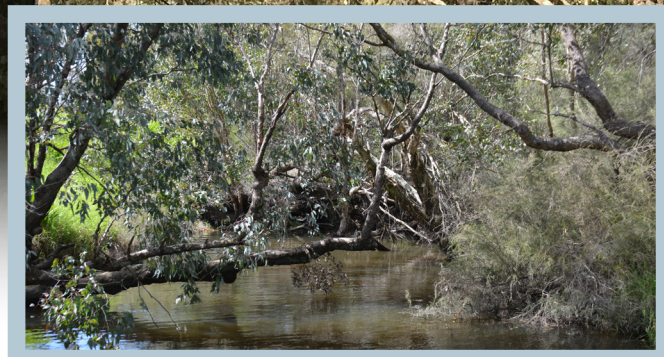
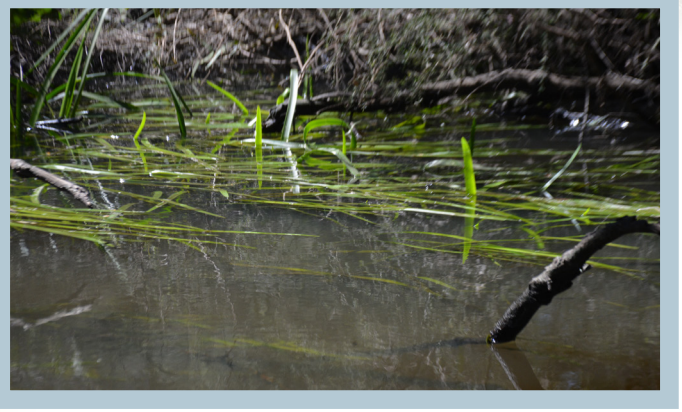
A river health assessment of the Serpentine River, Western Australia: Restoring the Serpentine River





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Peel-Harvey Catchment Council

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The Serpentine River, Western Australia

The Serpentine River lies in an ichthyological province known as the Southwestern Province, a region that has the highest proportion of endemic fishes and crayfishes on the continent, and is a globally recognosed endemic hotspot. Winding through the Darling Scarp before plunging through a series of waterfalls to the Swan Coastal Plain, the Serpentine Valley and its river is of biological, cultural and agricultural importance. Parts of the river remain in relatively pristine condition, yet there is a major reservoir on the river, and sections of the river have been engineered into drains.

The Peel-Harvey Catchment Council (PHCC), through the Alcoa Foundation's 'Three Rivers, One Estuary' initiative is undertaking rehabilitation of streamlines to enhance biodiversity and ecosystem function. There have been a range of surveys of aquatic fish, crayfish or freshwater mussels conducted in the system dating back to the 1930's with the majority of those sites surveyed post 2000. One of the more recent relevant surveys was by Klunzinger et al. (2011) who sampled three sites in the Lowlands Bush forever site and three downstream in the Lowlands property and Birrega Drain sites up to seven times between June 2010-September 2011 (using a combination of sampling techniques including fyke netting and back-pack elecrofishing). The latter study recorded four species of native freshwater fish and two species of estuarine native fishes and importantly, the anadromous Pouched Lamprey at two sites. However, catches were dominated by introduced fishes. Two native crayfishes were recorded and catches were dominated by the native Gilgie. Other fauna recorded included the introduced Yabbie, the South-west Snake-necked turtle, and the Carter's Freshwater Mussel; which is the only known threatened freshwater species in the lower reaches of the Serpentine River.

A decade on, the current study resurveyed these sites in spring 2019 and autumn 2020 and recorded a total of 27927 aquatic macrofauna. The vast majority (~90%) of these were the south-west glass shrimp. Of the 2535 fish captured, ~47% were native species and there were four south-western Australian endemic freshwater fishes and one native estuarine species along with two introduced species. The percentage composition of native species in the current study was far higher than that recorded by Klunzinger et al. (2011) who found only ~3% of total fish captures were native. However, this is likely to be due to the latter study including the summer-autumn period when Eastern Gambusia abundances are at their greatest (noting the species made up nearly 97% of all fish captures in 2010-2011).

The spawning movements and recruitment of common native freshwater fishes in south-western Australia are positively associated with the amount of winter-spring discharge (Beatty et al. 2014) and the amount of discharge in 2019 was much higher than in 2020. Abundances of native fish were dominated by the Western Minnow with the Nightfish, Western Pygmy Perch and Freshwater Cobbler less abundant. While abundances and evidence of recruitment varied among sites, it was clear that all native freshwater fishes were maintaining viable populations in both the lower Serpentine and to a lesser extent the Birrega Drain. This report also highlights the prevailing water quality and the use of macroinvertebrates as bioindicators of river health.

The Western Minnow (*Galaxias occidentalis*) is commonly seen schooling in the Serpentine River

A River Health Assessment of the Serpentine River, Western Australia:

Restoring the Serpentine River

Project Proponents

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Peel-Harvey Catchment Council, Mandurah, WA 6210, Australia
Alcoa Foundation

Foreword

South-western Australia's freshwater fish fauna is unique, with a level of endemism that is unparelled elsewhere on the Australian continent. Many of these fishes are now threatened, mainly through loss or reduction of their habitats as a result of reduced water quality, a drying climate and the seemingly continual spread of alien species. Similarly, the freshwater crayfish species from the region are found nowehere else and the region is home to a singular threatened freshwater mussel. Each river system plays a role in supporting the region's unique aquatic fauna, and this is no more evident through these challenging times.

Unlike many of the larger river systems of south-western Australia, which have become secondarily salinised and are now unsuitable to support stenohaline fishes, the Serpentine River remains fresh, has large sections of bushland and supports a vibrant community of aquatic organisms.

Ongoing studies are vital to detect changes in aquatic fauna and identify areas of important refuge. The Alcoa Foundation and the Peel-Harvey Catchment Council are commended for initiating such studies and generating community stewardship in the Serpentine catchment and indeed elsewhere.

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We acknowledge the assistance of staff from Alcoa, the Peel-Harvey Catchment Council and the Bindjareb Noongar community.

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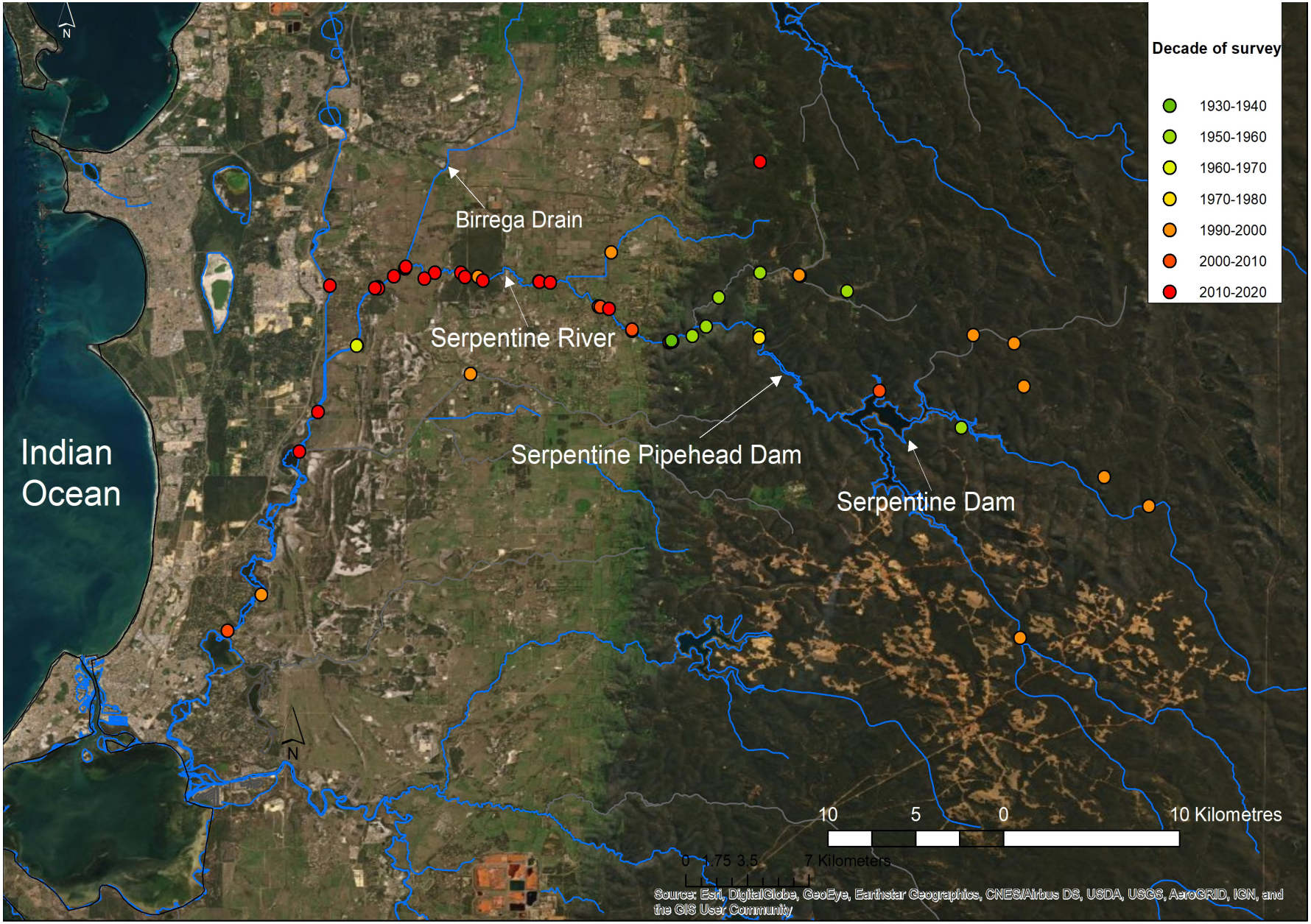

Figure 1: Documented surveys for fish, crayfish or freshwater mussels in the Serpentine catchment

Background

The Serpentine River catchment has variable land uses and levels of clearing. However, there remains large sections of relatively undisturbed habitat. The system consists of headwater streams in the forested Darling Scarp that flow into the Serpentine Dam, which then flows into the Serpentine Pipehead Dam. The river passes through the Serpentine National Park where it plunges onto the Swan Coastal Plain and through ~8 km of agricultural land before reaching the Lowlands Nature Reserve, then passing through approximately 4 river km through Lowlands and Riverlea properties. The river has then been altered by the creation of the Birrega Drain which connects to the river discharging into the drain and flowing south-south-west into Lake Amarillo where it again becomes a more natural form flowing into Geogrup Lake Nature Reserve and then the Peel-Harvey Estuary.

The Peel-Harvey Catchment Council (PHCC), through the Alcoa Foundation's 'Three Rivers, One Estuary' initiative is undertaking rehabilitation of streamlines to enhance biodiversity and ecosystem function. There have been a range of surveys for fish, crayfish or freshwater mussels conducted in the system dating back to the 1930's with the majority of those sites surveyed post 2000 (Figure 1) (e.g. Davis et al. 1988; Klunzinger et al. 2011). One of the more recent relevant surveys was by Klunzinger et al. (2011) who sampled three sites in the Lowlands Nature Reserve and three downstream in the Lowlands property and Birrega Drain sites up to seven times between June 2010 and September 2011 using a combination of sampling techniques including fyke netting and back-pack elecrofishing. The latter study recorded four species of native freshwater fish including the Western Minnow (*Galaxias occidentalis*) (89% of native freshwater fish captured), Western Pygmy Perch (*Nannoperca vittata*) (~6%), Nightfish (*Bostockia porosa*) (~5%) and Freshwater Cobbler (*Tandanus bostocki*) (0.14%). The study also recorded two species of estuarine native fishes and importantly, the anadromous Pouched Lamprey (*Geotria australis*) at two sites.

Overall fish captures were dominated by the introduced Eastern Gambusia (*Gambusia holbrooki*), and the Goldfish (*Carassius auratus*). Crayfishes recorded by Klunzinger et al. (2011) were dominated by the native Gilgie (*Cherax quinquecarinatus*) (~98% of the native freshwater crayfishes captured) and the Marron (~2%). The feral eastern Australian Yabby (*Cherax destructor*) was also discovered during these surveys. Other fauna recorded included the South-west Snake-necked turtle, and the Carter's Freshwater Mussel; which is the only known threatened (Vulnerable under the EPBC Act 1999) freshwater faunal species in the lower reaches of the Serpentine River. This species was listed by the Federal Government in 2018.

Distribution of fauna recorded by Klunzinger et al. (2011) revealed some interesting patterns that were likely related to levels of habitat disturbance and complexity. Native freshwater fishes in the study were recorded in both the Serpentine River and the Birrega Drain sites; although the Nightfish and Western Minnow were in relatively low abundances in the most downstream two drain sites. Moreover, most of the two introduced fishes were found downstream of the Lowlands Bush Forever sites with the introduced Yabby only recorded in the Birrega Drain sites. Carter's Freshwater Mussel were found throughout the six sites surveyed by Klunzinger et al. (2011) with the greatest densities recorded in two of the forested sites in the Lowlands Nature Reserve. The latter study noted that while present in the Birrega Drain sites, much of the benthos there was unsuitable due to hard substrate with the natural upstream sites providing more suitable habitat due to shading to buffer against extreme temperatures and the presence of more complex instream habitat.

Following the study by Klunzinger et al. (2011), which provided valuable baseline ecological data on the lower Serpentine River; a standardised assessment protocol has been more widely used in south-western Australia that was developed by the Department of Water and Environmental Regulation (DWER) known as the South West Index of River Condition (SWIRC). Using those methods, DWER sampled two sites in 2014 (upstream from Rapids Rd) and three sites in 2017 (including the Lowlands track crossing site in the current study). They also found the presence of similar species as Klunzinger et al. (2011); although the Freshwater Cobbler, Smooth Marron, and the Pouched Lamprey were not recorded at the Lowlands Nature Reserve during the 2017 sampling whereas they were recorded there (each in very low numbers) in the 2010/2011 sampling.

By similarly applying the SWIRC protocols to a range of sites with a range of levels of disturbance, including a subsample of those previously surveyed by Klunzinger et al. (2011) and DWER, an increased knowledge of the current ecological condition of the river would be achieved. It would also help to quantify how the faunal populations may have changed over the past 10 years and provide a robust baseline against which the effects of future restoration activities may be measured.

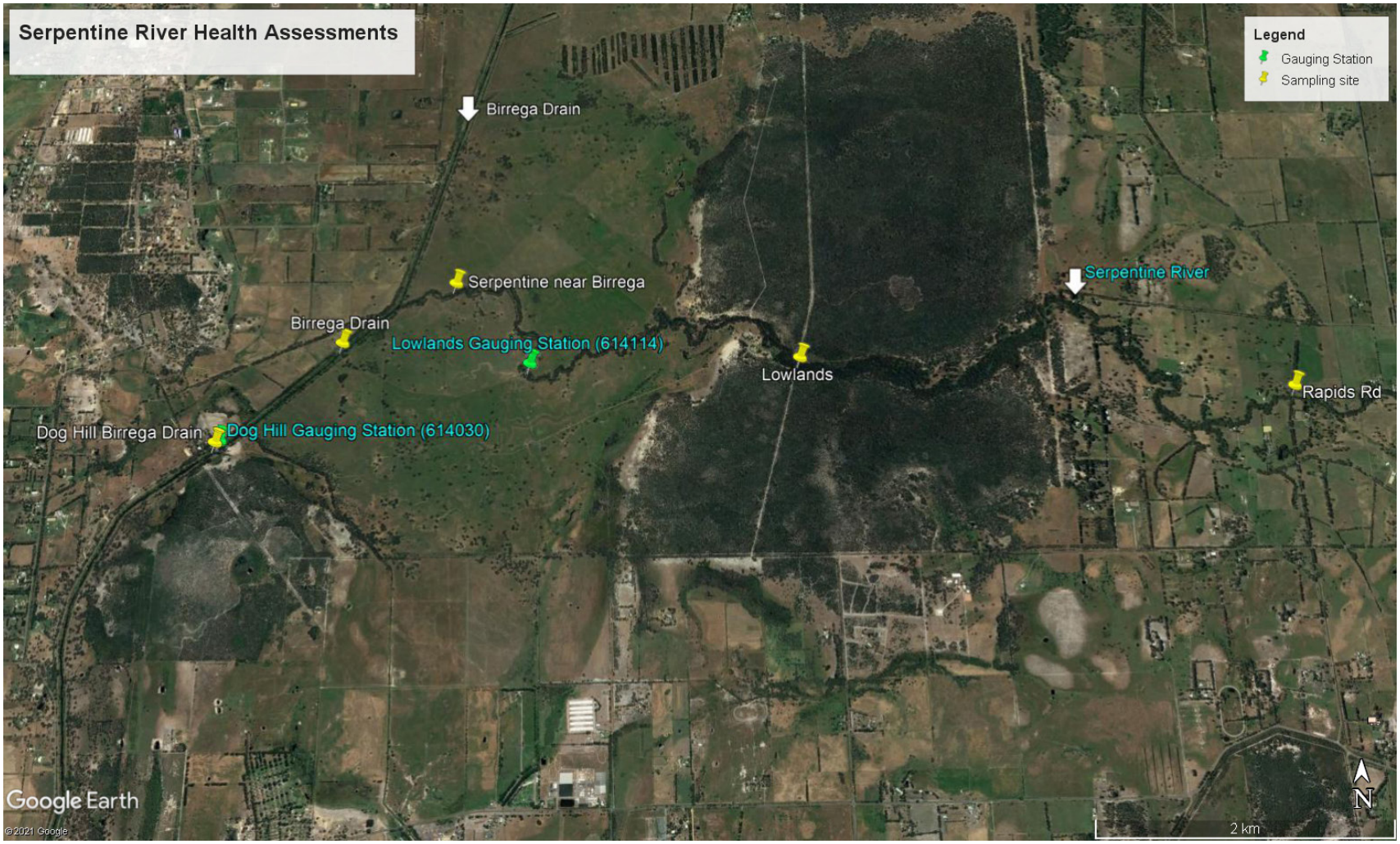

Figure 2: Sites where river health assessments were undertaken in the Serpentine catchment in November 2019 and September 2020

Project Scope

The scope of the current project was to ecologically survey five sites on the Serpentine River to provide a greater understanding of the current condition of the aquatic ecosystem. These assessments included *habitat descriptions, water quality, fish and crayfish population viabilities, and macroinvertebrate communities.*

The project aimed to provide an ecological baseline to quantify the effects of future management actions, particularly stream rehabilitation, on the aquatic ecosystem of the Serpentine River.

The study area and methods

The original timing of the sampling regime was to be in late Spring 2019 and Autumn 2020, however, due to COVID-19 pandemic and government restrictions, the Autumn survey was conducted in early Spring 2020 (September). Moreover, a bushfire occurred in January 2020 that impacted the lower sites (i.e. Birrega Drain and Dog Hill). Therefore, it was of interest to also determine the possible effect the fire had on the riparian zone, water quality and aquatic fauna. By conducting the two surveys during early and late spring, the study also encompassed the recruitment period of most native fishes and crayfishes.

The five sites that were sampled in the Serpentine River (including Birrega Drain) are shown in Figure 2.

Sampling methods included the following as per the DWER South West Index of River Condition (SWIRC) protocols:

- Sampling for fish movements and relative abundance involved the use of dual fyke-netting set overnight at upstream and downstream points at the site, and fish traps between the fyke nets.
- Sampling for crayfish involved the use of box-style crayfish traps.
- All fish and crayfish captured were identified, enumerated, and a sub-sample individually measured to provide a more fine-scale indication of population structure and viability.
- All native fish and crayfish were released unharmed at the site of capture and all introduced species were euthanased in an ice-slurry.
- Sampling for macroinvertebrates was undertaken using two invertebrate sweeps at each site (two minute duration) using a long-handled macroinvertebrate net (250µm mesh) in a macrophyte-dominated area (where present) and the deeper channel. The samples were immediately preserved in 100% ethanol for identification in the laboratory.
- Habitat and water quality data collection included those outlined in the DWER South West Index of River Condition Information protocols, which included:
  - i. General site description
  - ii. Connectivity
  - iii. Aquatic habitat
  - iv. Vegetation
  - v. Physical form and potential pollution
  - vi. Water quality in situ readings including measurements of water temperature, dissolved oxygen (% saturation and mg/L), conductivity (mS/cm), total dissolved solids (g/L), salinity (ppt), pH, and ORP (mV), Total Nitrogen, Total Phosphorus, and turbidity. Heavy metal concentrations were also determined at three sites in September 2020 to provide baseline data for future monitoring. The latter parameters were analysed by *ChemCentre WA*.
  - vii. Daily discharge data from the DWER Lowlands gauging station (station number 614114) and Dog Hill gauging station (station number 614030) were sourced for the period between June 2019 and December 2020. In order to determine the long-term annual trend in discharge within the lower Serpentine River and Birrega Drain, annual discharge at those respective gauging stations were downloaded for the period 1999-2019 (Lowlands) and 1980-2019 (Dog Hill).
  - viii. Photographs were taken at fixed locations at each site on each sampling occasion and compiled to track seasonal changes in riparian vegetation cover and surface water availability over the duration of the project.

Data Analysis

Length-frequency histograms for each fish and crayfish species (when captured in adequate numbers) for each site were plotted in order to give an indication of recruitment rates and population longevity at each site. Differences in the density of freshwater mussels among sites and left versus right stream bank were determined using a Generalised Linear Model assuming a negative binomial error distribution (for over-dispersed count data) in the lme4 package in R (R Studio version 1.1.463). Macroinvertebrate log-transformed abundances were tabulated and presence-absence data was used in the AUSRIVAS modelling software to determine how the macroinvertebrate community present compares with that predicted to be present in the absence of environmental stress. As per SWIRC protocols, the spring-channel model was selected with the minimum site information inputted into the model included annual discharge (sourced from the gauging stations above), latitude, longitude, log-transformed maximum velocity, and annual rainfall (Karnup Bureau of Meteorology station). Data from both 2019 and 2020 surveys were combined for each site for the AUSRIVAS modelling.

Results & Discussion

The winter-early spring discharge within the Serpentine River and Birrega Drain was much greater in 2019 compared with 2020 (Figure 3). For example, at the Lowlands track crossing, the mean instantaneous discharge for the major flow period (July-September inclusive) in 2019 and 2020 was 0.52 m^3/sec compared with 0.43 m^3/sec. At Dog Hill, the discharges for the major flow period in 2019 was 1.80 m^3/sec compared with 1.34 m^3/sec in 2020. Long term trends in discharge show a clear decline in both the lower Serpentine and Birrega drain reaches (Figure 4). Both trends were demonstrated to be significant (Lowlands track crossing $R^2 = 0.31$, $p < 0.01$, and Dog Hill $R^2 = 0.48$, $p<0.0001$) (Figure 4).

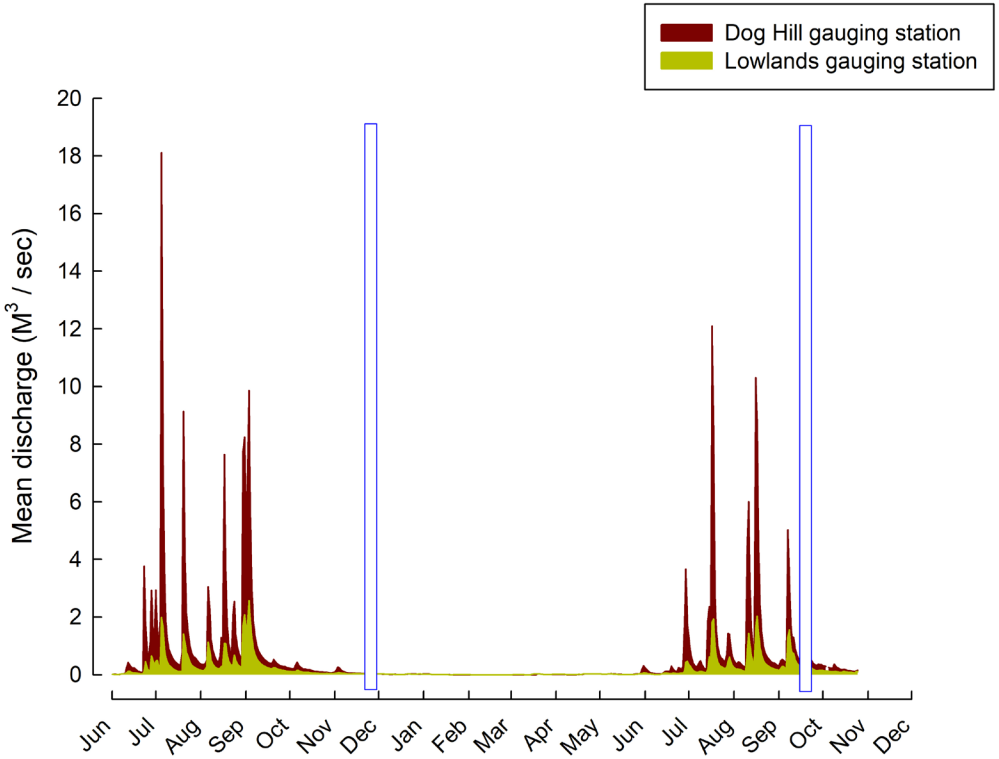

Figure 3: Mean daily instantaneous (cubic m/sec) discharge during 2019 and 2020. N.B. blue boxes represent the monitoring periods.

As water temperature is influenced by air temperature, maximum air temperature during each day of the study was sourced from the Bureau of Meteorology (Karnup station).

Water quality during both the November 2019 and September 2020 sampling periods was mostly within the known tolerance or preference for native freshwater fishes of south-western Australia (Beatty et al. 2013a) (Tables 1, 2). However, the two drain sites were clearly warmer than the three sites in the Serpentine River, with a stronger diurnal pattern evident at the Dog Hill site; particularly in November 2019 when temperatures exceeded 30 °C in the late afternoon compared with <24 °C at the Rapids Rd and Serpentine near Birrega sites. Native freshwater fishes in south-western Australia are rarely recorded in water with temperatures >32 °C (Beatty et al. 2013a); however, they are believed to utilise cooler microhabitats (e.g. benthic habitats) during periods of elevated daytime temperatures such as those experienced in drains. The greater maximum water temperature in the drain site occurred despite the maximum air temperature on the day during which it was logged being less than when the water quality was recorded in the two sites in the Serpentine River (see Table 1, Figure 5). This result is congruent with Klunzinger et al. (2011) who found that water temperatures of the Birrega Drain sites were up to 7 °C higher than the Serpentine River sites and can be attributed to the lack of riparian shading. Extreme temperature, along with the lack of complex instream habitats, is likely to be one of the major negative influences on native faunal populations in the Birrega Drain sites.

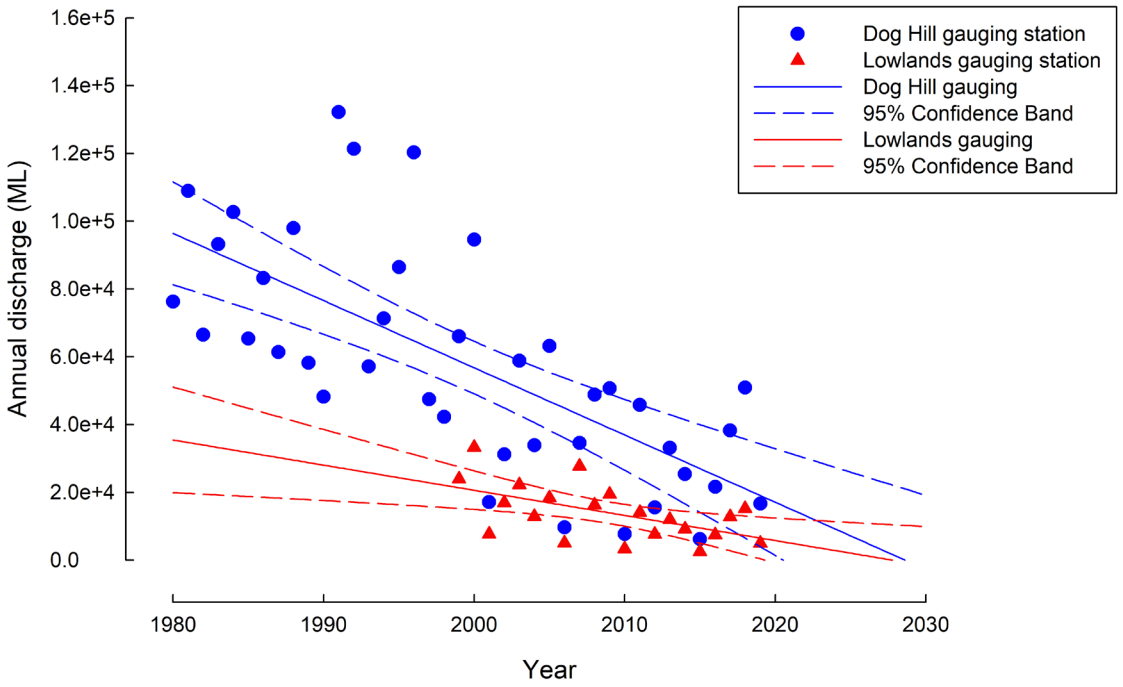

Figure 4: Long term annual discharge trends in the lower Serpentine (i.e. Lowlands track crossing) and Birrega Drain (i.e. Dog Hill gauging station).

Dissolved oxygen during the two sampling periods remained within the known field tolerance levels of south-western Australian freshwater fishes. The lowest mean dissolved oxygen was recorded at the Lowlands track crossing site in November 2019 (~4.83 mg/L) but dissolved oxygen generally declined at night. Such diel changes in dissolved oxygen were evident at the logged site upstream at Rapids Rd during that sampling period where it reached a minimum of ~4.8 mg/L at 07:00 h having been 6.6 mg/L the previous day at ~14:00 h (Figure 6). Klunzinger et al. (2011) found dissolved oxygen to be relatively consistent among river and drain sites during winter and spring and declined in summer. However, interestingly, they also found the dissolved oxygen concentrations in the less modified upstream sites in the Serpentine River declined the most in summer. This was attributed to the impact of more shading and larger concentrations of decaying material in the forested sites compared with degraded sites; that had higher concentrations of algae causing super-saturated dissolved oxygen concentrations (i.e., up to ~128 %) in the Birrega Drain (Dog Hill). High levels of algal growth in the two drain sites in the current study (see below for the individual site descriptions) and the influence on dissolved oxygen is very likely to have occurred during summer 2020 as it had in 2010. The reduced dissolved oxygen anticipated to occur during summer in the more upstream sites may be having an impact on the abundance of native fishes in the Serpentine River sites (such as causing density dependent effects); but is not currently threatening their viability.

The Total N was consistently higher in the two Birrega Drain sites during both sampling events in November 2019 and September 2020 compared with the three Serpentine River sites (Tables 2, 3). However, all values were within the default triggers values for lowland rivers in south-western Australia (i.e. <1.2 mg/L) according to ANZECC guidelines (2000). In contrast, total P exceeded the default trigger value of 0.065 mg/L in all sites aside from Rapids Rd in November 2019 (Table 3), whereas in September 2020, only the two Birrega Drain sites exceeded those guidelines (Table 4).

Fish can be sensitive to dissolved heavy metals. However, acute and chronic tolerances to nutrients and heavy metals remains a major knowledge gap relating to Western Australia's freshwater fishes. Concentrations of a range of total metals measured in water in September 2020 revealed all metal elements were undetectable aside from iron; which ranged from 1.2 – 2.2 mg/L being lowest at the most upstream Rapids Rd site, and highest at the most downstream Birrega Drain Dog Hill gauging station site (Table 4). There currently are no specific guidelines for iron concentrations for inland aquatic fish or crayfish in Western Australia. Iron has been shown to potentially precipitate on the surface of gills and eggs of fish hindering the uptake of oxygen. This is a result of ferrous iron (in the form of ferrous hydrogen carbonate) oxidising to the ferric form (ferric hydroxide) that precipitates on the gill surface. This occurs as gills are maintained at a more alkaline pH than the surrounding water (Authman et al. 2015). In a review of heavy metal toxicity in a range of fishes, Shuhaimi-Othman et al. (2013) determined a 96 h toxicity concentration of 1.46 mg/L Fe for the Guppy. Peuranen et al. (1994) found that iron was detrimental to Brown Trout at concentrations of 2 mg/L when pH was reduced which maintained iron in its ferrous form. However, they also found that the presence of dissolved organic compounds (humic acids) reduced the effect on gills and oxygen consumption. Further research is required to determine the possible effects of iron and other heavy metals on south-western Australian aquatic fauna.

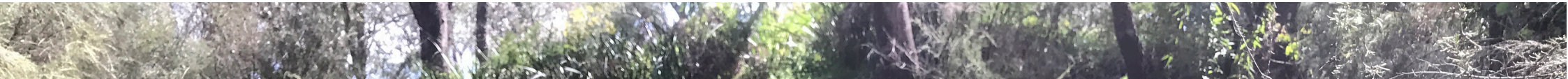

Table 1: Mean (±1 S.E.) values of water quality variables measured at three locations at each site during November 2019. N.B. based on overnight logged hourly readings for Rapids Rd, Serpentine near Birrega, and Dog Hill Gauging Station. Maximum air temperature on the day of water quality readings (point measurement or first day of logged measurements) is also shown.

	Serpentine Rapids Rd (n=23)	Serpentine Lowlands (n=2)	Serpentine near Birrega (n=17)	Dog Hill Gauging Station (n=22)
Salinity (ppt)	0.15 (0.001)	0.22 (0.00)	0.25 (0.00)	0.41 (0.00)
Dissolved Oxygen (mg/L)	5.53 (0.13)	4.81 (0.12)	-	-
pH	6.78 (0.03)	6.9 (0.13)	6.48 (0.01)	6.86 (0.03)
Water temperature (°C)	21.39 (0.24)	22.55 (0.05)	21.82 (0.07)	23.76 (0.79)
Maximum air temperature (°C)	30.1 (26/11/19)	30.5 (27/11/19)	30.5 (27/11/19)	27.8 (28/11/19)

Table 2: Mean (±1 S.E.) values of water quality variables measured at three locations at each site during September 2020. N.B. based on point measurements for Serpentine Lowlands and Birrega drain sites, and overnight logged readings for Rapids Rd, Serpentine near Birrega, and Dog Hill Gauging Station. Maximum air temperature on the day of water quality readings (point measurement or first day of logged measurements) is also shown. *Based on point measurements taken on 25/9/2020 due to faulty DO probe.

	Serpentine Rapids Rd (n=95)	Serpentine Lowlands (n=3)	Serpentine near Birrega (n=3)	Birrega Drain (n=3)	Dog Hill Gauging Station (n=110)
Salinity (ppt)	0.19 (0.00)	0.22 (0.00)	0.26 (0)	0.41 (0.00)	0.44 (0.00)
Dissolved Oxygen (mg/L)	5.97 (0.05)*	5.71 (0.03)*	6.88 (0.18)	7.43 (0.13)	6.85 (0.10)
pH	7.14 (0.01)	7.40 (0.06)	6.64 (0.02)	6.66 (0.01)	6.73 (0.01)
Water temperature (°C)	15.32 (0.06)	14.8 (0.00)	15.55 (0.10)	17.27 (0.08)	17.98 (0.10)
Maximum air temperature (°C)	17.2 (17/09/20)	19.8 (18/09/20)	23.2 (23/09/20)	25.7 (24/09/20)	25.7 (24/09/20)

Table 3: Nutrients and turbidity analysis from sites sampled in November 2019.

	Limits of reporting	Serpentine Rapids Rd	Serpentine Lowlands	Serpentine near Birrega	Birrega Drain	Dog Hill Gauging Station	ANZECC (2000) guidelines
N_total mg/L	*0.01*	0.3	0.43	0.42	0.56	0.56	1.2
P_total mg/L	*0.005*	0.06	0.19	0.11	0.15	0.14	0.06
Turbidity NTU	*0.5*	5.5	14	6.1	7.8	6.7	20

Table 4: Nutrients and turbidity analysis from sites sampled in September 2020. 95% species protection are provided (ANZG, 2018). N.B. those guidelines are for the dissolved fraction of metals and nutrients and the reported values below are the total amounts. * = ANZECC (2000) guidelines.

	Limits of reporting	Serpentine Rapids Rd	Serpentine Lowlands	Serpentine near Birrega	Birrega Drain	Dog Hill Gauging Station	ANZG (2018) 95%
N_total mg/L	*0.01*	0.48	0.55	0.54	0.85	0.87	1.2*
P_total mg/L	*0.005*	0.032	0.063	0.06	0.11	0.13	0.06*
Turbidity NTU	*0.5*	5.3	7.8	5.5	6.2	4.9	
HEAVY METALS (mg/L)							
As_total	*0.001*	<0.001		<0.001		<0.001	0.0024 (95%)
Cd_total	*0.0001*	<0.0001		<0.0001		<0.0001	0.0002 (95%)
Cr_total	*0.001*	<0.001		<0.001		0.001	0.001 (95%)
Cu_total	*0.001*	<0.001		<0.001		<0.001	0.0014 (95%)
Fe_total	*0.01*	1.2		1.6		2.2	-
Hg_total	*0.0001*	<0.0001		<0.0001		<0.0001	0.0006 (95%)
Ni_total	*0.001*	<0.001		<0.001		0.001	0.011 (95%)
Pb_total	*0.0005*	<0.0005		<0.0005		<0.0005	0.0034 (95%)
Se_total	*0.001*	<0.001		<0.001		<0.001	-
Zn_total	*0.005*	<0.005		<0.005		<0.005	0.008 (95%)

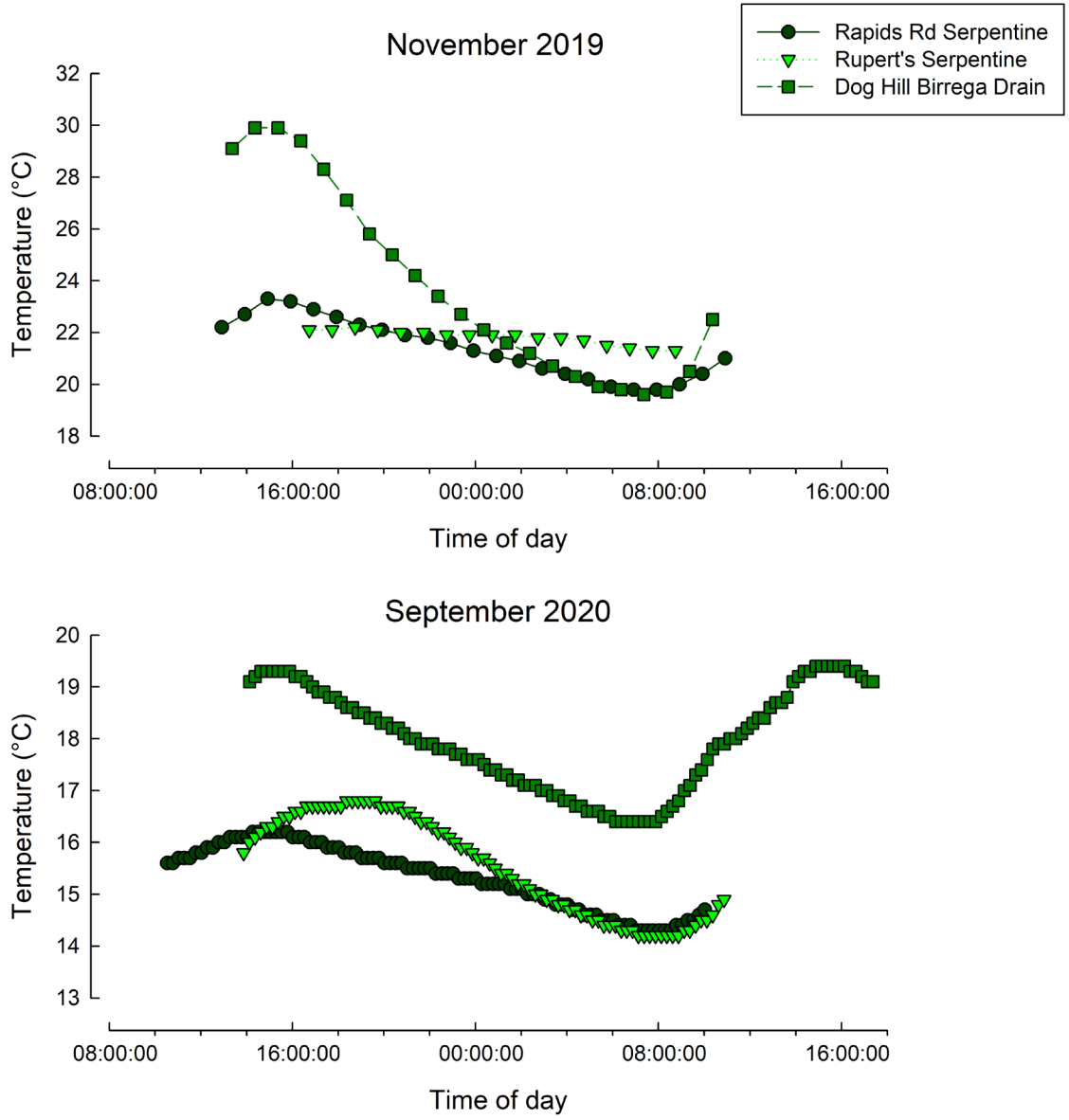

Figure 5: Temperature profiles (logged up to 18 hours) at the Rapids Rd, Serpentine near Birrega, and Dog Hill sites in November 2019 (top) and September 2020 (top). N.B. data were not recorded concurrently at each site but were within a one week period (see text for details and Tables 1 and 2 for variation in maximum air temperature during each data collection period).

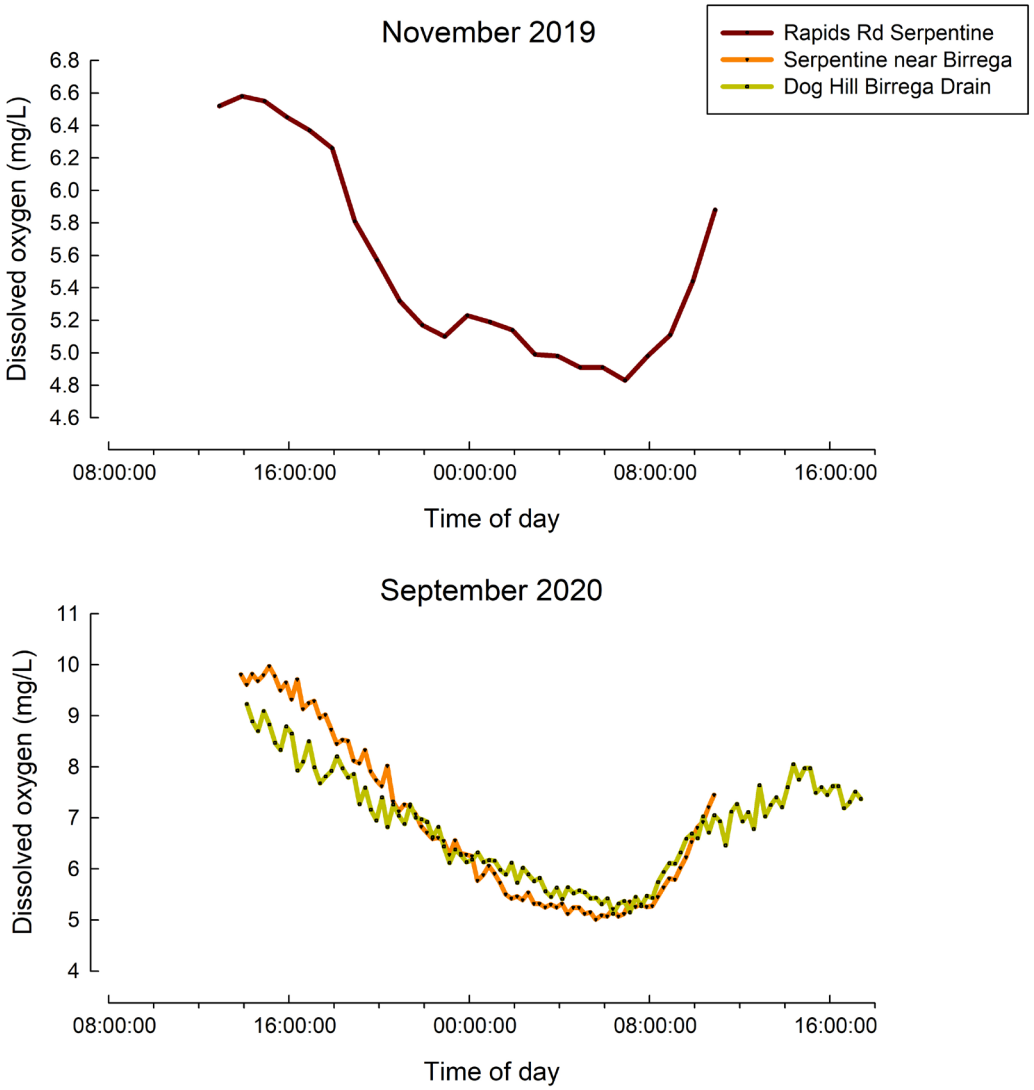

Figure 6: Dissolved oxygen profiles (logged up to 18 hours) at the Rapids Rd site in November 2019 (top) and Serpentine near Birrega, and Dog Hill sites in September 2020 (bottom). N.B. logged data at the two sites in September 2020 were logged on consecutive days (see text for details).

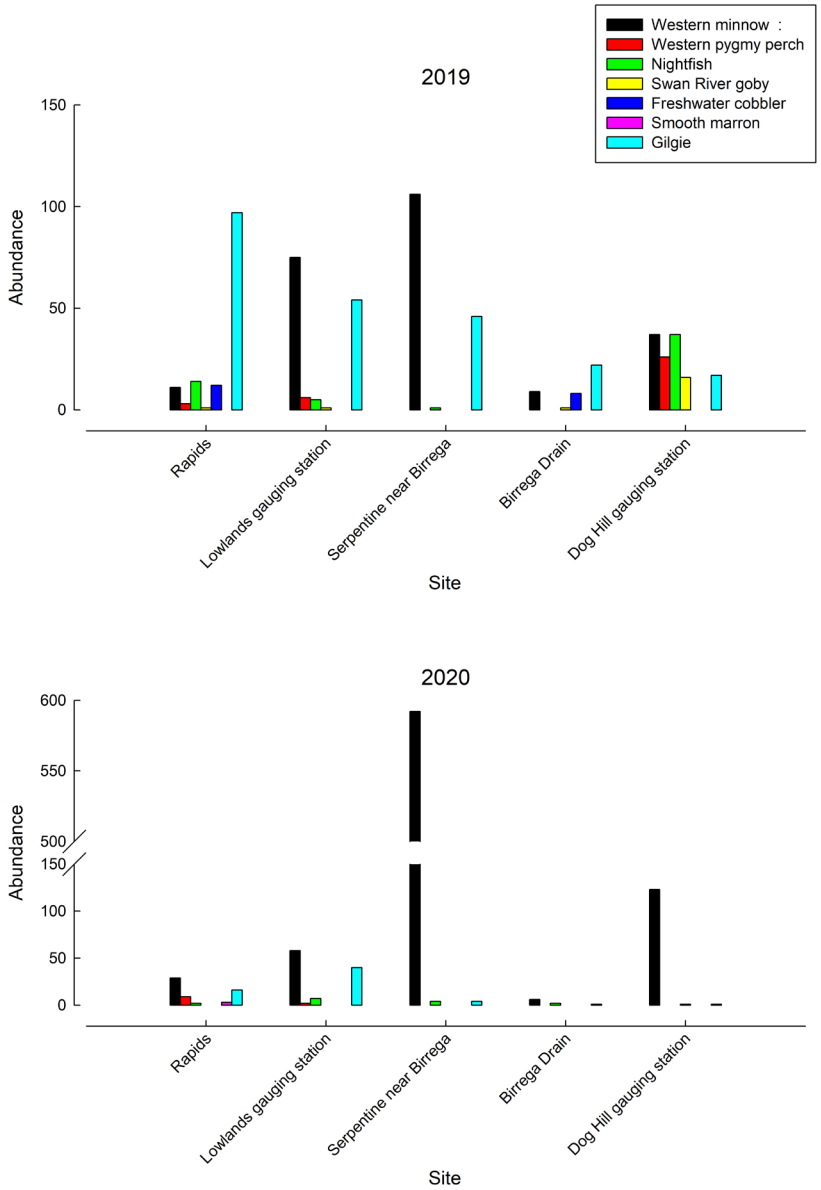

Figure 7: Total abundances of native fishes and crayfishes captured at each site in 2019 (top) and 2020 (bottom).

Fishes and crayfishes of the Serpentine River

The study recorded a total of 27927 aquatic macrofauna during the two sampling periods (Table 5). The vast majority (~90%) of these were the south-west glass shrimp. Of the 2535 fish captured, ~47% were native species and there were four south-western Australian endemic freshwater fishes and one native estuarine species along with two introduced species. The percentage composition of native species in the current study was far higher than that recorded by Klunzinger et al. (2011) who found only ~3% of total fish captures were native. However, this is likely due to the latter study including the summer-autumn period when Eastern Gambusia abundances are at their greatest (noting the species made up nearly 97% of all fish captures in 2010-2011).

The spawning movements and recruitment of common native freshwater fishes in south-western Australia are positively associated with the amount of winter-spring discharge (Beatty et al. 2014). The discharge in 2019 was much higher than in 2020 (see Figure 4). Abundances of native fish were dominated by the Western Minnow with the Nightfish, Western Pygmy Perch and Freshwater Cobbler less abundant (Table 5, Figure 7). While abundances and evidence of recruitment varied among sites, it was clear from overall length-frequency histograms that all native freshwater fishes were maintaining viable populations in both the lower Serpentine and to a lesser extent the Birrega Drain (see site summaries below).

The Western Minnow was recorded in both 2019 and 2020 at all sites, with the Nightfish recorded in all five sites (four sites in each survey period), Western Pygmy Perch (three sites) and Freshwater Cobbler (two sites) being less common and of lower overall abundance. The estuarine Swan River Goby was also present at four sites. These results were broadly similar to those of Klunzinger et al. (2011) who recorded the same four native freshwater fish at sites within and downstream of the Lowlands Nature Reserve; with the Western Minnow dominating the abundances of native fishes.

The Rapids Rd site had the highest overall native species diversity with the other four sites recording four of the five native fishes at some point during the study (Table 5). The November 2019 survey recorded a greater number of native fish species compared to the September 2020 sampling at the Rapids Rd site (Swan River Goby and Freshwater Cobbler detected in 2019 only), Lowlands track crossing (Swan River Goby detected in 2019 only), Birrega Drain (Swan River Goby and Freshwater Cobbler detected in 2019 only, however, Nightfish was detected in 2020 only), and Dog Hill gauging station (Western Pygmy Perch and Nightfish detected in 2019 only). The differences in overall captures in 2019 versus 2020 were likely attributable to the higher water levels and flow rates in September 2020 (particularly noticeable in the two Birrega Drain sites) resulting in less detectability of fishes rather that indicating a loss of the species from those sites.

The distribution of species in the current study are similar to adjacent sites surveyed by Klunzinger et al. (2011) with the exception of the absence of Freshwater Cobbler, Smooth Marron and Pouched Lamprey in the Lowlands track crossing in the current study. Klunzinger et al. (2011) recorded a single Freshwater Cobbler (at a site upstream from the current Lowlands track crossing) and a single Pouched Lamprey (downstream of the Lowlands track crossing with another recorded from the Lowlands gauging station further downstream) despite more intensive sampling. Freshwater Cobbler, Smooth Marron and Pouched Lamprey were not detected at the Lowlands track crossing when sampled in 2017 by DWER. However, these species may still be present in very low abundances in the reach between Birrega Drain confluence and Rapids Rd.

Introduced fish captures were dominated by the Eastern Gambusia that was present at all sites on both sampling occasions with the greatest abundances occurring during November 2019 compared to September 2020. Eastern Gambusia are known to reach high abundances in irrigation drain habitats in southwestern Australia due to

Table 5: Total abundances of fish, crayfish, turtles and shrimp captured at each site in November 2019, and September 2020.

	Rapids		Lowlands track crossing		Serpentine near Birrega		Birrega Drain		Dog Hill Birrega Drain		Grand Total	
Year	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Native Fish												
Galaxias occidentalis, Western minnow	11	29	75	58	106	592	9	6	37	123	**238**	**808**
Nannoperca vittata, Western pygmy perch	3	9	6	2	0	0	0	0	26	0	**35**	**11**
Bostockia porosa, Nightfish	14	2	5	7	1	4	0	2	37	0	**57**	**15**
Pseudogobius olorum, Swan River goby	1	0	1	0	0	0	1	0	16	1	**19**	**1**
Tandanus bostocki, Freshwater cobbler	12	0	0	0	0	0	8	0	0	0	**20**	**0**
Native Crayfish												
Cherax cainii, Smooth marron	0	3	0	0	0	0	0	0	0	0	**0**	**3**
Cherax quinquecarinatus, Gilgie	97	16	54	40	46	4	22	1	17	1	**236**	**62**
Exotic Fish												
Gambusia holbrooki, Eastern gambusia	2	14	112	82	115	40	8	30	364	9	**601**	**727**
Carassius auratus, Goldfish	0	0	3	0	0	0	0	0	0	0	**3**	**0**
Exotic Crayfish												
Cherax destructor, Yabby	0	0	0	0	0	0	12	0	11	1	**23**	**1**
Other												
Chelodina colliei, Southwestern snake-necked turtle	7	0	1	0	1	0	10	0	4	0	**23**	**0**
Palaemonetes australis, South-west glass shrimp	476	407	3171	1508	16152	1737	469	569	266	289	**20534**	**4510**
Grand Total	**623**	**480**	**3428**	**1697**	**16421**	**2929**	**539**	**608**	**778**	**424**	**21789**	**6138**

an extremely broad tolerance of high temperature and low dissolved oxygen. The species was also the dominant introduced species recorded by Klunzinger et al. (2011); with the highest abundances mostly occurring at sites downstream of the Lowlands Nature Reserve. In the current study, the species was most abundant at the Dog Hill gauging station site in the Birrega Drain in November 2019 (Table 5). Goldfish was also present in the current study at the Lowlands track crossing site in November 2019; whereas it was not recorded in 2017 by DWER at the site. It too was recorded by Klunzinger et al. (2011) mostly downstream of the Lowlands forested reach being most abundant at the Dog Hill gauging station site. Importantly, the current study did not detect the invasive Pearl Cichlid (*Geophagus brasiliensis*) and therefore the closure of the upper Birrega Drain connection to the Wungong Brook in 2014 successfully halted the spread of this species into the Serpentine River (Figure 8). This species is now very abundant in the Canning and Swan Rivers, including the estuary.

The native Gilgie was present at all sites on all occasions, being most abundant during the November 2019 sampling. The species has an adaptable life history and is found in all types of freshwater environments in south-western Australia (Beatty et al. 2005a). The Smooth Marron was also observed at the Rapids Rd site in 2019 and was captured there in September 2020 but was absent from other sites (Table 5). Klunzinger et al. (2011) recorded Smooth Marron in very low abundances at all sites surveyed from the Lowlands forested reach downstream to Dog Hill (only a single individual at the latter site, and it was absent from the Serpentine River confluence with Birrega Drain). The sampling by DWER did not record the species from the Lowlands track crossing, however, it was present at two sites located upstream from the Rapids Rd site. Smooth Marron generally favour permanent aquatic habitats with complex structure and require adequate dissolved oxygen; the high water temperatures in summer in Birrega Drain would be unfavourable and possibly lethal for the species (Beatty et al. 2019). Marron abundance is also often locally depleted by legal and illegal fishing (Beatty et al. 2019).

The introduced Yabby was present at both the Birrega Drain sites but was not detected at the three sites in the lower Serpentine River. This is consistent with the survey by Klunzinger et al. (2011), however in 2017 DWER recorded the species at the Lowlands track crossing site and further upstream. The species is known to favour altered habitats such as the drainage canals on the Swan Coastal Plain and has invasive life-history traits, with a high tolerance to temperature variation and low dissolved oxygen (e.g. Beatty et al. 2005). This helps to explain its dominance in the Birrega Drain sites.

The Southwest Snake-necked Turtle was present at all sites surveyed during the 2019 survey being greatest in abundance at the Rapids Rd and Birrega Drain sites; similar to its distribution recorded by Klunzinger et al. (2011). The species is under pressure in urban areas due to the impacts of land clearing around wetlands, as well as predation by introduced species (Santoro et al. 2020).

Figure 8: Stopping the spread of an invasive fish. In 2014, earthworks blocked the connection between the upper Birrega Drain and Wungong Brook to stop the South American Pearl Cichlid from moving from the Canning River catchment to the Serpentine River catchment. Photo: B. McKay

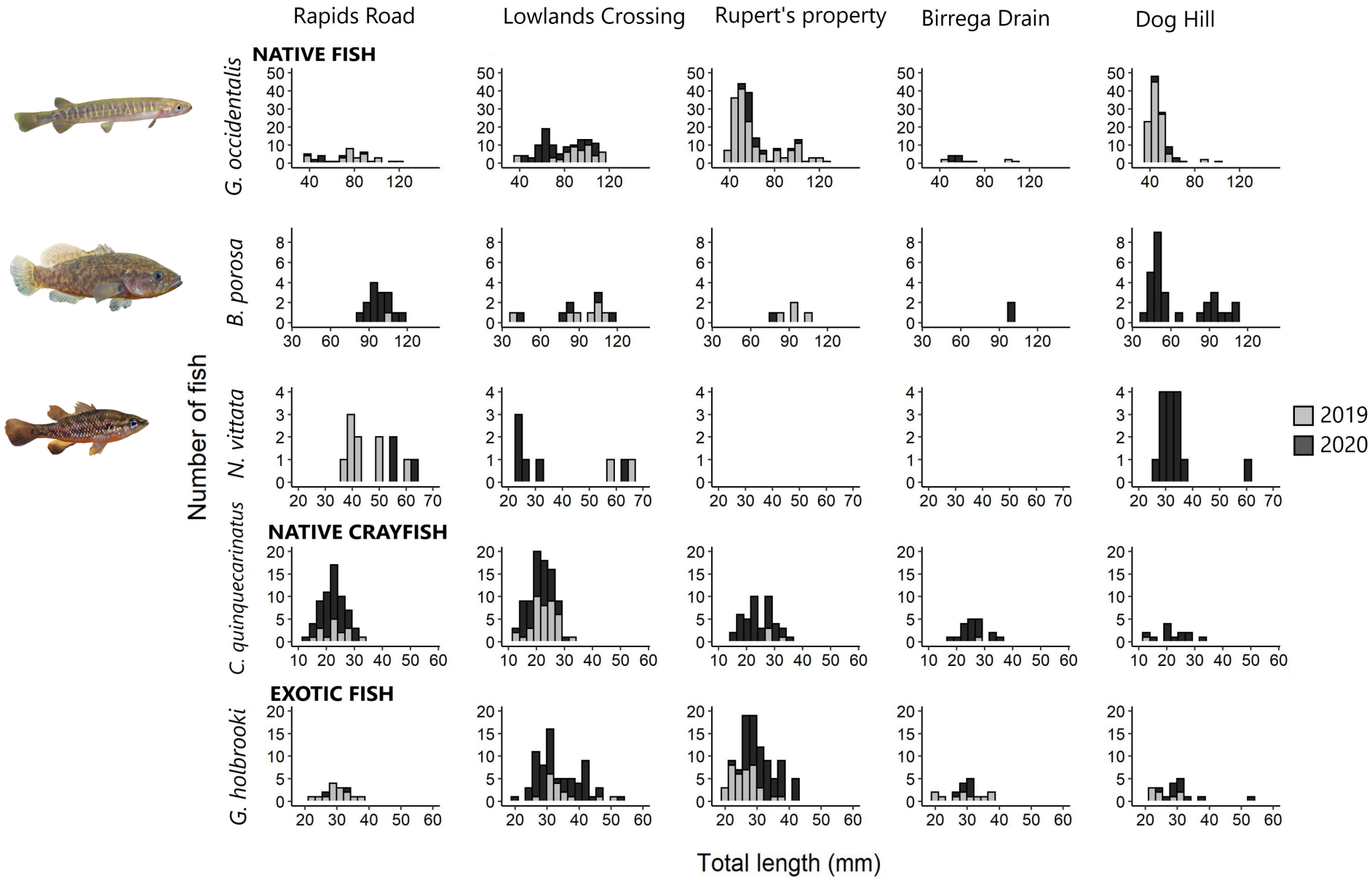

Figure 9: Length-frequency histogramss of commonly captured fish and crayfish in the Serpentine River and Birrega Drain in November 2019 and September 2020.

Carter's Freshwater Mussel

Freshwater mussels are important to aquatic ecosystems and their filter feeding can remove sediment and pollutants from the water (e.g. Caraco et al. 2006). In fact, entire lakes can be filtered by mussel populations in a few days (James et al. 1998). Due to human activities, freshwater mussels are one of the most endangered groups of organisms on the planet (IUCN, 2016). Klunzinger et al. (2015) revealed that secondary salinisation had primarily caused the range of Carter's Freshwater Mussel to have contracted by 49% in less than 50 years. As a result, in 2018 Carter's Freshwater Mussel was listed as Vulnerable under the EPBC Act 1999.

Much of their decline is attributed to an inability to tolerate even small changes in salinity above from what is fresh. Therefore, remnant populations are important from a species conservation perspective, as well as from their environmental services. The species is now confined to non-salinised rivers and streams, principally in forested catchments along the west and south coasts of the region. They are slow-growing and long-lived, with a maximum age of at least 52 years and an age at maturity of 4-6 years. Lymbery et al. (2020) found that they can survive water emersion for up the three months if they are shaded from direct sunlight. This increases the importance of protection and restoring riparian zones as flow continues to decline due to a drying climate.

Carter's Freshwater Mussel was recorded at all five sites sampled although there were significant differences among sites ($p < 0.001$). It was most prevalent at the Rapids Rd site where it was found at a density of 9.65 mussels/m^2 (±0.69 SE), followed by Dog Hill gauging station (6.8/m^2 ±1.03), Lowlands track crossing (1.95/m^2 ±0.19), Birrega Drain (1.8/m^2 ±0.36), with the Serpentine near Birrega site having the lowest density (0.3/m^2 ±0.03). Pairwise comparisons among sites found that all were significantly different in terms of mussel densities aside from Lowlands track crossing and Birrega Drain. The length-frequency histogram indicated that the Carter's Freshwater Mussel population consisted of a broad range of age cohorts (including very old individuals) and thus the species continues to be self-maintaining in the system (Figure 10). The size structure of the species in the current study was broadly similar to that recorded by Klunzinger et al. (2011).

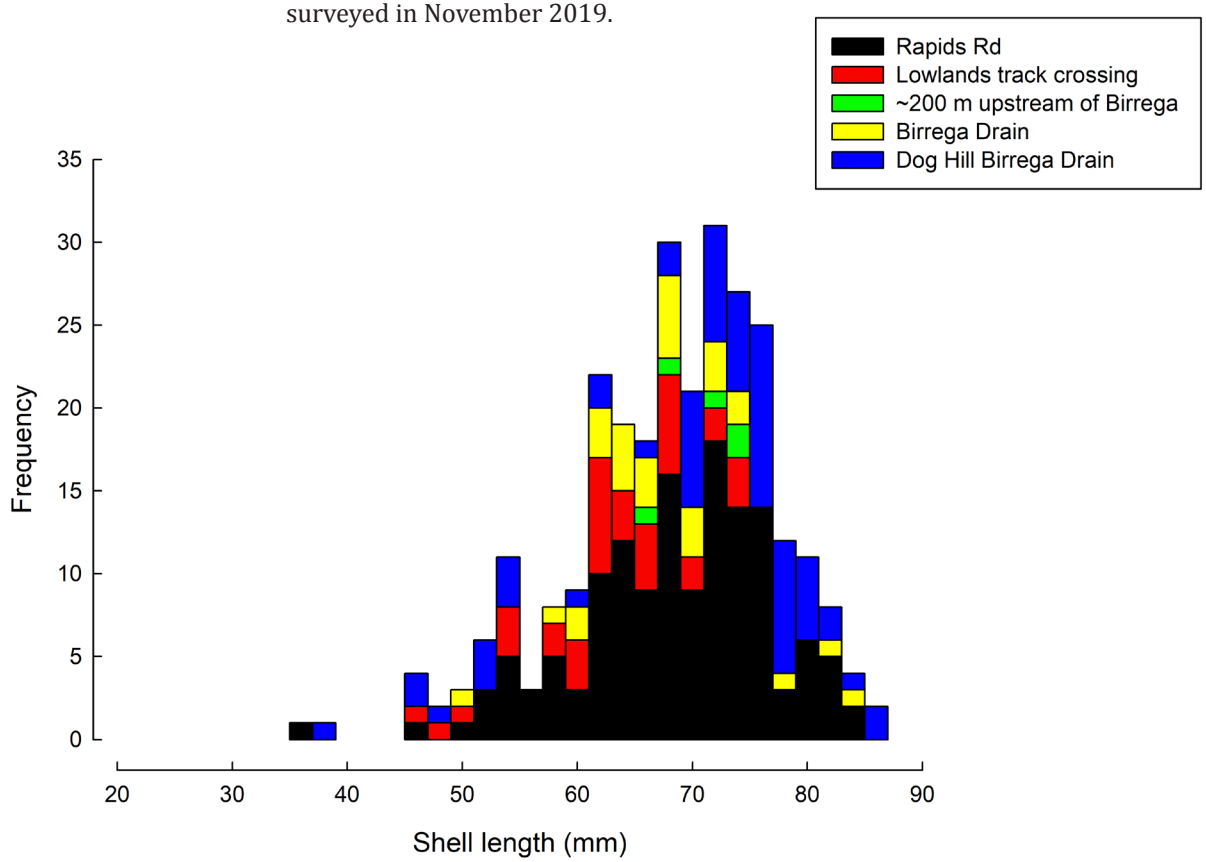

Figure 10: (right) Carter's Freshwater Mussel at the Dog Hill gauging station and (below) length-frequency histogram of Carter's Freshwater Mussel in the sites surveyed in November 2019.

Table 6: Macroinvertebrate log-abundances at the Serpentine River and Birrega Drain sites surveyed in November 2019 and September 2020. N.B. log10 abundances are shown.

	Rapids Rd	Lowlands track crossing	Serpentine near Birrega	Birrega Drain	Dog Hill Gauging Station
Gastropoda					
Ancylidae	1	2		1	1
Lymnaeidae			1	1	
Physidae	1		3	2	3
Planorbidae		1			1
Coleoptera					
Chrysomelidae			1		
Curculionidae	2	1	1	1	1
Dytiscidae	1	1	1	1	
Gyrinidae	2				
Hydraenidae	1				
Hydrochidae	1	1	1	1	1
Hydrophilidae	1			1	
Diptera					
Ceratopogonidae			1		
Chironominae	2	1	4	3	3
Tanypodinae	1		3	3	2
Orthocladinae			3	2	2
Culicidae	1	1	1	2	2
Ephydridae				1	1
Simuliidae	2	1	1		1
Ephemeroptera					
Baetidae	2	1		1	1
Caenidae	1	1		1	1
Hemiptera					
Corixidae			1	1	1
Odonata					
Aeshnidae		1			
Coenagrionidae	1		1	2	
Corduliidae			2		
Trichoptera					
Hydroptilidae	1		1	2	2
Leptoceridae	2		1	1	2
Amphipoda					
Perthidae	2	1	1	1	
Decapoda					
Palaemonidae	4	3	4	4	4
Parastacidae	1	1			
Isopoda					
Amphisopidae				1	1
Cladocera					
Daphniidae			2	1	1
Arhynchobdellida					
Hirudinidae			1	1	1
Oligochaeta					
Naididae		1	2	1	2
Cyclopoida			1	1	
Collembola	2	1			1
Ostracoda					
Cyprididae	1		2	1	2
Arachnida					
Pisauridae	1	1	1	1	1
Tetragnathidae	1	1	1		1
TOTAL RICHNESS	22	16	24	26	23
MEAN (±SE) RICHNESS/SWEEP	10.5 (±2.43)	7 (±1.49)	9.75 (±3.57)	12.5 (±2.77)	10.5 (±3.42)

Macroinvertebrates of the Serpentine River

There was a total of 36 macroinvertebrate taxa (excluding terrestrial fauna) recorded at all sites in November 2019 and September 2020 (Table 6). Total richness per site ranged from 16 (mean per sweep = 7 ±1.49) at the site ~200m upstream from Serpentine to 26 (mean per sweep = 12.5 ±2.77) in the Birrega Drain site. There was no significant difference in the mean richness between November 2019 (mean per sweep = 9.8 ±1.62) and September 2020 (10.3 ±1.61).

More common and abundant taxa included dipterans, particularly at the more downstream sites. Of note was the presence of two of the pollution sensitive EPT Orders (Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)) with two families of Ephemeroptera present at all sites (aside from Serpentine near Birrega Drain) and two Trichoptera families present at all sites aside from the Lowlands Track crossing. The relatively high richness at the two sites in the Birrega Drain along with the presence of all the EPT taxa that were recorded during the study at those sites highlights that the modified systems can still support relatively high value biodiversity in terms of macroinvertebrates compared to less modified reaches.

The AUSRIVAS modelling of observed and expected macroinvertebrates revealed the Serpentine River near Birrega site had the highest OE50 score indicating the least biological impairment in terms of macroinvertebrate communities. However, when considering the observed and expected ratios weighted for sensitivity of taxa to pollution (Signal), all sites scored evenly (Table 7). The final AUSRIVAS condition bands for the sites were within B or C (significantly or severely impaired).

Table 7: Outputs from the AUSRIVAS macroinvertebrate predicted modelling (W.A. spring channel model). N.B. NTE50=sum of the probabilities of all the families predicted with >50% change of occurrence, NTP50=count of number of families predicted with >50% probability of occurrence, NTC50=number of families that were predicted (above probability of 50%) that were also collected, OE50= observed to expected ratio (i.e. NTC50/NTE50), E50Signal=expected signal score for taxa having probability of occurrence >50%, O50Signal=average signal score for observed taxa that had a probability of occurrence >50%, OE50=observed to expected signal ratio (i.e. O50Signal/E50Signal), E0Signal=same as E50Signal but all taxa with probability >0% included in calculation, O0Signal=average signal score for all observed taxa, OE0Signal=observed to expected Signal ratio (i.e. O0Signal/E0Signal).

Site	NTE50	NTP50	NTC50	OE50		E50Signal	O50Signal	OE50Signal	E0Signal	O0Signal	OE0Signal	Band
Rapids	10.97	13	6	0.55		4.7	4	0.85	4.56	3.33	0.73	B
Lowlands	10.97	13	4	0.36		4.7	3.5	0.74	4.56	3.38	0.74	C
200m US Birrega	10.93	13	8	0.73		4.68	4	0.85	4.53	3.38	0.75	B
Birrega	12.67	16	7	0.55		4.54	3.86	0.85	4.42	3.19	0.72	B
Lowlands	12.57	16	6	0.48		4.57	4.33	0.95	4.47	3.26	0.73	C

Sample Site Summaries

Rapids Road

Habitat

The Rapids Rd site had a relatively natural channel morphology with a variety of habitat types present but was dominated by runs in both November 2019 and September 2020 (Figure 11). Bank full width was up to 30 m and maximum channel depth (to the top of the bank) being ~5 m. Mean channel width during both sampling events was ~5-6 m with maximum depth ranging from ~1.5-2 m with the average water depth in November 2019 and September 2020 being ~0.3 and 0.5 m, respectively. There was a range of instream structure including a variety of complex woody debris with the substrate ranging from silt through to bedrock and boulders. There were considerable zones of erosion on both banks (20-49% of each bank showing signs of erosion) reflected in a relatively low SWIRC score for erosion (0.33, see page 29). Longitudinal connectivity within the site was adequate for fish passage at the times of sampling. However, there was a cascade riffle zone upstream of the site with a maximum vertical fall of ~0.1 m that could restrict movements of the larger bodied Freshwater Cobbler.

Riparian zone was fenced off from surrounding agriculture and the riparian vegetation consisted of a largely exotic understory species such as kikuyu (reflected in the low (i.e., 0.1) SWIRC riparian nativeness score, which is based on proportion of native groundcover). However, there were a range of native shrubs and trees present and evidence of ongoing recruitment of those native species. Stream shading was considerable throughout most of the site due to the presence of large (>10m height) native trees (10-50% coverage on each bank) and shrubs. Potential sources of pollution at the site was from non-point sources from surrounding agricultural land.

Water quality

The water quality at the site measured in both November 2019 and September 2020 was generally good with SWIRC scores >0.8 for all metrics (see page 29). The site recorded the lowest TN and TP and diurnal fluctuations in temperature was relatively low with dissolved oxygen also being maintained levels >4.8mg/L at the times of sampling.

Aquatic macrofauna

Rapids Rd site had the greatest diversity of native freshwater fishes (four species) including the Western Minnow, Western Pygmy Perch, Nightfish and the Freshwater Cobbler and the site had high the highest overall SWIRC scores Fish/Crayfish (i.e. >0.77). There was evidence of multiple age/size cohorts for all native freshwater species including numerous older Nightfish and Western Pygmy Perch. However, the presence of 0+ fish (recent recruitment) was only evident for Western Minnows. Freshwater Cobbler, Nightfish and Western Pygmy Perch consisted of mature adult fish. While we did not detect recent recruitment of the latter species, additional sampling effort would likely have detected the species given the relatively diverse instream habitat and high SWIRC scores for the water quality theme. The site also housed a self-maintaining population of the native Gilgie, with very low abundances of Smooth Marron also present. It is likely that Smooth Marron are self-maintaining in the reach but the high level of public accessibility to the site has resulted in a high level of legal and illegal fishing for the species (anecdotal report from local landholder, pers. comm., September 2020). The Eastern Gambusia was also present at the site but in the lowest abundance of all sites sampled. This was expected given the reach had diverse instream habitat complexity, and stable temperature profile that would favour native species over this highly invasive species. There was an abundance of South-west Glass Shrimp and both juveniles and small adults of the Southwest snaked-necked turtles were recorded at the site.

Figure 11: Rapids Rd site in November 2019 (top) and September 2020 (bottom). N.B. the elevated water levels in the latter sampling event (~0.2 m rise).

South West Index of River Condition

South West Index of River Condition scores in November 2019 and September 2020. N.B. Also presented are the DWER scores for two relevant reaches with 6141902 containing all of the 2019 and 2020 sites, with Dog Hill site being at the juncture of 6141902 and 6141985.

	November 2019					September 2020					DWER 2005	
	Rapids	Lowlands Crossing	200 m Upstream of Birrega Drain	Birrega Drain	Dog Hill (Birrega Drain)	Rapids	Lowlands Crossing	200 m Upstream of Birrega Drain	Birrega Drain	Dog Hill (Birrega Drain)	REACH 6141902	REACH 6141985
WQI theme score	0.8	0.73	0.8	0.8	0.65	0.85	0.87	0.85	0.73	0.8		
TN score	1	1	1	1	1	1	1	1	0.8	0.8	1	
TP score	0.8	0.6	0.6	0.6	0.6	0.8	0.8	0.8	0.6	0.6	0.6	
Turbidity score	0.8	0.6	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1	0.8	
Temperature score	0.8		0.8		0.2	0.8		0.8		0.8		
Mean (TN, TP, Turb & Temp)	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.9		
Salinity score	1	1	1	1	1	1	1	1	1	1	1	1
DO score	0.8	0.6				0.93		0.94		0.95		
PFI theme score												
Artificial channel	1	1	1	0	0	1	1	1	0	0	1	1
Longitudinal Connectivity *												
Erosion	0.33	0.60	0.25	0.60	0.46	0.33	0.60	0.25	0.60	0.46		
FZI theme score*											0.6	0.7
Fringing zone length score*											0.6	0.7
Fringing zone width score*											0.7	0.8
Nativeness score	0.1	0.8	0.1	0.1	0.2							
Fish and crayfish score	0.89	0.67	0.58	0.67	0.66	0.77	0.63	0.67	0.50	0.63		
Expectedness	0.86	0.71	0.50	0.67	0.83	0.71	0.57	0.50	0.50	0.50		
Nativeness	0.92	0.63	0.66	0.67	0.49	0.82	0.68	0.84	0.49	0.76		

Figure 12: Freshwater Cobbler (top) and Western Minnow (bottom) being measured at the Rapids Rd site in November 2019.

Lowlands track crossing

Habitat

The Lowlands track crossing site was the least disturbed site in terms of channel morphology with riffles, pools and runs present during the November 2019 sampling. Water levels were higher in the November 2019 compared with September 2020 (i.e., gauging station reading was 0.16m in November 2019 compared with 0.33m during the September 2020 sampling), which resulted in the conversion of the riffle zone into a run habitat at the track crossing in the latter sampling year. Bank full width was a maximum of 25m with the mean channel width ~5-6 m during the sampling events. Maximum depth was ~1.2-1.4m for the two sampling occasions with the average water depth ~0.4-0.6m in November 2019 and September 2020, respectively. Instream habitat was quite complex with a variety of sizes of woody debris and considerable stands of emergent macrophytes (including *Lepidospermum* sp. and *Juncas* sp.) (Figure 13). Substrate consisted of a range of sized particles from clay up to cobble size. Despite the relatively intact riparian zone, there was evidence of some bank erosion particularly on the left bank although both are now fenced from stock access (erosion SWIRC score 0.6).

Riparian vegetation the most intact of any site being located in the forested Bush Forever reach and there was evidence of revegetation having occurred adjacent to the right bank. It scored the greatest SWIRC score for nativeness in groundcover of the fringing zone (i.e., 75-100% natives, SWIRC score = 0.8 with all other sites ≤0.2). A range of native shrubs and trees were also present and moderate levels of healthy recruitment was occurring; with the native vegetation providing a high level of shading to the streamline.

Water quality

The water quality theme score at the Lowlands track crossing site measured in November 2019 and September 2020 was 0.73 and 0.87, respectively. Temperature and DO was based on spot measurements at the times of sampling, however, the site would have expected to score highly based on 24 hr logged data.

Aquatic macrofauna

Lowlands track crossing housed Western Minnows, Western Pygmy Perch and Nightfish. While evidence of new recruits (0+ individuals) were present for all three of these freshwater native species, the latter two were in relatively low abundances. However, the site housed larger cohorts of Nightfish and Western Pygmy Perch (three individuals >58 mm TL), which indicates that it is suitable for maintaining these species. The fish/crayfish SWIRC score for the site was slightly less than Rapids Rd due to the absence of Freshwater Cobbler, and relatively low abundance of the native species relative to the Eastern Gambusia. The absence of Freshwater Cobbler at the site (also not detected by DWER in 2017 sampling) requires further investigation with Klunzinger et al. (2011) recording very low abundances of the species at a site upstream between this site and Rapids Rd. The native Gilgie was also self-maintaining with the Smooth Marron not being detected during this study, or the assessments by DWER in 2017, but was recorded in very low abundances (three individuals) by Klunzinger et al. (2011). A very high abundance of South-west Glass Shrimp was recorded. A single South-western snaked-necked turtle was recorded at the site in November 2019.

Figure 13: Lowlands track crossing site in September 2020. N.B. the extensive aquatic macrophyte growth at the downstream section of the site.

Serpentine River near Birrega Drain

Habitat

The site is situated ~200 m upstream from the confluence of Birrega Drain and had a variety of habitat types but was dominated by runs and pools (Figure 14). It also had artificial instream barriers both upstream and downstream of the surveyed reach. Water depths were moderately varied with a maximum depth of >2m and average depths in November 2019 and September 2020 were ~0.4m and 0.6m, respectively. There was a variety of instream structure including a moderate abundance of varied sizes of large woody debris with the substrate ranging from bedrock through to silt. There was a relatively high level of erosion on the banks with the site having the lowest SWIRC score for that sub-theme of any site (i.e. 0.25, see page 29).

There was considerable evidence of impact to the riparian zone from the bushfire that swept through the Richardson property and Birrega Drain sites in January 2020 (Figure 15). This included a burnt mid-story and also the deposition of ash around the riparian zone. There was evidence of regrowth in the overstory and the ground cover that consisted of mostly introduced species had regenerated (Figure 15).

While the site was connected, there was a barrier just upstream of the site that was blasted coffee rock (Rupert Richardson, pers. comm.) that would pose a potential barrier for some fishes (Figure 16). The barrier had a maximum vertical and horizontal drop of up to 30 cm during the sampling periods; however, during peak flow events would likely drown out and enable passage of all species. The barrier just downstream from the site was much more substantial and during the November 2019 sampling the water flowed through the rocks that would create a potential barrier during low-moderate flows (Figure 17). During high flows, the ~1m m vertical drop across the ~10m horizontal structure may prevent the passage of most species; apart from Western Minnows. The potential for fish passage over the structure should be properly assessed by undertaking a targeted fish passage survey across a variety of flows.

Water quality

Water quality at the site was generally high across both survey events with an overall SWIRC WQI score of 0.8 and 0.85 for the November 2019 and Sept 2020 events, respectively. There was no evidence that the potential inflow of ash from the bushfire in January 2019 was impacting dissolved oxygen the site having a SWIRC DO score of 0.94 in September 2020. However, it is unknown as to how the first input of ash into the system that likely occurred in in early winter may have temporarily impacted water quality.

Aquatic macrofauna

The site housed high abundance of Western Minnows (the greatest abundance of all sites) including a very high abundance of juveniles in September 2020. The Nightfish was also present in very low abundance with multiple sizes present. However, the Western Pygmy Perch was not recorded from the site. Kluinzger et al. (2011) recorded small numbers of Western Pygmy Perch at sites in the lower Serpentine River both upstream and downstream from the site. Its absence during the current study warrants further investigation; particularly as to the potential impact of the barriers in the reach. Gilgies were prevalent at the site and it also had a high abundance of South-west Glass Shrimp. A single Southwest Snake-necked turtle was recorded.

There was little evidence that the bushfire that moved through in January 2020 had impacted the macrofauna although there was a reduction in the abundance of Gilgies recorded between the survey periods. Bushfire has previously been shown to have major, medium term impacts on freshwater fish abundances in eastern Australia due to sediment slug input (Lyon and O'Connor, 2008), however, the impact of bushfire on south-western Australian fishes remains a major knowledge gap.

Figure 14: Serpentine River near Birrega site in November 2019 (top) and September 2020 (bottom). N.B. the elevated water levels in the latter sampling event

Figure 15: Evidence (in September 2020) of the bushfire that passed through the Serpentine River region near Birrega (and adjacent properties) in January 2020. N.B. The regrowth occurring in the canopy (top) and the layer of ash persisting in the riparian zone (bottom).

Figure 16: The instream barrier at the upstream end of the Serpentine River near the Birrega site in November 2019 (top) and September 2020 (bottom). N.B. The barrier was assessed as likely to impede upstream movement of some native fishes.

Figure 17: The instream barrier at the downstream end of the Serpentine River near Birrega site in November 2019 (top) and September 2020 (bottom). N.B. the barrier was assessed as likely to be a barrier to most native fishes.

Figure 18: A cattle crossing restricting livestock from accessing the riparian zone.

Birrega Drain

Habitat

The Birrega Drain site is located between the confluence of the lower Serpentine River and Hymus Swamp that flows into Birrega Drain from the east. It was the site with the least natural stream morphology being effectively a uniform drain with a lack of riffles or variable water depth (Figure 19). Bank full width was a maximum of ~45m with the mean channel width ~5-6 m during the sampling events. Maximum depth was ~1.0-1.2m for the two sampling occasions with the average water depth ~0.5-0.7m in November 2019 and September 2020, respectively. Instream habitat was devoid of complex woody debris or rocks. Despite the heavily modified riparian zone, evidence for erosion was only moderate (SWIRC score of 0.6); one ephemeral tributary entering the site from the adjacent property having a sand slug associated with it (Figure 20). This should be fenced and revegetated to mitigate the effects of nutrient and sediment input from the property.

Riparian vegetation was largely devoid of native species aside from small numbers of trees and shrubs. Introduced groundcover species dominated (SWIRC score for nativeness was 0.1) and included grasses draped into the water. Substrate was dominated by clay. It scored the greatest SWIRC score for nativeness in ground-cover of the fringing zone (i.e., 75-100% natives, SWIRC score = 0.8 with all other sites ≤0.2). A range of native shrubs and trees were also present and moderate levels of healthy recruitment was occurring; with the native vegetation providing a high level of shading to the streamline. There was evidence of the January 2020 bushfire in the few native shrubs and trees present although the introduced groundcover dominated by *Watsonia* and kikuyu had regenerated.

Water quality

The water quality theme score at the Birrega Drain site measured in November 2019 and September 2020 were 0.80 and 0.73, respectively. However, temperature and DO was based on spot measurements at the times of sampling, and diel temperature fluctuation would be expected to be substantial; particularly during summer.

Aquatic macrofauna

The Birrega Drain site housed low numbers of native freshwater fishes including the Western Minnow, Nightfish and Freshwater Cobbler being recorded in very low abundances. A single Swan River Goby was also recorded. There was some evidence for the recruitment of juvenile Western Minnows at the site. The site recorded the lowest fish/crayfish SWIRC score during September 2020 (i.e. 0.50). The native Gilgie was present and self-maintaining with the introduced Yabby being recorded in November 2019. As mentioned, the Yabby is known to favour altered drain habitat sites in this region. A moderate abundance of South-west Glass Shrimp were along with both adult and juvenile South-western snaked-necked turtles in November 2019.

Figure 19: Birrega Drain site in November 2019 (top) and September 2020 (bottom). N.B. the burnt Melaleucas in September 2020 resulting from the bushfire in January 2020.

Figure 20: The ephemeral drainage line entering the Birrega Drain site. Top photo is looking upstream along the bank of Birrega Drain (note the erosion from the drainage line in foreground). Bottom photo is taken from the same spot looking upstream along the drainage line in September 2020.

Dog Hill Gauging Station

Habitat

The habitats at the Dog Hill gauging station (study reach located immediately downstream of the gauging station weir) was quite varied compared to many drain sites in the region. For example, it contained riffle, run and pool habitats with areas of low and high water velocity (Figure 21). Bank full width was ~60 m with the average depths being ~0.25 and ~0.5 m (maximum ~1.0 and 1.3m) in November 2019 and September 2020, respectively. There was sparse large woody debris present with a range of rocky habitats along with sand and silt banks. Evidence for erosion was moderate (SWIRC sub theme score was 0.46). The presence of the gauging station weir would represent a barrier to fish movement during low-moderate flows with the structure representing a 0.25m vertical drop along with a 3 m horizontal weir passage of laminar flows (Figure 22). Velocities across the weir at the time of sampling in November 2019 being ~0.5m/sec ranging up to 1.4m/sec in September 2020. While the weir would drown-out during peak flows, it would represent a barrier to all species for the majority of the year aside from the Western Minnow that has the greatest known swimming and jumping ability.

Riparian zone had a range of remnant trees and shrubs (more so than the other Birrega drain site) although the represented a relatively low overall percentage of coverage. The groundcover had a high percentage (50-74%) of exotic species which resulted in a low nativeness SWIRC sub-theme score (i.e. 0.2). There was a small degree of stream shading at the site. Evidence from the January 2020 bushfire was again present via the burnt mid-story with the introduced groundcover having fully regenerated.

Water quality

The site had the lowest SWIRC water quality score in November 2019 (i.e., 0.65) owing to considerable fluctuation in diel water temperatures (Temperature score being 0.2 at that time, See page 29). It would be expected that this would become more extreme in summer due to the low degree of shading present both here but particularly at more upstream sites in the Birrega Drain. However, the greater diversity of instream habitat, including some deeper pools, may also afford aquatic fauna access to thermal refuges during the summer compared with the site further upstream in the Birrega Drain. The importance of the presence of a range of habitat types, particularly deeper habitats (>1m during summer), was also highlighted during the recent ecological assessments undertaken in the Harvey River (Beatty et al. 2019). There was no evidence of potential impact of ash input from the January 2020 bushfire on dissolved oxygen at the site in September 2020 having a SWIRC sub-them score of 0.95 (See page 29).

Aquatic macrofauna

The Dog Hill site housed self-maintaining populations of Western Minnows, Nightfish and Western Pygmy Perch. A high proportion of younger cohorts of both the Western Minnow and Western Pygmy Perch were present along with a wide range of age cohorts of Nightfish. The site thus represents an example of a drain site that is broadly maintaining the ecological integrity in terms of small-bodied native freshwater fishes. Eastern Gambusia were present in high abundances in November 2019 and it would be expected to increase greatly in numbers throughout summer. Gilgies were present in relatively low abundance but a range of size cohorts were present. The introduced Yabby was present at the site and as mentioned, does particularly well in drainage habitats. South-west Glass Shrimp were also present along with low numbers of adult and juvenile Southwestern Snaked-necked Turtles. Of note, was the observation of a mature Southwestern Snake-necked Turtle passing upstream over the weir in September 2020.

Figure 21: Dog Hill gauging station site (in Birrega Drain) in November 2019 (top) and September 2020 (bottom). N.B. The relatively diversity instream habitats compared with the Birrega Drain site further upstream.

Figure 22: The Dog Hill gauging station in November 2019 (top) and September 2020 (bottom). N.B. The barrier was assessed as an impediment to the movement of most fish species (apart from Western Minnows) for all times of the year aside from when the weir would inundate during high flow events.

Conclusions and Recommendations

The results revealed that all five sites surveyed continue to support native fish populations with varying abundances and apparent recruitment rates. Overall, the Rapids Rd site had the highest diversity and abundance of native fishes, the Dog Hill gauging station site also housed four of the five species (and the greatest overall native fish abundance), which was much higher than the other Birrega Drain site upstream. This was likely due to the habitat downstream of the Dog Hill gauging station being relatively complex including pool and riffle habitats with emergent riparian vegetation.

Predictably, the alien Eastern Gambusia dominated overall fish captures and the native Gilgie became more abundance at upstream sites. The Yabby was also only present in the Birrega Drain sites. Importantly, the highly invasive Pearl Cichlid was not detected during the study. This is a major positive result and suggests that the emergency closure of the connection to Wungong River (i.e. Swan-Canning catchment) that occurred in September 2014 was successful in preventing its colonisation of the Peel-Harvey catchments; which would have likely caused considerable ecological change (including potentially in the Peel-Harvey Estuary) given its invasive life history traits, high salinity tolerance and omnivorous diet (Beatty et al. 2013b).

The major bushfires that occurred in early January 2020 that burnt through the Dog Hill Gauging Station site, Birrega Drain and parts of the Serpentine River property site noticeably impacted the riparian zone burning to the mid-storey (which included to the tops of *Melaleuca*) but not to the canopy of the overstorey (i.e. the crowns of larger *E. rudis* remained unburnt). Ash was visible in the riparian zone and the understorey, mostly introduced species, had largely regenerated. However, any impact that the fire may have had on the water quality or native biota was not evidenced during the September 2020 sampling; although it may have had a temporary impact on dissolved oxygen during the early winter rains in 2020.

Future instream and riparian restoration works to create reaches more similar to the Dog Hill gauging station site should occur within the Birrega Drain to increase the aquatic diversity by creating more complex habitat. Moreover, the lower sections of drainage lines from paddocks on the Serpentine River near Birrega could also be fenced and restored to prevent erosion and mobilisation of sediments and nutrients.

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