.015	0.015	0.014	0.012	0.014	<0.005		0.014	0.014	0.013	0.012	0.014	<0.005	<0.005	<0.005	0.021	<0.005	0.012
	P-total	0.005	0.01	0.02	0.01	0.04	0.019	0.023	0.019	<0.01	0.01	0.029	0.024	0.011	0.009	0.013	<0.01	0.01	0.034	0.029	0.024	0.022	0.018	0.03	0.037	0.016	0.036	<0.005	0.056
Herbicide	Atrazine (µg/L)	0.5												<0.5									<0.5		<0.5				<0.5
	Dibromo-DDE (%)*	0.5												69									69		76				68
	DEF (%)*	0.5												73									74		93				71

Appendix 2. Sediment quality values (mg/kg unless indicated), obtained from potentially impacted lower Keep River and estuary sites in 2021. Values highlighted purple = SS-SQGV exceedance. ANZG (2018) sediment default guideline values (DVG) and default guideline values-High (GV-H) are also displayed. N.B. For red values, the limit of reporting (LOR) was greater than the SS-SQGV.

			Major Ions							Nutrients					Total Metals																											Herbicide		
Site		Analyte	Si	Cl	SO4	Na	K	Ca	Mg	NO3-N	N-Total	P-Total	NH4-N	TOC%	Al	Sb	As	Ba	Be	Bi	B	Cd	Cr	Co	Cu	Ga	Fe	La	Pb	Li	Mn	Mo	Hg	Ni	Se	Ag	Sn	Ti	U	V	Zn	Atrazine	DDE%	DEP%
		LOR	1	10	10	50	50	50	50	0.1	20	2	0.2	0.02	50	0.5	1	10	1	0.1	50	0.1	1	1	1	0.1	50	0	1	0.1	10	2	0.01	1	0.1	0.1	0.1	10	0.1	2	1	0.05	0.05	0.05
		DGV														2	20					1.5	80		65				50				0.15	21		1					200			
		GV-High														25	70					10	370		270				220				1	52		4					410			
K4		**SS-SQGV**	**190**	**850.4**	**384**	**936**	**1300**	**4140**	**5900**	**<1**	**732**	**150**	**35**	**1**	**16620**	**0.13**	**2.1**	**170**	**0.73**	**0.16**	**2.5**	**<0.05**	**29**	**23**	**18**	**8.2**	**32000**	**20**	**11**	**6**	**748**	**0.22**	**0.286**	**18**	**0.11**	**<0.05**	**0.8**	**73.4**	**1**	**66**	**29**			
	1	L	25	30	<10	100	630	1360	1770	<0.1	160	68	10.2	0.19	6410	<0.50	<1.00	70	<1	<0.1	<50	<0.1	12.5	9.4	7.5	2.1	14600	7.6	5.2	1.6	370	<2	<0.01	6.8	<0.1	<0.1	0.5	100	0.3	36.2	9	—	—	—
		M	6	20	<10	50	260	2370	680	<0.1	60	30	4.1	0.24	2150	<0.50	1.33	460	<1	<0.1	<50	<0.1	5.6	37.1	5.4	1	8680	12.4	9.2	0.7	2350	<2	<0.01	11.4	<0.1	<0.1	0.2	40	0.2	38.4	4	—	—	—
		R	12	40	20	90	500	1370	1280	<0.1	150	40	20.8	0.27	4440	<0.50	<1.00	70	<1	<0.1	<50	<0.1	9.9	9.6	5.8	1.6	11100	6.8	4.5	1.3	380	<2	<0.01	5.9	<0.1	<0.1	0.4	80	0.3	34.5	7.4	—	—	—
	2	L	13	20	<10	110	1100	4520	3490	<0.1	390	86	64.8	0.71	12900	<0.50	2.03	180	<1	0.1	<50	<0.1	23.4	24.4	15	4.1	29700	16.3	10	3.1	893	<2	<0.01	14.9	0.2	<0.1	0.8	140	0.7	79.2	16.9	—	—	—
		M	16	30	20	170	1250	4880	4720	<0.1	370	89	69.3	0.1	14500	<0.50	1.79	390	<1	0.1	<50	<0.1	25.1	36.7	17.2	4.6	32000	19.5	8.8	3.8	1890	<2	<0.01	19.8	0.2	<0.1	0.8	180	0.7	80.4	19.3	<0.05	113	111
		R	9	<10	30	<50	190	900	540	<0.1	70	37	4.9	0.44	1540	<0.50	<1.00	30	<1	<0.1	<50	<0.1	5.1	7	2.1	0.6	4100	3.3	3.4	0.4	268	<2	<0.01	3.5	<0.1	<0.1	0.2	40	0.1	15.2	2.5	—	—	—
	3	L	10	20	<10	<50	130	310	230	<0.1	50	33	4.8	0.04	930	<0.50	<1.00	90	<1	<0.1	<50	<0.1	4.4	11.9	1.9	0.5	4300	4.9	2.7	0.3	522	<2	<0.01	4.1	<0.1	<0.1	0.2	20	0.1	15.9	2.1	—	—	—
		M	14	20	10	<50	200	280	360	<0.1	70	31	3.3	0.19	1560	<0.50	<1.00	40	<1	<0.1	<50	<0.1	4.8	8.1	2.4	0.6	4910	3.6	2.4	0.5	217	<2	<0.01	3.1	<0.1	<0.1	0.2	30	0.1	15.4	2.5	—	—	—
		R	28	80	70	320	1840	3450	5030	0.1	620	152	65.4	0.97	17200	<0.50	2.22	180	<1	0.3	<50	<0.1	29.9	28.1	22.8	5.8	36200	21.3	13.7	5	669	<2	<0.01	20.4	0.3	<0.1	1.1	200	1	93.3	28.1	—	—	—
K2		**SS-SQGV**	**160**	**5840**	**812**	**5160**	**2200**	**4720**	**6720**	**1**	**522**	**160**	**7.2**	**0.7**	**17300**	**0.12**	**2.3**	**172**	**0.76**	**0.16**	**6.2**	**<0.05**	**29**	**23**	**19**	**8.3**	**33200**	**20**	**11**	**7**	**1100**	**0.28**	**0.49**	**19**	**0.11**	**<0.05**	**0.7**	**100**	**1**	**66**	**31**			
	1	L	6	5470	820	3990	1560	2140	2760	<0.1	440	98	18.4	0.5	6850	<0.50	1.39	60	<1	0.1	<50	<0.1	16.5	11.3	10.1	2.6	15600	9.7	6.6	2.7	249	<2	<0.01	9.7	0.1	<0.1	0.5	150	0.5	46.6	13.4	—	—	—
		M	6	2990	480	2670	730	54100	4830	<0.1	80	76	3.2	0.11	3280	<0.50	4.1	1520	<1	<0.1	<50	0.2	11.8	15.6	13	2.1	17400	82.3	15.9	1.5	11500	<2	<0.01	43.8	0.5	<0.1	0.2	100	1.6	103	10.2	—	—	—
		R	9	12400	2320	11200	4320	2210	7210	<0.1	650	162	11.1	0.54	19700	<0.50	2.23	180	<1	0.2	<50	<0.1	33.2	25.5	24.7	6.7	35000	20.6	12.6	5.9	636	<2	<0.01	22	0.2	<0.1	1.2	240	1.2	95.5	31.6	—	—	—
	2	L	8	7080	780	7020	2940	2660	5870	0.2	670	174	70.7	0.58	17600	<0.50	2.08	170	<1	0.2	<50	<0.1	30.9	23.2	23.2	6.1	32700	21.5	13.5	4.7	619	<2	0.01	20.6	0.2	<0.1	1.1	220	1	93.6	27.9	—	—	—
		M	10	1950	160	1540	720	1730	1720	<0.1	200	59	13.4	0.1	3700	<0.50	1.03	60	<1	<0.1	<50	<0.1	11.4	12.4	5.9	1.5	10400	8.3	6	1.2	528	<2	<0.01	7.3	<0.1	<0.1	0.3	100	0.2	32.9	7.8	—	—	—
		R	12	23600	3600	16300	4360	3970	7470	<0.1	1320	194	59.7	1.5	18600	<0.50	2.38	140	1	0.2	<50	<0.1	29.1	26.1	21.2	6	35000	18.9	12.6	6.3	664	<2	0.01	19.8	0.3	<0.1	1.2	220	1.1	83.8	30	—	—	—
	3	L	8	6170	320	5050	2350	3680	5830	<0.1	600	119	61.2	0.54	17300	<0.50	2.04	150	<1	0.2	<50	<0.1	29.7	22.6	21.8	5.7	33300	19	11.8	4.7	731	<2	<0.01	19.5	0.2	<0.1	1	240	1	88.1	27.2	—	—	—
		M	6	1840	30	1500	600	1550	1670	<0.1	90	44	24.9	0.21	4180	<0.50	1.25	60	<1	<0.1	<50	<0.1	12.9	11.6	6.3	1.6	11700	7.8	7	1.3	439	<2	<0.01	7.4	<0.1	<0.1	0.4	120	0.3	36.4	8.6	<0.05	108	111
		R	7	4160	480	3130	740	2350	1590	<0.1	170	54	13.2	0.12	3720	<0.50	1.34	320	<1	<0.1	<50	<0.1	9.9	18	6.4	1.4	11100	15.1	8.8	1.2	1540	<2	<0.01	9.6	<0.1	<0.1	0.3	90	0.4	45.7	7.3	—	—	—
	4	L	5	3720	310	3520	1720	2160	4000	<0.1	430	95	34.7	0.5	11800	<0.50	1.61	110	<1	0.1	<50	<0.1	22.8	16.7	15	3.9	24500	14.4	9.4	3.4	269	<2	<0.01	14.4	0.1	<0.1	0.7	200	0.7	69.1	18.7	—	—	—
		M	6	4910	800	3980	1020	1510	1780	0.1	200	55	3.1	0.15	4260	<0.50	<1.00	40	<1	<0.1	<50	<0.1	10.2	8.8	5.5	1.5	9630	6.2	4.8	1.6	459	<2	<0.01	5.8	<0.1	<0.1	0.4	90	0.3	27.7	8.3	—	—	—
		R	14	11200	1850	9980	3630	2270	6330	<0.1	1340	178	18.7	2.96	15400	<0.50	2.8	80	<1	0.2	<50	<0.1	27.5	23.2	23.5	5.2	36700	18.6	11.2	6.4	447	<2	0.01	18.5	0.3	<0.1	1.1	220	1.4	97.6	30.2	—	—	—
	5	L	11	10600	1910	10000	3440	3140	5650	<0.1	620	131	23.6	0.74	13400	<0.50	2.82	70	<1	0.2	<50	<0.1	23.2	20.7	17.3	4.3	29600	15.1	9.7	5.5	1050	<2	<0.01	15.1	0.2	<0.1	0.9	180	1	67.9	23.1	—	—	—
		M	6	4800	830	2960	520	3320	1050	<0.1	80	35	4.1	1.74	2160	<0.50	<1.00	40	<1	<0.1	<50	<0.1	8.1	8.5	3.3	0.9	6080	5.7	4.2	0.8	312	<2	<0.01	4.6	<0.1	<0.1	0.2	60	0.2	20.8	4.2	—	—	—
		R	5	3850	550	2870	520	12400	2410	<0.1	80	32	1.6	0.06	2440	<0.50	<1.00	40	<1	<0.1	<50	<0.1	8.8	9	3.8	1	7390	9.5	4	0.9	844	<2	<0.01	4.7	<0.1	<0.1	0.2	80	0.2	24	5	—	—	—
K1		**SS-SQGV**	**190**	**10400**	**1820**	**8080**	**2640**	**11200**	**6520**	**1**	**460**	**150**	**4.2**	**0.7**	**17000**	**0.09**	**2.5**	**114**	**0.75**	**0.14**	**13.2**	**<0.05**	**27**	**21**	**15**	**7.7**	**29400**	**18**	**10**	**7**	**630**	**0.32**	**0.45**	**17**	**0.11**	**<0.05**	**0.6**	**112**	**0.8**	**56**	**25**			
	1	L	9	10300	1950	8920	3830	16400	8220	<0.1	410	174	12.2	0.38	12700	<0.50	3.03	60	<1	0.2	<50	<0.1	23.3	13.8	13.3	4.2	24400	13.4	8.2	8.9	312	<2	0.01	13.9	0.2	<0.1	0.8	260	0.7	48.7	21.8	—	—	—
		M	26	30600	5100	23400	8000	18900	18400	<0.1	750	292	67.2	0.54	23800	<0.50	7.26	40	2	0.3	60	<0.1	44	20.4	21.4	7.2	40400	17.5	12	9.5	504	<2	0.01	22.4	0.2	<0.1	1.3	400	0.8	67.8	36.2	—	—	—
		R	12	17600	3310	15200	5270	3990	9090	<0.1	680	189	36	0.55	22100	<0.50	3.44	190	<1	0.3	<50	<0.1	35	25	25.4	7.3	39000	22.9	14	9	254	<2	0.01	22	0.3	<0.1	1.3	280	1.1	99.9	32.9	—	—	—
	2	L	6	6040	940	5300	2160	2250	4250	0.1	340	94	19.3	0.2	10200	<0.50	1.98	100	<1	0.1	<50	<0.1	21.6	18.4	13	3.5	23100	12.3	9.5	3.8	380	<2	<0.01	13.6	0.1	<0.1	0.7	210	0.5	58.2	17.4	—	—	—
		M	10	10500	2010	10300	3800	27900	7760	<0.1	420	169	11.2	0.26	12200	<0.50	3.79	80	<1	0.2	<50	<0.1	23.1	20.8	14.2	4	24500	23	8.5	7	2290	<2	<0.01	14.8	0.2	<0.1	0.8	220	0.7	53.9	20.7	—	—	—
		R	10	16200	2960	16100	5250	4200	9360	<0.1	780	181	26.3	0.61	21700	<0.50	3.23	170	1	0.2	<50	<0.1	34.3	26	25.4	7.1	39800	21.3	13.6	8.1	336	<2	0.01	21.9	0.3	<0.1	1.3	280	1.1	105	32.8	—	—	—
	3	L	15	42800	6930	28900	5360	7330	9050	<0.1	1440	186	43.6	0.9	16000	<0.50	3.58	110	2	0.2	<50	<0.1	26.1	27.9	19	5.3	32000	18	11.6	6.7	5390	<2	<0.01	17.5	0.3	<0.1	1.1	220	0.8	81.9	23.5	—	—	—
		M	4	3820	570	2440	280	9300	810	<0.1	90	48	0.7	0.08	920	<0.50	1.18	140	<1	<0.1	<50	<0.1	4.4	20.7	2.4	0.6	4880	13.6	5.7	0.5	880	<2	<0.01	6.4	<0.1	<0.1	0.2	30	0.6	21.5	22	—	—	—
		R	5	4770	720	3750	570	5160	1100	<0.1	60	32	2.3	0.09	1820	<0.50	<1.00	80	<1	<0.1	<50	<0.1	7.2	7.9	2.9	0.7	5420	8.2	5.8	0.7	481	<2	<0.01	4.1	<0.1	<0.1	0.2	60	0.4	20	3.6	—	—	—
	4	L	6	5130	800	4330	1110	1140	2510	<0.1	150	62	15.3	0.09	5560	<0.50	1.18	60	<1	<0.1	<50	<0.1	14.9	10.2	7.7	2.1	14700	7.4	5.9	1.8	312	<2	<0.01	8.1	<0.1	<0.1	0.4	160	0.4	40.2	10.9	—	—	—
		M	6	4830	910	3820	1020	1520	2080	<0.1	120	53	12	0.13	4670	<0.50	1.32	90	<1	0.1	<50	<0.1	12	13.1	6.8	1.7	12700	9.9	7.9	1.6	372	<2	<0.01	8.3	<0.1	<0.1	0.4	120	0.2	36.4	8.9	—	—	—
		R	8	8640	670	7560	2900	2870	6170	<0.1	600	143	83.9	0.54	17600	<0.50	2.06	180	<1	0.2	<50	<0.1	30.2	24	22.3	5.8	35800	19.9	12.8	4.9	592	<2	<0.01	20.5	0.2	<0.1	1	280	1	90.5	27.4	—	—	—
	5	L	9	13100	2550	11000	3290	3160	5810	<0.1	720	144	14.2	0.67	13800	<0.50	2.36	120	<1	0.2	<50	<0.1	27.1	19.4	19	5	27100	17.5	10.9	5.5	957	<2	<0.01	17.4	0.2	<0.1	1	200	0.7	74.3	24.2	—	—	—
		M	6	4030	610	3020	440	5370	1060	<0.1	40	34	1.3	0.09	1530	<0.50	<1.00	60	<1	<0.1	<50	<0.1	5.9	10.8	3	0.7	5010	9.7	4.4	0.6	744	<2	<0.01	4.8	<0.1	<0.1	0.2	50	0.2	20	3.5	<0.05	94.3	95.2
		R	6	5750	950	4380	1510	1940	3000	<0.1	220	64	14.4	0.21	7360	<0.50	1.34	100	<1	0.1	<50	<0.1	19.5	14.4	10.6	2.7	16800	11.2	9.2	2.6	532	<2	<0.01	11.2	0.1	<0.1	0.5	160	0.4	49.7	13.9	—	—	—
EST01		**SS-SQGV**	**154**	**8800**	**1580**	**6560**	**2900**	**48600**	**7980**	**1**	**344**	**210**	**2**	**0.71**	**10520**	**0.06**	**3.6**	**17**	**0.34**	**<0.05**	**23**	**<0.05**	**18**	**10**	**8.5**	**4.3**	**18000**	**12**	**6**	**8**	**290**	**0.23**	**0.21**	**10**	**0.06**	**<0.05**	**<0.5**	**220**	**0.5**	**29**	**18**			
	1	L	10	11400	1850	8310	2350	47000	8180	<0.1	240	199	42.2	0.11	8080	<0.50	3.09	10	<1	<0.1	<50	<0.1	15.8	7.8	6.8	2.7	14900	10.3	4.7	6.7	252	<2	<0.01	8.8	<0.1	<0.1	0.5	380	0.5	27.7	15.6	—	—	—
		M	10	10200	1610	7520	2290	46200	7820	<0.1	190	213	19	0.13	7780	<0.50	3.32	10	<1	<0.1	<50	<0.1	15.8	7.6	6.8	2.6	14400	10.1	4.7	6.7	249	<2	<0.01	8.8	<0.1	<0.1	0.5	360	0.5	27.2	15.6	<0.05	114	74.6
		R	9	9760	1580	6850	2160	47500	7600	<0.1	240	201	23.2	0.21	7220	<0.50	3.31	10	<1	<0.1	<50	<0.1	14.9	7.3	6.3	2.5	13700	10.1	4.6	6.4	245	<2	<0.01	8.5	0.1	<0.1	0.4	350	0.5	25.8	15	—	—	—

Appendix 3. Historic fish species and numbers recorded from each potentially impacted and reference (KR2 and DR1) site sampled in 2021.

	K1					K2					K4					Reference				
Species	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021
Acanthopagrus palmaris		1																		
Ambassis interruptus						1														
Ambassis sp.										1										
Amniataba percoides				1					1					1		37	2	2	2	1
Anodontiglanis dahli																4		2	2	
Arrhamphus sclerolepis	5	10		5	2	1		10		1										
Carcharhinus leucas	13		2	1	6					9										1
Eleutheronema tetradactylum			14	2	16					7										
Ellochelon vaigiensis	7	6	3	13	9			6	38	15										
Elops hawaiensis	3				1	1														
Gerres filamentosus																		1		
Glossamia aprion	1									1					1	1				
Glossogobius spp.										1					1					
Hephaestus jenkinsi							1								1	4				1
Hypseleotris compressa																				
Kurtus gulliveri	1						2													
Lates calcarifer	4	3	11	2	10	2		4	4	11	1	12		1	5	21	5	1		
Leiognathus equula	14	2		1	2	8	7													
Leiopotherapon unicolor														1			1			1
Lutjanus argentimaculatus	1				1															
Marilyna meraukensis				1	3		1		1	2										
Megalops cyprinoides			2		1		1		4	1	2	1		2	3	5		3	2	4
Melanotaenia australis															1					1
Mogurnda mogurnda											1									
Moolgarda buchanani		6		8	33															
Nematalosa erebi	72	146	155	149	242	68	116	108	84	76	19	8	42	48	11	52	94	48	32	7
Nematalosa vlaminghi		4																		
Neoarius graeffei	9	7	8	7	4	13	18	4	22	16	21	8	7	14	10	75	17	7	20	1
Neoarius midgleyi			1		2					3					1	16	2	2	3	1
Neosilurus ater									1		8	6	2	1		2		1	1	1
Nibea squamosa							2													
Parambassis gulliveri								1			1		1			7			6	
Planiliza ordensis	46	27	14	9	7	22	19	11	14	18	24	5	4	2	15	27	17	39	6	
Plicofollis argyropleuron		1																		
Plicofollis nella				2																
Polydactylus macrochir	1	1			2	1														
Pomadasys kaakan					1															
Pristis pristis		1		2		5	2	1						1	1	1	1		1	1
Scatophagus argus										4										
Scomberoides commersonnianus		1																		
Strongylura kreffti			1	1	1	2	2					1			1	2		1		2
Syncomistes bonapartensis						1										4		1	3	
Syncomistes trigonicus																1				
Thryssa Kammalensis						14		1												
Thryssa sp.		11			7		1													
Toxotes chatareus	4	4	1		10	4	3	5	1	5	1	2	2	2	1	2	5	3	5	1
Zenarchopterus sp										1										

Appendix 4. Historic edge macroinvertebrate species data (adjusted taxa level of identification) from each site sampled in 2021. X = taxa recorded.

		Keep River															Reference									
PHYLUM / CLASS / Order	Lowest Taxon	K1					K2					K4					KR2					DR1				
		2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021
ANNELIDA																										
OLIGOCHAETA	Oligochaeta spp.					X	X	X		X		X	X	X	X	X	X		X	X	X	X	X	X	X	X
POLYCHAETA	Polychaeta spp.	X	X	X	X	X			X		X															
ARTHROPODA																										
ACARINA	Acarina					X							X	X	X	X	X	X	X	X	X	X	X	X	X	X
ENTOGNATHA																										
Entomobryomorpha	Entomobryoidea spp.									X		X							X							
Poduromorpha	Poduroidea spp.																									
INSECTA																										
Coleoptera	Allodessus bistrigatus		X					X																		
	Amphiops australicus						X	X	X	X										X						
	Amphiops duplopunctulatus																									
	Amphiops spp.																		X							
	Anacaena spp.																									
	Austrolimnius spp.							X														X	X	X	X	
	Batrachomatus spp.																									
	Berosus dallasae																									X
	Berosus josephenae																									
	Berosus munitipennis											X														
	Berosus pulchellus													X	X	X										
	Bidessini spp.								X																	
	Carabidae spp.													X												
	Clypeodytes feryi											X	X		X	X		X	X							X
	Clypeodytes larsoni																									X
	Clypeodytes migrator											X														
	Clypeodytes weiri																									X
	Coelostoma fabricii																									
	Copelatus clarki	X																								
	Copelatus nigrolineatus														X	X								X	X	X
	Curculionidae spp.										X															
	Cybister godeffroyi																									
	Cybister tripunctatus				X																					
	Enochrus deserticola				X			X	X	X				X	X				X							
	Enochrus esuriens	X																								
	Enochrus eyrensis	X					X					X														
	Georissus spp.									X														X		
	Helochares clypeatus																									
	Helochares marreensis															X										
	Helochares spp.									X				X		X			X							
	Helochares tatei	X			X		X			X												X				
	Helochares tristis									X																
	Heteroceridae spp.																									X
	Hydaticus consanguineus											X														X
	Hydaticus vittatus	X													X		X									
	Hydraena spp.	X					X	X		X		X	X	X	X	X	X		X	X		X		X	X	X
	Hydrocanthus micans				X		X							X	X	X						X				
	Hydrochus spp.	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Hydroglyphus basalis	X					X	X		X		X	X	X	X	X		X	X							X
	Hydroglyphus daemeli						X	X				X						X								
	Hydroglyphus fuscolineatus																		X							
	Hydroglyphus godeffroyi						X					X														
	Hydroglyphus grammopterus									X						X									X	
	Hydroglyphus leai	X	X				X	X	X				X	X		X						X				
	Hydroglyphus orthogrammus														X										X	
	Hydroglyphus trifasciatus	X					X					X														
	Hydroglyphus trilineatus																	X								
	Hydrovatus opacus																									
	Hydrovatus ovalis				X		X				X	X			X	X				X		X			X	X

PHYLUM / CLASS / Order	Lowest Taxon	Keep River K1 2011	K1 2012	K1 2013	K1 2020	K1 2021	K2 2011	K2 2012	K2 2013	K2 2020	K2 2021	K4 2011	K4 2012	K4 2013	K4 2020	K4 2021	Reference KR2 2011	KR2 2012	KR2 2013	KR2 2020	KR2 2021	DR1 2011	DR1 2012	DR1 2013	DR1 2020	DR1 2021
	Hydrovatus parallelus							X					X	X												
	Hyphydrus contiguus																									
	Hyphydrus decemmaculatus														X											
	Hyphydrus elegans																									
	Hyphydrus lyratus	X					X	X		X			X	X	X											
	Hyphydrus spp.																									X
	Laccobius billi									X																
	Laccophilus cingulatus						X	X				X		X	X			X					X	X		
	Laccophilus clarki	X					X	X		X		X	X	X	X	X	X	X	X	X		X	X		X	
	Laccophilus religatus							X																		
	Laccophilus seminiger														X											
	Laccophilus sharpi				X		X	X		X		X	X	X	X		X	X					X		X	
	Laccophilus spp.													X		X		X	X							
	Laccophilus unifasciatus											X														X
	Laccophilus walkeri									X		X	X				X			X				X	X	X
	Limbodessus compactus	X	X									X		X		X		X	X			X				
	Limnebius spp.													X												X
	Limnichidae spp.							X		X				X	X	X			X			X			X	X
	Macrogyrus darlingtoni													X												
	Macrogyrus spp.																						X			
	Megaporus ruficeps				X		X	X	X	X		X	X		X	X										
	Neobidessodes flavosignatus	X					X																			X
	Neobidessodes mjobergi						X																			X
	Neobidessodes spp.						X							X												
	Neohydrocoptus subfasciatus	X	X				X					X			X	X						X		X		
	Notomicrus tenellus															X								X	X	X
	Notriolus spp.																									
	Ochthebius spp.	X	X				X	X	X	X			X	X		X			X	X				X		
	Onychohydrus spp.																									
	Paracymus pygmaeus	X	X				X	X		X	X	X	X	X	X	X			X	X		X	X		X	X
	Paracymus spenceri																		X							
	Paracymus spp.									X										X						
	Regimbartia attenuata	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	
	Regimbartia spp.																									
	Rhantaticus congestus														X											
	Scirtidae spp.													X					X	X			X	X	X	X
	Spercheus spp.									X																
	Staphylinidae spp.					X				X	X				X	X				X						
	Sternolophus marginatus											X														
	Sternolophus spp.																									
	Sternopriscus aquilonaris																							X		
	Tiporus josepheni															X					X					
	Tiporus undecimmaculatus																									
Diptera	Aedes spp.									X		X														X
	Anopheles spp.						X	X	X	X	X	X	X	X	X	X								X		X
	Cecidomyiidae spp.																									X
	Ceratopogonidae spp.	X		X			X	X	X	X		X			X		X	X	X	X		X	X		X	X
	Ceratopogoninae spp.	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Chironomidae spp.	X			X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
	Chironominae spp.	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Culex spp.							X		X				X	X									X		
	Culicidae spp.							X	X	X			X		X					X					X	X
	Dasyheleinae spp.	X		X			X	X	X	X		X	X	X		X	X		X					X		
	Dolichopodidae spp.							X																		
	Empididae spp.																									
	Ephydridae spp.													X												
	Forcipomyiinae spp.									X		X				X										
	Muscidae spp.													X											X	X
	Orthocladiinae spp.			X				X				X	X	X	X	X	X	X	X	X			X	X	X	
	Psychodidae spp.																		X							

PHYLUM CLASS Order	Lowest Taxon	Keep River															Reference									
		K1					K2					K4					KR2					DR1				
		2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021
	Sciomyzidae spp.														X											
	Simuliidae spp.			X			X	X						X				X								
	Stratiomyidae spp.							X		X		X	X	X	X	X	X	X	X			X		X	X	
	Tabanidae spp.									X		X		X	X	X			X	X		X	X		X	
	Tanyderidae spp.												X	X									X	X		
	Tanypodinae spp.	X		X	X		X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Tipulidae spp.																									
Ephemeroptera	Atalophlebia spp.																						X			
	Baetidae spp.	X			X		X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X
	Caenidae spp.				X		X	X		X		X	X	X	X	X			X	X	X	X	X	X	X	X
	Cloeon fluviatile	X			X		X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X		X
	Cloeon sp. NT2						X																			
	Cloeon sp. Red Stripe				X		X	X	X				X	X	X	X					X					X
	Cloeon spp.							X				X	X													
	Leptophlebiidae spp.																					X		X		
	Manggabora wapitja																									
	Platybaetis spp.																									
	Pseudocloeon hypodelum																									
	Pseudocloeon plectile							X							X											
	Pseudocloeon spp.																									
	Tasmanocoenis sp. E						X											X			X		X			
	Tasmanocoenis sp. M									X				X		X			X					X		X
	Tasmanocoenis sp. P/arcuata						X						X	X	X	X	X	X	X		X		X	X	X	
	Tasmanocoenis spp.												X										X			
	Thraulus spp.																									
	Wundacaenis dostini												X	X		X			X	X	X	X		X	X	X
Hemiptera	Anisops spp.																									
	Austronecta bartzarum												X		X										X	
	Austronecta micra									X			X	X	X	X		X	X	X			X	X	X	X
	Austronepa angusta																									
	Belostomatidae spp.							X		X			X	X	X											
	Diplonychus eques											X														
	Diplonychus spp.				X			X		X		X			X				X	X		X				X
	Enithares atra																									
	Enithares loria						X	X		X		X	X				X	X								
	Gerridae spp.	X	X				X	X	X				X													
	Hebridae spp.																		X							
	Hebrus axillaris																									
	Hebrus nourlangiei																									
	Hydrometra spp.							X																		
	Laccotrephes tristis														X											
	Limnogonus fossarum gilguy	X					X	X	X			X		X												
	Limnogonus hungerfordi																									
	Limnogonus luctuosus											X		X			X									
	Limnogonus spp.							X																		
	Merragata hackeri						X							X										X		
	Mesovelia ebbenielseni		X				X										X									
	Mesovelia horvathi	X							X			X		X			X		X			X		X		
	Mesovelia spp.							X	X			X	X	X		X										
	Mesovelia vittigera							X								X										
	Mesoveliidae spp.																							X		
	Micronecta adelaidae				X																			X	X	
	Micronecta annae													X												
	Micronecta gracilis				X																					
	Micronecta lansburyi																									X
	Micronecta ludibunda												X		X											
	Micronecta paragoga													X	X	X										
	Micronecta robusta		X					X					X													
	Micronecta spp.				X					X				X	X	X										X
	Micronecta virgata															X										

PHYLUM CLASS Order	Lowest Taxon	Keep River															Reference									
		K1					K2					K4					KR2					DR1				
		2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021
	Micronectidae spp.	X		X	X		X			X		X	X	X	X	X	X					X		X	X	X
	Microvelia herberti						X												X							
	Microvelia katherinae																						X			
	Microvelia malipatili													X												
	Microvelia odontogaster																		X							
	Microvelia peramoena													X					X				X			
	Microvelia spp.						X	X	X			X	X	X					X			X	X			
	Microvelia torresiana																									
	Naucoris subopacus							X																		
	Nepidae spp.									X															X	
	Nerthra spp.																									
	Nesidovelia herberti									X																
	Nesidovelia peramoena									X																
	Notonectidae spp.						X	X		X		X		X	X	X			X	X	X		X	X		X
	Nychia sappho						X			X		X	X	X	X	X	X	X	X	X		X	X			X
	Nychia spp.									X																
	Paraplea spp.	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X
	Petrovelia katherinae									X																
	Ranatra diminuta			X	X					X	X			X	X					X						
	Ranatra occidentalis		X				X	X	X			X	X	X			X	X								
	Ranatra spp.							X						X												
	Rhagadotarsus anomalus						X						X					X					X			
	Veliidae spp.						X			X		X		X	X	X	X		X			X		X		
Lepidoptera	Acentropinae spp.																									
	Eoophyla repetitalis																									
	Lepidoptera spp.													X												
	Margarosticha spp.																									
	Parapoynx spp.																									
	Teleremia spp.																									
Neuroptera	Sisyridae spp.																		X						X	
Odonata	Agriocnemis spp.							X					X													
	Anax spp.																									
	Anisoptera spp.	X			X		X	X	X	X		X	X	X	X	X			X	X		X		X	X	X
	Antipodogomphus neophytus														X	X					X	X				
	Argiocnemis rubescens										X		X													
	Austroagrion spp.																									
	Austrocordulia territoria																									
	Austroepigomphus turneri																X					X				
	Austrogomphus arbustorum																									
	Austrogomphus gordoni																						X			
	Austrogomphus pusillus																								X	
	Coenagrionidae spp.						X		X					X												
	Crocothemis nigrifrons																									
	Diplacodes bipunctata														X											
	Diplacodes haematodes				X			X		X			X	X	X	X			X			X	X			
	Diplacodes spp.													X												
	Eurysticta kununurra																		X			X				
	Hemicordulia intermedia												X										X	X		
	Hemicordulia spp.																						X			
	Hydrobasileus brevistylus																									
	Ictinogomphus australis																									
	Ischnura aurora	X			X		X	X		X																
	Ischnura heterosticta								X																	
	Ischnura spp.								X	X				X												
	Libellulidae spp.												X										X			
	Macrodiplax cora								X									X								
	Nannophlebia mudginberri																									
	Nannophlebia spp.																									
	Neurothemis stigmatizans																									
	Nososticta spp.						X					X		X												

PHYLUM / CLASS / Order	Lowest Taxon	Keep River															Reference									
		K1					K2					K4					KR2					DR1				
		2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021
	Orthetrum caledonicum													X												
	Pantala flavescens																									
	Pseudagrion aureofrons	X	X		X		X	X		X	X	X	X		X	X	X	X		X		X	X			X
	Pseudagrion lucifer																									
	Pseudagrion microcephalum	X			X		X			X	X	X		X		X			X			X		X		
	Pseudagrion microcephalum		X					X					X					X					X			
	Pseudagrion spp.								X					X									X			
	Tramea spp.																									
	Zygoptera spp.	X	X		X		X	X	X	X	X	X	X	X	X	X		X	X		X			X	X	X
Thysanoptera	Thysanoptera spp.											X														
Trichoptera	Anisocentropus spp.												X	X	X			X								
	Cheumatopsyche wellsae						X	X				X		X	X											
	Chimarra spp.							X																		
	Chimarra uranka							X																		
	Ecnomina spp.																									
	Ecnomus spp.						X					X	X	X	X	X		X	X	X		X	X	X		X
	Helicopsychidae spp.																									
	Hellyethira spp.			X									X													
	Hydropsychidae spp.																									
	Hydroptilidae spp.												X													
	Leptoceridae spp.						X			X		X	X		X	X		X		X			X	X	X	
	Leptocerus atsou																								X	
	Leptocerus spp.																					X	X			
	Oecetis spp.	X			X		X	X		X			X	X	X	X	X	X	X	X		X	X	X	X	
	Orthotrichia spp.				X													X	X	X					X	
	Paranyctiophylax spp.																						X			
	Philopotamidae spp.																									
	Triaenodes spp.			X	X								X	X	X			X	X	X		X	X	X		
	Trichoptera spp.																									
	Triplectides australicus																									
	Triplectides australis						X	X					X										X			
	Triplectides ciuskus seductus	X			X		X	X		X		X	X	X	X	X			X	X			X	X	X	
	Triplectides helvolus												X	X												
	Triplectides parvus						X																			
	Triplectides spp.						X	X					X		X		X	X								X
	Trolectides helvolus	X																								
MALACOSTRACA																										
Amphipoda	Amphipoda spp. (stygofauna)		X																							
	Corophiidae spp.			X	X	X			X		X															
	Grandidierella spp.		X				X	X					X													
	Melitidae spp.					X																				
Decapoda	Amarinus lacustris	X	X	X		X					X															
	Atyidae spp.	X			X		X			X					X					X						
	Brachyura spp.																									
	Caridina nilotica	X	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X						
	Caridina serratirostris		X				X	X	X			X	X	X	X	X	X	X	X	X		X	X	X	X	
	Caridina spp.	X	X	X		X	X	X			X					X					X					X
	Caridina thermophila																					X				
	Macrobrachium australe											X														
	Macrobrachium bullatum	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X			
	Macrobrachium lar																						X			
	Macrobrachium rosenbergii	X	X	X	X	X	X	X			X	X	X	X			X	X			X					
	Macrobrachium spp.	X	X	X		X	X		X		X	X	X	X		X	X	X			X	X	X	X		
	Palaemonidae spp.				X					X					X											
	Penaeus spp.		X																							
CNIDARIA																										
HYDROZOA																										
Anthoathecata	Hydra spp.									X			X	X												
MOLLUSCA																										
BIVALVIA																										

		Keep River															Reference									
PHYLUM CLASS Order	Lowest Taxon	K1					K2					K4					KR2					DR1				
		2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021	2011	2012	2013	2020	2021
Cardiida	Corbicula spp.	X					X							X	X	X								X		
Sphaeriida	Pisidium spp.		X																							
	Sphaeriidae spp.												X													
Unionida	Hyriidae spp.	X	X		X			X	X	X	X									X						
GASTROPODA	Gastropoda spp.	X	X	X																						
Cerithimorpha	Melanoides spp.																			X					X	
Cerithimorpha	Thiara spp.																					X	X	X		
Hygrophila	Amerianna spp.																							X		
	Bullastra vinosa																									
	Ferrissia petterdi									X				X	X			X	X					X	X	
	Gyraulus spp.				X		X	X		X		X	X	X	X		X	X	X	X			X	X	X	X
	Leichhardtia spp.																									
Hypsogastropoda	Bithuniidae spp.																									
	Bithyniidae spp.		X			X					X															
	Coleglabra spp.					X					X															
	Gabbia spp.							X																		
	Tateidae spp.		X			X		X	X																	
Neotaenioglossa	Hydrobiidae spp.	X					X																			
	Notopala spp.				X																X				X	
NEMATODA	Nematoda spp.				X		X								X	X					X					
NEMERTEA	Nemertea spp.													X										X		
PLATYHELMINTHES TURBELLARIA	Turbellaria spp.												X	X												

End Document