Marron, More than a Meal
Harvey River restoration, Western Australia

A project funded by :

Alcoa Foundation

Greening Australia

GOVERNMENT OF WESTERN AUSTRALIA

Department of Primary Industries and Regional Development

PHCC Working Together

Peel-Harvey Catchment Council

Suggested citation:
Beatty, S.J, Watsham, J., Emery-Butcher, H. & Morgan, D.L. (2019). Marron, more than a meal. Harvey River restoration, Western Australia. Freshwater Fish Goup & Fish Health Unit, Harry Butler Institute, Murdoch University, Murdoch, WA.

Published by: Freshwater Fish Group & Fish Health Unit, Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute, Murdoch University
Design & Graphics: David Morgan

Email: fish@murdoch.edu.au

Harry Butler Institute
MURDOCH UNIVERSITY

Murdoch UNIVERSITY

Freshwater Fish Group &
Fish Health Unit

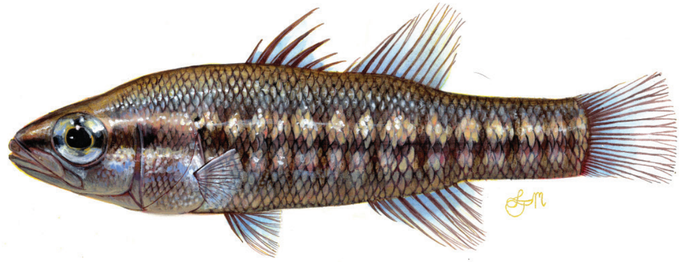
Marron - More than a Meal

Harvey River restoration, Western Australia

The Southwestern Province has the highest proportion of endemic fishes and crayfishes on the continent, and as a globally recognosed endemic hospot. Over the last few decades, there has been a growing body of evidence that has suggested that the inland aquatic fauna of the Southwestern Province of Western Australia is declining. Much of this decline has been driven by large scale modification to habitat quality and quantity. The loss of suitable habitats through stream channelisation, river regulation, land clearing, flood abatement and the impact of introduced species, has resulted in large-scale losses of aquatic fauna. This, coupled with the increasing impact of climate change driven reductions in rainfall and subsequent run-off and aquifer recharge continue to challenge the aquatic fauna and necessitates adaptive manangement to help with their conservation.

Since the turn of the Century, five of the region's freshwater fish species, four freshwater crayfish species and the sole species of freshwater mussel have been listed as threatened under the Federal Government's Environment and Biodiversity Conservation Act (EPBC Act 1999). Other species are variously listed under State legislation. Surprisingly, in 2013, the significant discovery of a previously undetected fish species was made, and since that time, several other species have been discovered in the region, but await formal description.

The Marron (*Cherax cainii*) is recognised as a south-western Australian aquatic icon, not only for the important and unique recreational fishery that it supports, but also for its aquaculture potential and the sheer size to which it attains; while also being considered a delicacy and a biological indicator of ecosystem health. The Marron, More than a Meal Project aims to demonstrate how the restoration of drainage channels can lead to an improvement of the aquatic ecosystems.



Harry Butler Institute
MURDOCH UNIVERSITY

Freshwater Fish Group & Fish Health Unit

PHCC Working Together
Peel-Harvey Catchment Council

Department of Primary Industries and Regional Development
GOVERNMENT OF WESTERN AUSTRALIA

Greening Australia

Alcoa Foundation

HARVEY RIVER RESTORATION TASKFORCE INC.

Marron - More than a Meal,

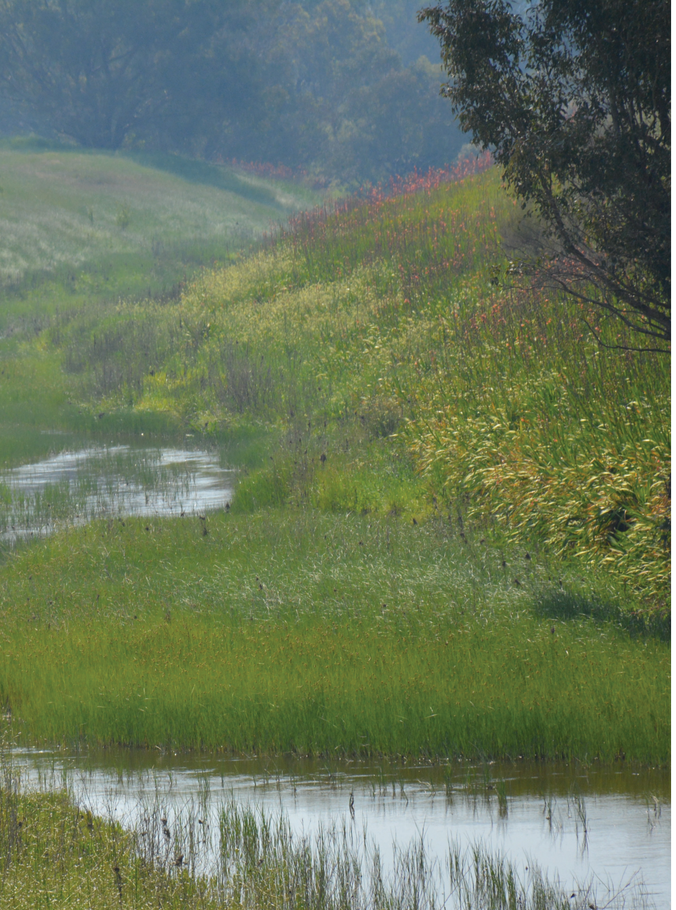
Harvey River restoration, Western Australia:

A summary of the crayfish and fish of the Harvey River and the restoration of the river for the iconic Marron

marron, more than a meal
REVIVE OUR RIVERS

Project Proponents

Freshwater Fish Group & Fish Health Unit, Centre for Fish & Fisheries Research, Harry Butler Institute, Murdoch University, Murdoch, WA 6150, Australia
Harvey River Restoration Taskforce, Waroona, WA 6125, Australia
Greening Australia, Shenton Park, WA 6008, Australia



Foreword

The south-west of Western Australia has the highest proportion of endemic freshwater fishes in the continent, with over 80% found nowhere else, while there is 100% endemicity within the freshwater crayfishes; the most iconic of which is the Marron (*Cherax cainii*).

Marron, which is the third largest of all the species of freshwater crayfish, supports a unique recreational fishing industry in south-western Australia. It also is the subject of a boutique aquaculture industry, whose potential is still to be unlocked. At the same time, the species is declining from many of its natural habitats, due to many anthropogenic changes in habitat quality and quantity. It is considered an excellent bioidicator of river health.

The need to conserve this unique species has driven this project, with the longterm goal of improving habitat suitability for it as a flagship species; with other aquaitc species that are unique to the region being similarly afforded better habitats in the process. Based on newly established and existing collaborations between researchers, managers and the community, this project has provided exciting new information and knowledge relating to the distribution and ecology of aquatic fauna in the lower Harvey River, and has identified key findings that, if implelemted may provide a longterm solution to the restoration of the river which will simulataneously future proof the aquatic fauna.

Stephen Beatty and David Morgan

Freshwater Fish Group & Fish Health Unit, Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute, Murdoch University

Harry Butler Institute
MURDOCH UNIVERSITY

Harvey River Restoration Taskforce

The Marron More than a Meal program within the Harvey River Restoration Trust main aim is to communicate to a diverse audience the importance of, and benefits derived from, improving waterway and wetland habitats within the Harvey River catchment.

Our Vision: The waterways and wetlands of the Harvey River catchment are revitalised and thriving, supporting healthy communities and productive landscapes.

We have three focus areas with associated long-term goals:

Catchment Resilience - Improve long-term reilience and area protected of waterway and wetland habitat within the Harvey River catchment.

Practice Change - Increase stakeholder adoption of best practice waterway and wetland habitat within the Harvey River catchment.

Community Connection - Maintain a 'sense of place' to enhance, and connect community with, the waterways of the Harvey River catchment.

Jennifer Stringerd

Community Chairperson, Harvey River Restoration Taskforce

HARVEY RIVER RESTORATION TASKFORCE INC.

Project Participants

Stephen Beatty (Murdoch University)
David Morgan (Murdoch University)
Jake Watsham (Murdoch University)
Holly Emery-Butcher (Murdoch University)
Jane Townsend (Harvey River Restoration Taskforce)
Christine Allen (Greening Australia)
Alcoa Foundation
Department of Primary Industries and Regional Development
Peel Harvey Catchment Council

Acknowledgements

This project was jointly supported by Greening Australia through funding from the Alcoa Foundation, and the Peel Harvey Catchment Council Inc., though funding from the Royalties for Regions, Regional Community Services Fund. Field days were attended by members of the wider community including members from the Shires of Murray, Harvey and Waroona, and students from the Waroona District High School Bushrangers Program, managed by science teacher Fiona Brown. Thanks are also extended to Clive Piggott from the Water Corporation and Vita Summers (Murdoch University).

Alcoa Foundation

Greening Australia

GOVERNMENT OF WESTERN AUSTRALIA
Department of Primary Industries and Regional Development

PHCC Working Together
Peel-Harvey Catchment Council

marron, more than a meal
REVIVE OUR RIVERS

HARVEY RIVER RESTORATION TASKFORCE INC.

Murdoch University

Freshwater Fish Group & Fish Health Unit

Harry Butler Institute
MURDOCH UNIVERSITY

Fishes and crayfishes of the Southwestern Province

The Southwestern Province of Australia encompasses all of the inland water bodies between the Arrowsmith River (south of Dongara) and the Thomas River (to the east of Esperance). It is one of Western Australia's five ichthyological provinces and is one of the most unique on the continent. Over 80% of the freshwater fish species and 100% of the freshwater crayfishes in this region are found nowhere else in the world, and the fauna includes some species of global significance.

The most recognisable of all of the region's aquatic freshwater species is the Marron, a species that is highly prized by recreational fishers, and one that is identifiable to all local inhabitants of the south-west. The species also supports a boutique aquaculture industry and is cultured in many private dams for its quality flesh.

The Salamanderfish, being one of the world's most unusual fishes and the sole representative of an early divergent lineage within teleost evolution, has a mean age of divergence at over 20 million years. Recent studies have also suggested that Freshwater Cobbler, the largest native freshwater fish in the south-west, has been incorrectly placed in the genus *Tandanus*, and actually represents an undescribed genus which is one of the earliest branching lineages of the freshwater eel-tailed catfishes. These two species represent unusual and ancient lineages that have persisted in the Southwestern Province and represent legacies in the evolution of Australia's unique freshwater fauna (see Unmack 2013; Morgan et al. 2014).

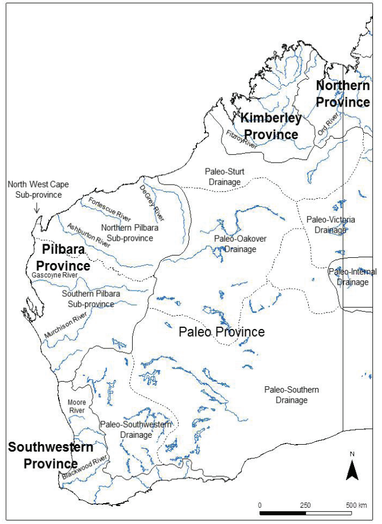
Most of the other species in the Southwestern Province have very old relationships with the eastern Australian fauna that were severed following the formation of the Nullarbor Plain and through increasing aridity of the continent. These include seven endemic species of the Percichthyidae (including *Bostockia* and *Nannatherina*), some of which represent undescribed species, as well as five species of the Galaxiidae, three of which are endemic to the region.

Unfortunately, a number of these species are now threatened and populations are declining in both abundance and distribution, principally due to declining water quality (including secondary salinisation), loss of habitat (large scale land clearing and dewatering), water extraction, river regulation and threats from introduced species. More recently, climate change has become a significant threat to the aquatic fauna of south-west Western Australia with significant declines in rainfall, surface flow and fresh groundwater occuring across the region since the mid-1970s.

The need for conservation

While there has been an increase in our understanding of the ecology and threats faced by this unique fauna, critical knowledge gaps remain. This has hampered the development and implementation of management strategies to conserve and protect these important populations and the habitats critical for their survival.

In 2018, the Marron, More than a Meal project was developed to direct much needed baseline information into the highly modified habitats of the lower Harvey River; using the Marron as a flagship approach to the determine and ultimately direct rehabilitation efforts. Much rehabilitation has occurred in the area by passionate NRM groups, and researchers have identified a number of species that have the potential to be biological indicators of ecosystem health and change as rehabilitation efforts increase over time.



The ichthyological provinces of Western Australia (after Unmack 2013 and Morgan et al. 2014)

The presence or persistance of species such as Marron, Freshwater Cobbler, Freshwater Mussels and other fishes and crayfishes are key species that allow us to gain an insight into the ecosystem function, and how it can be better rehabiliated.

The Western Minnow (*Galaxias occidentalis*) is one of five species of galaxiids found in south-western Australia. It is most easily recognised by the distinct barred patterning on its sides. It is common from the Arrowsmith River south of Dongara, to the Waychinnicup River east of Albany (Photograph: Mark Allen)

Major aims

This study was designed to assess the baseline cological condition of reference sites on the lower Harvey River, much of which now consists of a network of drainage channels that support only remnant pockets of riparian vegetation. Such vegatation not only provides shade and thus buffers the waters from high temperatures, but falling debri and branches provide shelter and three-dimensional structures which are critical for some species. By assessing the aquatic fauna at a selected number of sites, we are able to provide an insight into the species present and their population demographics. One rehabilitated site was chosen to compare the fauna with the unrehabilitated reference sites that were characteristically shallow and lacked instream habitat or riparian vegetation. This information will guide the development and prioritisation of rehabilitation, restoration and ecosystem management projects to protect, maintain or improve river habitats for Marron, and other species, including fishes.

A complementary aim was to engage the wider community in the aquatic surveys, in an effort to increase the awareness of the aquatic fauna.

The study area and design

The fieldwork component of this study surveyed aquatic fauna across four reference sites and one rehabilitated site in the lower Harvey River (see Study sites). Each reference site also had a paired control site where species denisty and macroinvertebrates were also assessed. This will enable a before/after control impact (BACI) assessment of changes in ecological condition following future restoration of the reference sites.

Sampling for fish movements and relative abundance involved the use of dual fyke-netting set overnight at upstream and downstream points at each site.

Box-traps and crayfish opera traps were installed between the two fyke nets to sample fish and crayfish.

In order to estimate fish and crayfish densities, replicate back-pack electrofishing was employed at each site. All fish and crayfish captured were identified, enumerated, and a sub-sample measured to provide an 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 involved the use of an invertebrate sweep at each site (two minute duration) undertaken using a long-handled macroinvertebrate net (250µm mesh) across conspicuous aquatic habitat types at each site. These samples were immediately preserved in ethanol for identification in the laboratory. All macroinvertebrate samples were examined under a dissecting microscope and identified to family level.

Habitat and water quality data collection included those outlined in the DWER South West Index of River Condition Information protocols. Other than general site descriptions, these included:

- Connectivity
- Aquatic habitat

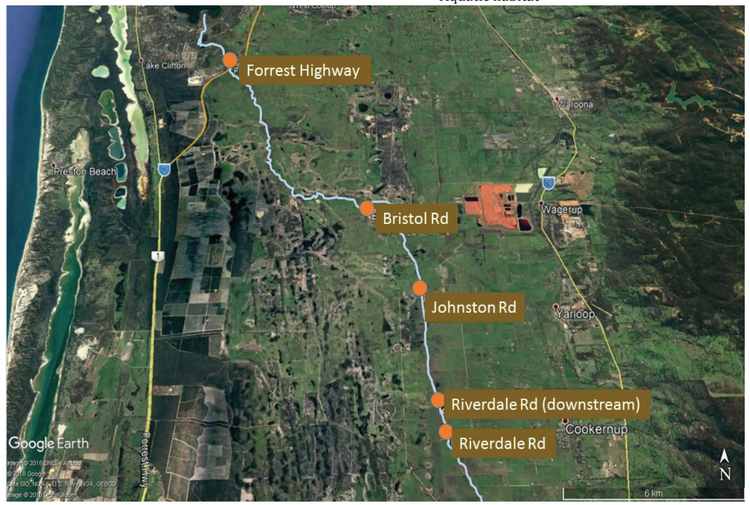


Figure 1: The study sites in the lower Harvey River that were sampled for aquatic fauna

- Vegetation
- Physical form and potential pollution
- 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).
- 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.

Study sites

The five study site photographic reference points provide a snap-shot of the habitat availability and water levels for late-spring (2018) (above photographs) and mid-autumn (2019) (below photographs). While water levels declined at all sites between these periods (~0.1m), all sites continued to flow as they were supplemented by releases from upstream reservoirs.

At each site, habitat descriptions were recorded using the South-west Index of River Condition sheets. Similarly, at each sit water quality paramters were recorded.

The baseline data gathered during this study should be used to determine if there is any long-term change in the aquatic fauna at each site following their rehabilitation. For example, the Forrest Highway site has been subjected to a considerable amount of rehabilitative works, including re-planting of the riparian zone, however, baseline aquatic fauna data is lacking from earlier rehabilitation events. Regardless, changes to the aquatic fauna can be monitored hereon into the future.

Riverdale Rd

The Riverdale Road site was a relatively shallow (<1 m deep) homogenous drain with no riparian trees or shrubs. Introduced grassess and weeds offer some littoral instream habitat. It was low conductivity, has moderate dissolved oxygen levels and was relatively turbid with high pH.

The instream habitat and riparian habitat is poor compared to a more natural system, offering little day-time refuges for nocturnal species such as mature Nightfish, Freshwater Cobbler and Marron. Solar radiation would be high over summer resulting in water temperatures being higher than is tolerable to sensitive species, e.g. Marron.

Downstream of Riverdale Rd

This site is ~1 km downstream of the Riverdale Road site and was similarly relatively shallow (<1 m deep), with no riparian trees or shrubs. Introduced grassess and weeds offer some littoral instream habitat. It was low conductivity, had high dissolved oxygen levels and was relatively turbid with high pH.

Like the Riverdale Rd site, the habitats offered for native fish and crayfish is poor and lacks refuges for nocturnal species. This site would also experience high water temperatures druing summer.

Johnston Rd

Although relatively shallow, there was some heterogeneity to habitats here, with shallow runs, a deep pool at the confluence of a small tributary and some riparian vegetation. It was relatively shallow (<1 m deep), and contained introduced grassess and weeds offer some littoral instream habitat. It was low conductivity, had high dissolved oxygen levels and had lower turbidity than the upstream sites.

The habitats offered for native fish and crayfish were better than upstream sites, but still lacked refuges for nocturnal species. High exposure to solar radiation over summer would result in water temperatures being intolerable to sensitive species.

Bristol Rd

This site similarly lacked riparian vegetation but had some small pools that were <1 m depth; offering cooler summer refuge habitats for less temperature tolerant species. There were some very shallow runs (<0.2m) between the pools but some complex habitat was created by the bridge.

Forrest Hwy

The Forrest Highyway site offered a variety of habitats from deep pools, instream habitat complexity higher than any other site and had a barrier that would impede the upstream migration of some species that are poor swimmers. There was more shade at this site due to rehabilitation efforts and the presence of bridges, and it had the highest diversity of fish and crayfish of any sites.

Newly hatched Marron (*Cherax cainii*) remain attached to the pleopods on the abdomen of their mother for an extended period; this is termed 'berried'. Following detachment the small juveniles are at their most vulnerable and require safe refuge habitats to avoid predators (Photograph: S. Beatty)

Aquatic species of the lower Harvey River

Smooth Marron

Within the study sites in the lower Harvey River however, Marron were only recorded at the Forrest Highway site (Table 1). Here, a total of 7 Marron were captured, all of which were smaller than the legal size.

For milennia the Marron has provided sustenance to the people of Western Australia. The third largest of all freshwater crayfish, the Marron is also prized for its delicate flesh, aquaculture potential and as a recreationally fished species with no other equal in south-western Australia.

Stories of Marron of over 2 kg are by no means exaggerated, and large exoskeletons adorn the walls of many establishments in south-west towns. Having a biogeographic range that was confined to waters between Harvey and Albany, the species was translocated to rivers north of Geraldton and east to Esperance. Despite now being more widespread than previously, its range within some of the large river systems over recent decades, e.g. the Blackwood River, has contracted downstream with the increase in secondary salinisation.

Channelisation of habitats for delivery of water for agriculture (such as within the Harvey River catchment) has led to a decline of the species across much of the Swan Coastal Plain. The absence of Marron from across of this region is possibly related to thermal tolerance, whereby Marron are unable to tolerate water temperatures greater than 31^{o}C with sublethal effects occuring at lower temperatures. The channelised waters can exceed these temperatures in summer months. One way to reduce solar radiation on the water is to rehabilitate the systems by providing riparian vegetation that deliver shade and eventually provides ecosystem services in the form of debri and falling branches and leaves, which offer habitat and shelter for many aquatic organisms.

Marron typically spawn between August and November, with almost all mature females being berried by November (Beatty et al. 2003). The eggs at this point are attached to the females pleopods, and for much of this time the females guard their eggs uder their abdomen and seek refuge amongst logs or rocks to reduce the risk of egg predation. The larger the Marron, the higher the egg carrying capacity that they have, so it is important to protect the larger females or ensure that suitable refuge habitats are available for berrieed females. Once the eggs hatch, the juveniles remain attached to the pleopods until they release in November or December, which is one of the reasons that the recreational Marron season does not commence until January.

Much of the recreational fishery within the Harvey River is concentrated within the Harvey Dam, which is a recognised Marron trophy water and receives a high proportion of the overall reservoir fishing effort.

Marron are routinely observed in many of the rivers, lakes and impoundemnts of south-western Australia (Photograph: D. Morgan)

Table 1: The aquatic fauna captured during the surveys in November 2018 and April 2019 at each site.

Species	Riverdale Rd	D/S Riverdale Rd	Johnston Rd	Bristol Rd	Forrest Hwy
Native fishes					
Freshwater Cobbler (*Tandanus bostocki*)				3	40
Western Minnow (*Galaxias occidentalis*)	603	901	1062	956	284
Western Pygmy Perch (*Nannoperca vittata*)	4	31	261	543	208
Nightfish (*Bostockia porosa*)	6	49	437	337	44
South-West Goby (*Afurcagobius suppsoitus*)					40
Swan River Goby (*Pseudogobius olorum*)	5				6
Sea Mullet (*Mugil cephalus*)		1			10
Western Hardy Head (*Leptatherina wallacei*)					30
Alien fishes					
Eastern Gambusia (*Gambusia holbrooki*)	672	1221	1640	2402	45
Goldfish (*Carassius auratus*)	2	5	11		
Native decapods					
Marron (*Cherax cainii*)					7
Gilgie (*Cherax quinquecarinatus*)					59
Glass Shrimp (*Palaemonetes australis*)	624	1179	2908	400	849
Alien decapods					
Yabby (*Cherax destructor*)	91	218	25	74	2
Other fauna					
Oblong Turtle (*Chelodina colliei*)	2		5	1	7
Motorbike Frog (*Littoria moorei*)	1				
Total Catch	2012	3605	6349	4716	1631

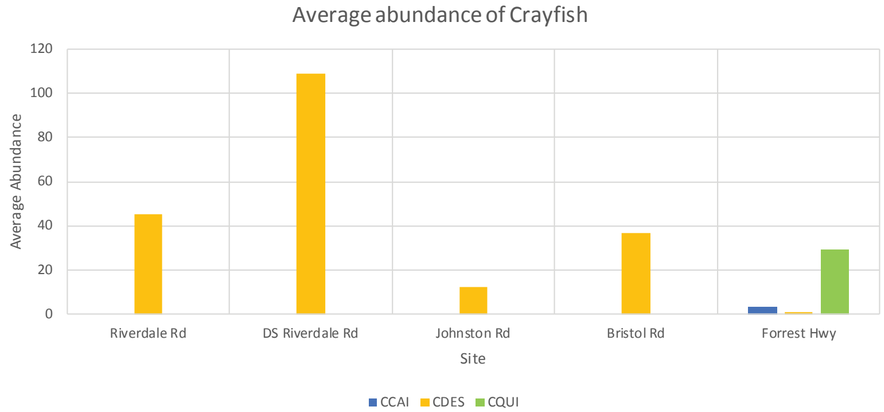


Figure 2: The average abundance of freshwater crayfish captured during the aquatic surveys in November 2018 and April 2019 at each site.
N.B. CCAI = Marron, CDES = introduced Yabby, CQUI = Gilgie

Table 2: Water quality parameters at each sample site in November 2018 and April 2019 at each site.

Parameter	Riverdale Rd		DS Riverdale Rd		Johnston Rd		Bristol Rd		Forrest Hwy	
	Spring	*Autumn*	*Spring*	*Autumn*	*Spring*	*Autumn*	*Spring*	*Autumn*	*Spring*	*Autumn*
Temperature (°C)	21.2	13.4	20.8	13.4	22.3	16	23.6	16.7	18.9	14.1
Specific Conductivity (µs/cm)	1125	696	1013	645	938	767	653	697	900	659
Salinity	0.6	0.44	0.55	0.41	0.49	0.46	0.32	0.41	0.5	0.41
Dissolved Oxygen (%)	73.5	55	128.1	95.6	87	81	153	104.4	81	91.5
Dissolved Oxygen (mg/L)	6.53	5.7	11.3	9.93	7.86	8	12.8	10.13	7.46	9.1
pH	8.47	8.56	7.67	8.42	7.69	6.92	8.4	6.87	7.65	6.69
Turbidity (NTU)	2.71	1.73	2.44	1.75	1.75	1.03	1.09	0.97	1.71	2.17

Other freshwater decapods

The most common freshwater decapod captured was the South-west Shrimp (*Palaemonetes australis*) with a mean of 1192 captured across all sites and all seasons. Similar to the Marron, the Gilgie (*Cherax quinquicarinatus*) was only captured at the Forrest Highway site, where 54 were recorded across a number of size ranges (Table 1).

The Yabby (*Cherax destructor*) was found at all sites, with a total of 409 recorded. They were most abundant in the upstream sites, with only 2 recorded at the Forrest Highway. The species was introduced in 1932 and is actively aquacultured in the Wheatbelt, however, in recent years it has spread throughout many catchments within the south-west, where it competes with native species. The Yabby is reportedly tolerant to higher water temperatures than the native crayfishes, which may explain their successful colonisation and proliferation in the homogenous drainage sites.

The Gilgie (*Cherax quinquecarinatus*) is a species of freshwater crayfish found only in south-western Australia, and one that can survive drying of habitats

Macroinvertebrates

The macroinvertebrates sampled across all sites were relatively similar, with some seasonal differences (Tables 3 and 4, Figure 3). Interestingly, the rehabilitated site, more so than other sites, was dominated by decapod crustaceans (mainly shrimp) which is important food source for many fish and other aquatic fauna. Dipterans were the most abundant order of invertebrates across all other sites, although decapods were also recorded (see Tables 3 and 4). Using ANOSIM there was significant different found between season across all sites when comparing log-transformed abundance date (Global R = 0.117, p = 0.002). Samples were dominated by Overall mean richness per macroinvertebrate sweep (excluding terrestrial fauna) was 7.7 (±0.48). Mean richness was higher in spring compared to autumn (i.e. 9.0 (±0.77) compared with 6.6 (±0.57) taxa per sweep for spring and summer, respectively) Table 5). A Generalised Linear Model (assuming a Poisson error distribution) revealed that there was an overall significant effect of season (P = 0.002) with no significant differences among sites (Tukey's pairwise tests). However, there was also a significant effect of the interaction between site and season (Chi squared p = 0.001). That is, the effect of season depended on site (Figure 4).

Other aquatic fauna

Low numbers of Oblong Turtles (*Chelodina colliei*) were recorded at four of the five sites, most of which were large individuals.

A single Motorbike Frog (*Littoria moorei*) was captured in a fyke net at the most upstream site.

Several sites contained Carter's Freshwater Mussel (*Westralunio carteri*), south-western Australia's only freshwater mussel, which has recently been listed as Vulnerable to its dramatic decline in range over the last few decades. The species relies on native fishes that host their parasitic larval stage and which are used for their dispersal. They are an excellent bioindicator of environmental pollution, and they have a very low loterance to dissolved salts. The fact that they were recorded at most sites suggests that water quality is suitable and that they are actively being transported upstream. Their highest densities were at the Forrest Highway site.

A South-west Glass Shrimp (*Palaemonetes australis*), which is common in the rivers and wetlands of south-western Australia between the Hill River and Esperance, is seeking shelter between woody debri and a Carter's Freshwater Mussel (*Westralunio carteri*) (Photograph: Stephen Beatty)

Members of the general public are learning about the aquatic fauna of the lower Harvey River at one of the field days that were organised during the propject

Table 3: The log-abundances of macroinvertebrates at the Harvey River sites in November 2018 (N.B. 1 = 1-10, 2 = 10-100, 3 = 100-1000 individuals)

	Forrest Hwy		Bristol Rd		Johnston Rd		900 m D/S Rivedale Rd		Riverdale Rd	
	Site	Control	Site	Control	Site	Control	Site	Control	Site	Control
Amphipoda										
Perthidae					1			1	1	2
Coleoptera		NA								
Gyrinidae	1		1	2	2		1	1	1	1
Hydraenidae					1	1	1	2	1	1
Dytiscidae	1		2	1	1	1		1	1	1
Hydrophilidae	1			2	2	1	1	2	1	2
Haliplidae								1		
Noteridae							1	1		
Decapoda										
Palaemonidae	3		2	1	1	1	2	1	1	1
Parastacidae			1	1	1				1	1
Diptera										
Chironomidae	1		3	3	2	1	3	3	2	2
Tipulidae										
Tabinidae										
Ceratopogonidae			1	1						
Simuliidae			1	2	1	1		1		1
Stratiomyidae			1					1		
Culidae					1					
Psychodidae								1	1	
Corydalidae						1				
Ephemeroptera										
Caenidae			2	2	1	1	1	1	2	1
Baetidae				1						
Hemiptera										
Corixidae			1		1	1	1	1	2	1
Gelastocoridae						1				
Notonectidae	1				1					1
Neptidae										1
Hebridae										
Hygrophila										
Physidae	3			2	2	2	1	1	2	2
Lymnaeidae								1		
Lepidoptera										
Nymphulinae									1	
Megaloptera										
Corydalidae										
Odonata										
Libelluidae			1	1	1	1	1			
Aeshnidae										1
Lestidae				1						
Corduliidae				1						
Coenagrionidae			1					1	1	
Trichoptera										
Leptoceridae	1		2	2	1	1	2	2	1	1
Hydropsychidae				2	1	2				1
Ecnomidae			2	2	2	1		1	1	1
Hydroptilidae										
Other										
Pupae			1	1	1	1	1	1	1	
Adult fly	1		1	1					1	
Terrestrial spider	1			1				1		1
Terrestrial cricket						1				
Terrestrial silverfish										
Hirudinea			1							
Copepoda								2		
Cladocera										
Slug										
Oligochaeta								1	1	
Collembola				1				1	1	
Ancylidae				1			1	1	1	1
Ostracoda			1	1				1	1	1

Table 4: The log-abundances of macroinvertebrates at the Harvey River sites in April 2019 (N.B. N.B. 1 = 1-10, 2 = 10-100, 3 = 100-1000 individuals)

	Forrest Hwy		Bristol Rd		Johnston Rd		900 m D/S Rivedale Rd		Riverdale Rd	
	Site	Control	Site	Control	Site	Control	Site	Control	Site	Control
Amphipoda										
Perthidae								1	1	1
Coleoptera										
Gyrinidae	2	1	1					1	1	
Hydraenidae	1	1						2		
Dytiscidae	1	1			1		1	2		1
Hydrophilidae	1				3			1		
Haliplidae								1		
Noteridae										
Decapoda										
Palaemonidae	2	2		1	1	1	2	2	1	2
Parastacidae	1							1		1
Diptera										
Chironomidae	2	2	2	3	3	3	1	3	2	2
Tipulidae	1									
Tabinidae						1				
Ceratopogonidae					1	1			1	
Simuliidae			1		1	1	1	2		
Stratiomyidae										
Culidae						1				
Psychodidae							1			
Ephemeroptera										
Caenidae	1	1	2	2	1	1		1		
Baetidae	1		1	2	1	1				1
Hemiptera										
Corixidae		1				1	1	1		
Gelastocoridae										
Notonectidae										
Neptidae										
Hebridae										1
Hygrophila										
Physidae		2	1	2	1	3		2	1	1
Lymnaeidae						1		1		
Lepidoptera										
Nymphulinae										1
Megaloptera										
Corydalidae										
Odonata										
Libelluidae				1	1	1				
Aeshnidae						1				
Lestidae					1					
Corduliidae										1
Coenagrionidae				2	2	2	1	1		2
Trichoptera										
Leptoceridae	1	2	1	1	1	1	1	1	1	1
Hydropsychidae										
Ecnomidae	1	1	1	1		1			1	
Hydroptilidae		1				1				
Other										
Pupae	1	1	1	2	1	1	1	1	1	1
Adult fly	1						1	1		
Terrestrial spider		1	1	1	1		1	1	1	1
Terrestrial cricket		1								
Terrestrial silverfish										
Hirudinea	1				1	1				
Copepoda		1			2	2	1	1	1	
Cladocera					2	2				
Slug		1							1	1
Oligochaeta	1	1	1	1	2	2	1	2	1	1
Collembola		1								
Ancylidae	1		1		1			1		1
Ostracoda		1		1	2	2		2		

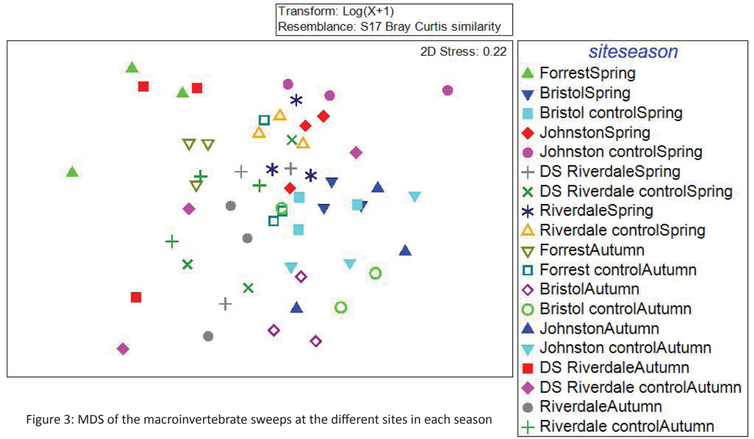


Figure 3: MDS of the macroinvertebrate sweeps at the different sites in each season

Table 5: The log-abundances of macroinvertebrates at the Harvey River sites in November 2018 (N.B. 1 = 1-10, 2 = 10-100, 3 = 100-1000 individuals)

Season	Forest Highway	Bristol Road	Johnston Road	900 m D/S Rivedale Rd	Riverdale road
Autumn	6.83 (0.60)	5.33 (0.49)	9.50 (1.34)	5.67 (1.80)	5.50 (1.23)
Spring	4.00 (0.58)	10.33 (1.15)	8.83 (1.58)	8.67 (2.11)	10.83 (0.70)
Total mean	5.89	7.83	9.17	7.17	8.17

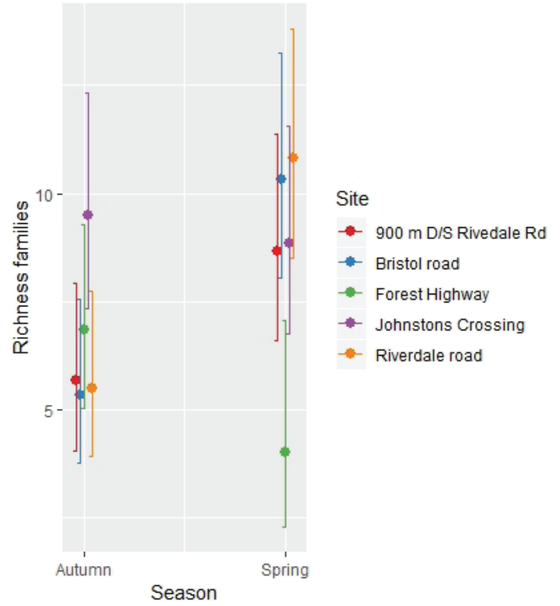


Figure 4:Macroinvertebrate richness (by family) across the different sites in the different seasons

Fishes of the Harvey River

In total, we captured 10 different fish species in the lower Harvey River. This included four species that are considered to be obligate freshwater species that are endemic to the region, e.g. Freshwater Cobbler, Western Minnow, Western Pygmy Perch and Nightfish.

A further three species, that are typically referred to as species of estuarine origin but do breed in freshwaters were recorded. Two of these are endemic to the region, including the South-western Goby, the Swan River (or Blue-spot) Goby and the Western Hardyhead. Sea Mullet were also recorded and are considered a marine migrant as they spawn at sea, with juveniles moving on mass into estuaries and even further into freshwaters.

The remaining fish species captured were non-native fishes, one of which was introduced into the region in the 1930s as a biological control for nuisance dipterans (Eastern Mosquitofish), the other as an ornamental escapee (Goldfish). Of the 11913 individual fish captured, just over 50% were exotic.

Nine of the 10 species were found at the Forrest Highway site, and this is probably a reflection of its close proximity to the estuary, where several species have most liekly arrived from.

Native freshwater fishes

Of the native freshwater fishes, the Western Minnow was the most abundant, where it was commonly encountered at all sites and contributed to over 30% of all fish captured. Durng spring sampling, large numbers of new recruits were encountered moving downstream on declining flows.

The next most abundant was the Western Pygmy Perch, which accounted for approximately 9% of all fish captured, and it was also recorded at all sites, yet only in low numbers at the Riverdale sites. Evidence of successful recruitment was found, with many new recruits being found at the middle sites, and included larger individuals.

The Nightfish was similarly abundant to the Western Pygmy Perch, and was most common at Bristol Rd and Johnston Rd, where large numbers of new recruits were recorded on each sampling occasion.

Each of these small to medium size freshwater fish are excellent indicators of habitat suitability. For example, a typical population in a pristine habitat should be comprised of a series of age classes, with each successive age class being lower than the previous. That each of these fish is successfully recruiting in the system is an important point, the challenge for managers is to now afford the juveniles and young adults with habitats than increase their longevity. This is further impeded by the presence of the introduced Eastern Mosquitofish, which has been demonstrated to severely impact native fishes such as the Western Pygmy Perch in habitats that lack structure that are critical refuge habitats.

Marine and estuarine fishes

The estuarine and marine fishes captured in the study were mostly found at the downstream site. Although they were only encountered in relatively low numbers, Western Hardyheads were only captured downstream of the weir at Forrest Highway, which suggests that this may be a barrier to their upstream colonisation.

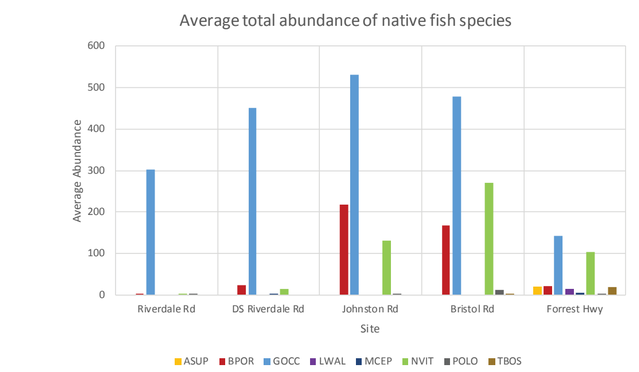
The Sea Mullet were mostly also only found below the weir at the Forrest Highway, although a single individual had migrated as far upstream as the Riverdale Road site; the species can penetrate long distances inland and has a good jumping ability which may increase its likelihood of moving past small barriers, or it may have migrated past the barrier during high water levels.

Much of the lower reach of the Harvey River has been channelised. Note the fyke net positioned facing downstream, to capture fish that were moving upstream

Both goby species are often found in freshwaters, where they are capable of breeding. They are able to navigate barriers with the morphological adaptation of possessing joined pelvic fins which can add as a suctorial pad for climbing. The Swan River Goby was found at the most upstream site and may be more widespread than our catches revealed.

Introduced fishes

The Eastern Mosquitofish was abundant at all sites with the exception of the Forrest Highway site and contributed to almost 50% of all catches. It is an extremely aggressive species that is known to harass native fishes, the Western Pygmy Perch most susceptible to fin attack from the species that lead to reduced swimming ability and even death (Gill et al. 1999). Fin damage was recorded on most pygmy perch at the upstream sites. Small numbers of Goldfish were reported at the most degraded sites. Goldfish has been implicated with the introduction of an exotic parasite into the Canning, Serpentine and Murray rivers; which can also lead to death of native fishes (Morine 2018).



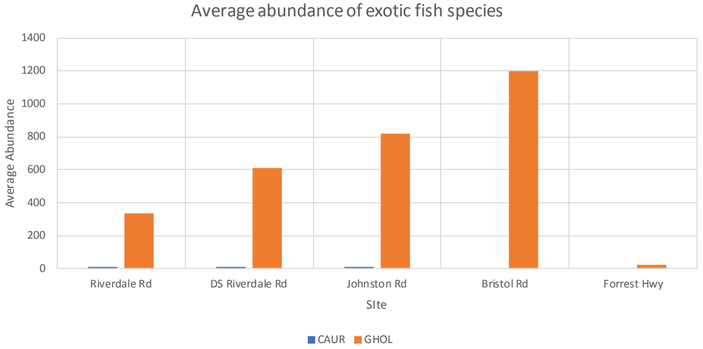


Figure 3: The average abundance of native (above) and introduced (below) fish captured during the aquatic surveys in November 2018 and April 2019 at each site. N.B. (Top) ASUP = South-western Goby, BPOR = Nightfish, GOCC = Western Minnow, LWAL = Western Hardyhead, MCEP = Sea Mullet, NVIT = Western Pygmy Perch, POLO = Swan River Goby, TBOS = Freshwater Cobbler; (Bottom) CAUR = Goldfish, GHOL = Eastern Mosquitofish

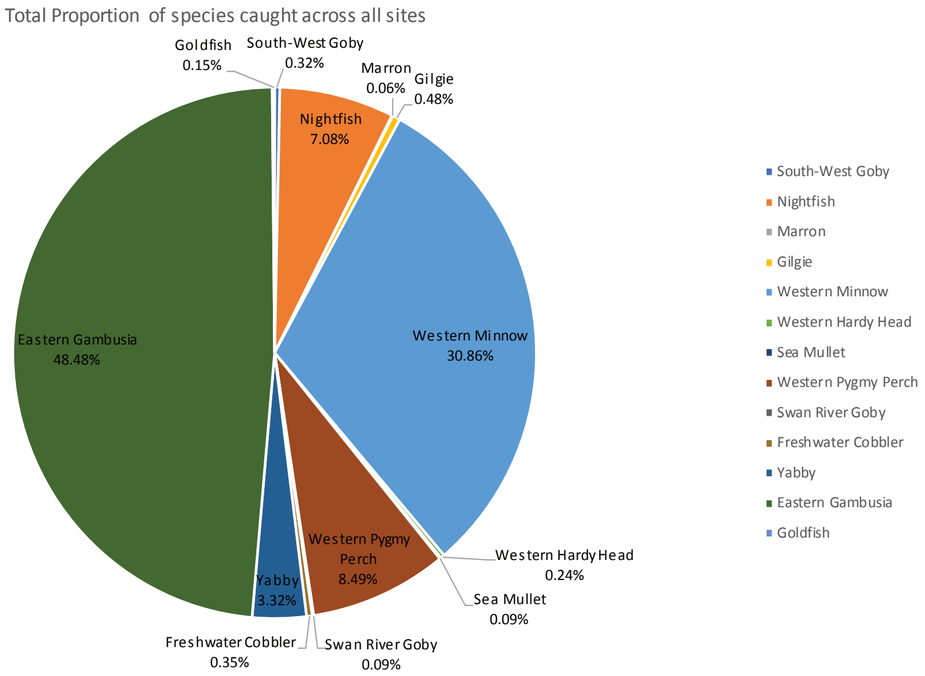


Figure 4: The proportion of all native and introduced fish and crayfish captured during the aquatic surveys in November 2018 and April 2019 at all sites (excluding South-west Glass Shrimp, reptiles and amphibians)

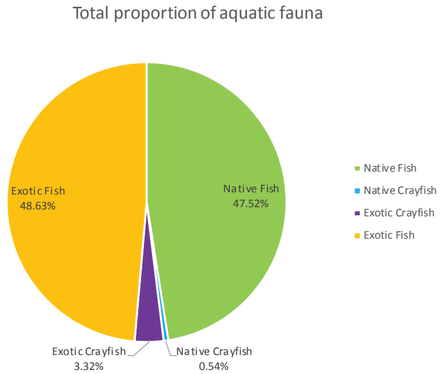
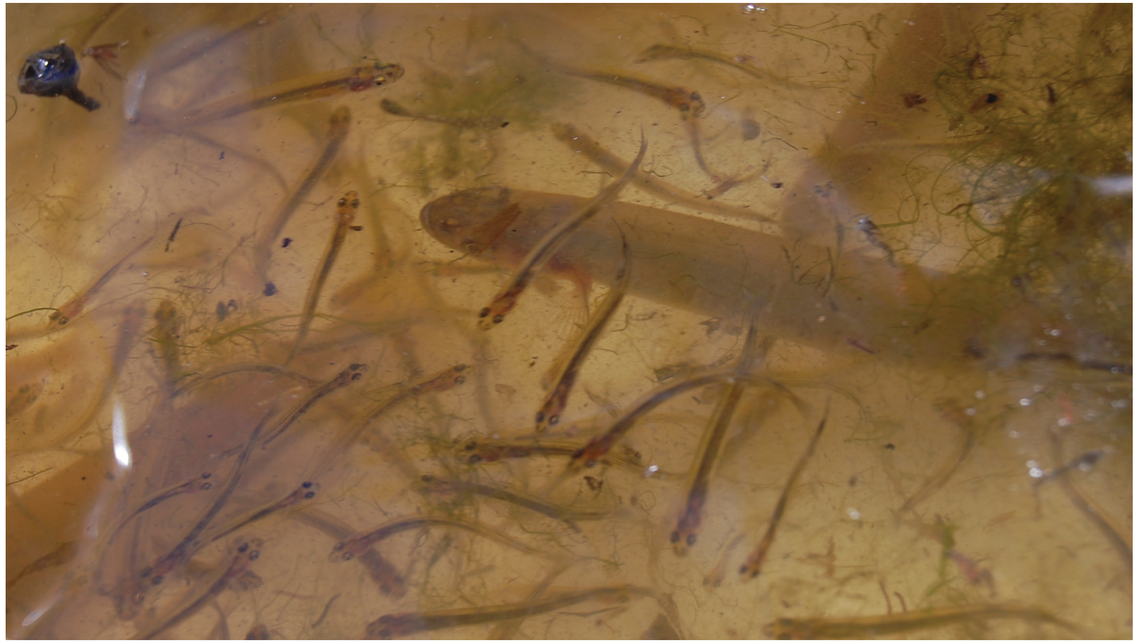


Figure 5: The proportion of all native and introduced fish and crayfish captured during the aquatic surveys in November 2018 and April 2019 at all sites.

A single Common Jollytail (*Galaxias maculatus*) has been recorded from the lower Harvey River. This species is common in the rivers east of Albany, as well as south-eastern Australia across to South America; its wide distribution facilitated by a marine larval phase in some populations, and the likely reason that an individual was found in the Harvey River (see Morgan et al. 2006 for more information) (Photograph: D. Morgan)



Large schools of juvenile Western Minnow (*Galaxias occidentalis*) can be observed in spring in lakes and rivers of south-western Australia, including the Harvey River where they were the most abundant native fish captured. They are often found with larger individuals forming mixed cohorts, and retreat from tributaries as water levels decline in late spring (Photograph: D. Morgan)

Seasonal differences in the aquatic fauna

During spring 2018, at most sites there was a notable downstream trend in the migration of young of the year of Nightfish and Western Pygmy Perch. It is likely that as water levels decline, these species migrate downstream with the declining flow and are passively transported (Beatty et al. 2014). Populations of Nightfish at the most upstream sites were similar, the cohorts of the new recruits all quite similar with the exception of the Forrest Hwy site. Further, there was a greater proportion of larger, older fish at the Forrest Hwy site, compared to the other sites which were dominated by young juvenile fish.

In contrast, to the percichthyids, there was a considerable amount of upstream and downstream movements by the Western Minnow, possibly related to feeding. All sites were occupied by both new recruits and older age classes of this galaxiid, although length-frequency analysis demonstrates that the majority of the population is comprised of young of the year.

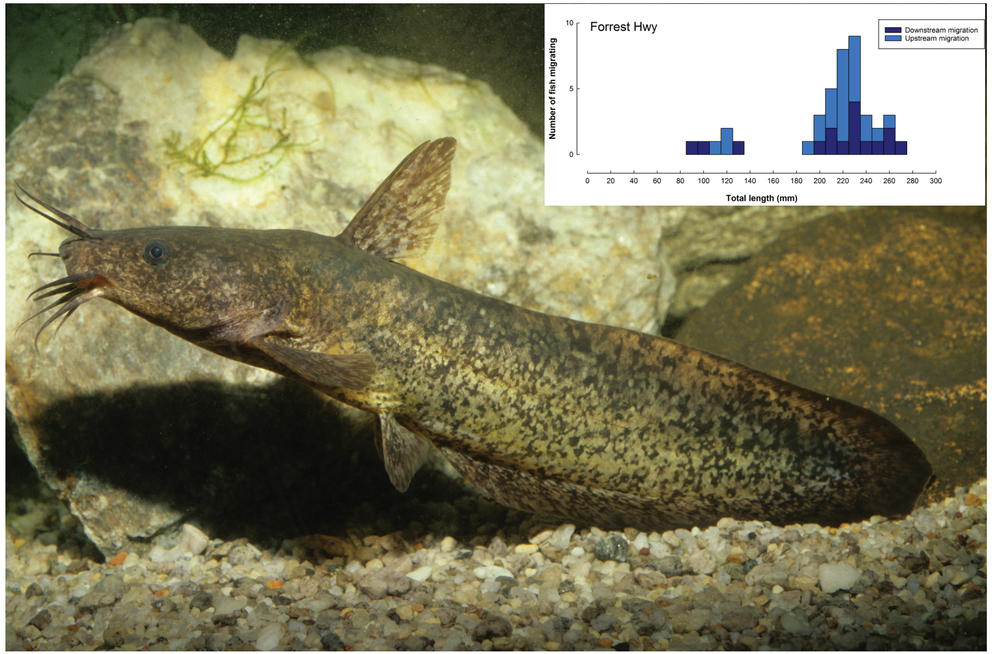
Freshwater Cobbler routinely migrate short distances during the night for feeding and breeding purposes in late spring and early summer (Beatty et al. 2010). The movement patterns observed for this species at the Forrest Highway site are probably both linked to their nocturnal feeding and possibly as a precursor to the onset of their breeding period. A small cohort of small individuals relates to the fish that are approximately one year old (< 140 mm TL), and the cohort of larger fish are considered mature adults (inset Figure, page 26). Absent from this population are the very large adults (300 -400+ mm TL), suggesting that logevity is being impacted for this and the other freshwater obligates.

Other fishes of the Harvey River

Other studies have demonstrated that there are several species of fish that are found within the freshwaters of the Harvey River catchment. These include four introduced species, including the Redfin Perch (*Perca fluviatilis*), Brown Trout (*Salmo trutta*), Rainbow Trout (*Oncorhynchus mykis*), One-spot Livebearers (*Phalloceros harpagos*) and Silver Perch (*Bidyanus bidyanus*) (see Morgan et al. 2004, Beatty and Morgan 2013). While some species have been deliberately stocked, and continue to be stocked to promote recreational fishing opportunites, most of these species have the ability to compromise native fishes and crayfishes, including Marron stocks (see Morgan et al. 2002, 2004, Tay et al. 2007). For example, dietary studies of Redfin Perch and Rainbow Trout in south-western Australian waters have revealed that in impoundments the diets of larger fish are dominated by Marron.

Additionally, the native Common Jollytail (*Galaxias maculatus*) was found in the lower reaches of the Harvey River, where it is believed to have migrated to the river from the marine environment as a larvae (see Morgan et al. 2006). This species is typically located within the rivers and lakes on the south coast of WA (east of Albany), but it is also widespread across southern Australia to Pacific Islands and South America; the marine larval stage facilitating this large dispersal. Most populations in WA are believed to be landlocked, and thus complete their life-cycle within inland waters (Chapman et al. 2006).

Some of the native fishes captured in this study: from top right, Western Pygmy Perch, Nightfish, Western Hardyhead, South-western Goby, Swan River Goby (Photographs: S. Beatty and M. Allen)



The Freshwater Cobbler (*Tandanus bostocki*) is the largest obligate freshwater fish in south-western Australia, and although incorrectly placed in the genus *Tandanus*, it represents an undescribed genus which is one of the earliest branching lineages within freshwater eel-tailed catfishes, its divergence dates to the early Tertiary (Morgan et al. 2014); INSET - Length-frequency histogram and the directional movement of Freswhater Cobbler at the Forrest Hwy site in November 2018 (Photograph: M. Allen)

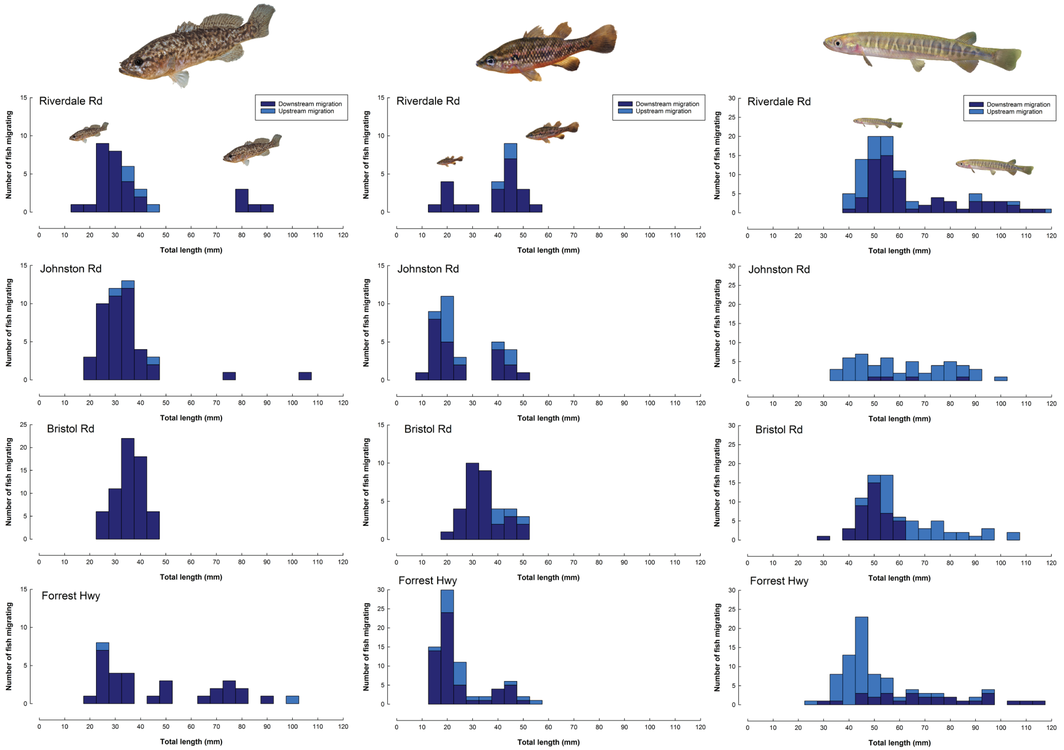


Figure 6: Length-frequency histograms of Nightfish, Western Pygmy Perch and Western Minnows at the Riverdale sites, Johnston Rd, Bristol Rd and Forrest Highway during November 2018 showing directional (upstream or downstream) movement of individual fish.

Table 5: The seasonal differences in the aquatic fauna captured during the surveys in November 2018 and April 2019 at each site.

	Riverdale Rd		DS Riverdale Rd		Johnston Rd		Bristol Rd		Forrest Hwy	
Native Species	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Freshwater Cobbler (*Tandanus bostocki*)							3		40	
Western Minnow (*Galaxias occidentalis*)	77	526	711	190	397	665	323	633	94	190
Western Pygmy Perch (*Nannoperca vittata*)	3	1	31		218	43	89	454	113	95
Nightfish (*Bostockia porosa*)	5	1	47	2	401	36	172	165	38	6
South-West Goby (*Afurcagobius suppositus*)										40
Swan River Goby (*Pseudogobius olorum*)	5				1		21	1	5	1
Western Hardy Head (*Leptatherina wallacei*)										30
Sea Mullet (*Mugil cephalus*)			1						1	9
Marron (*Cherax cainii*)									5	2
Gilgie (*Cherax quinquecarinatus*)									49	10
Alien Species										
Goldfish (*Carassius auratus*)	2			5	2	9				
Eastern Gambusia (*Gambusia holbrooki*)	341	331	1039	182	623	1017	478	1924	6	39
Yabby (*Cherax destructor*)	58	33	178	40	9	16	23	51	2	
Other Species										
Freshwater Shrimp (*Paleomonetes australis*)	373	251	889	290	1084	1824	68	332	684	165
Motorbike Frog (*Littoria moorei*)	1									
Long-Neck Turtle (*Chelodina colliei*)	4				5		1			
Total Catch	784	615	2107	517	1724	2866	591	2308	752	296
Species Diversity	8	5	5	5	9	6	8	7	7	8

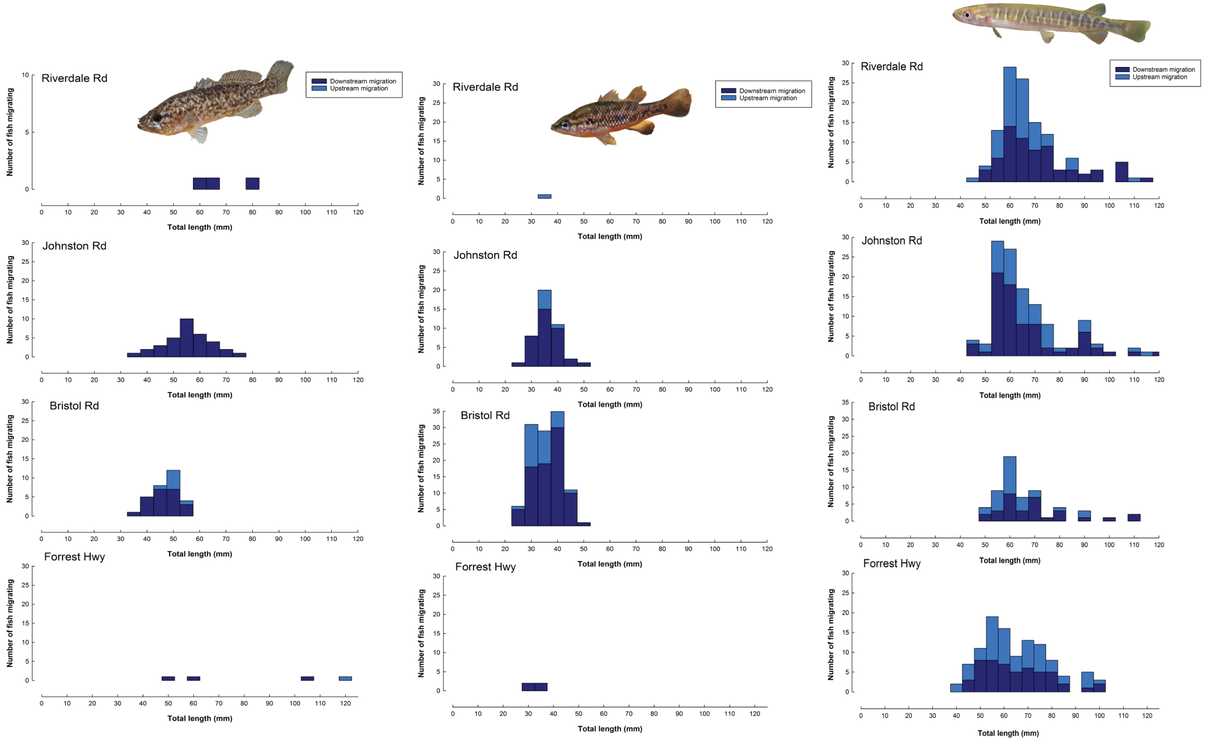


Figure 7: Length-frequency histograms of Nightfish, Western Pygmy Perch and Western Minnows at the Riverdale sites, Johnston Rd, Bristol Rd and Forrest Highway during April 2019 showing directional (upstream or downstream) movement of individual fish.

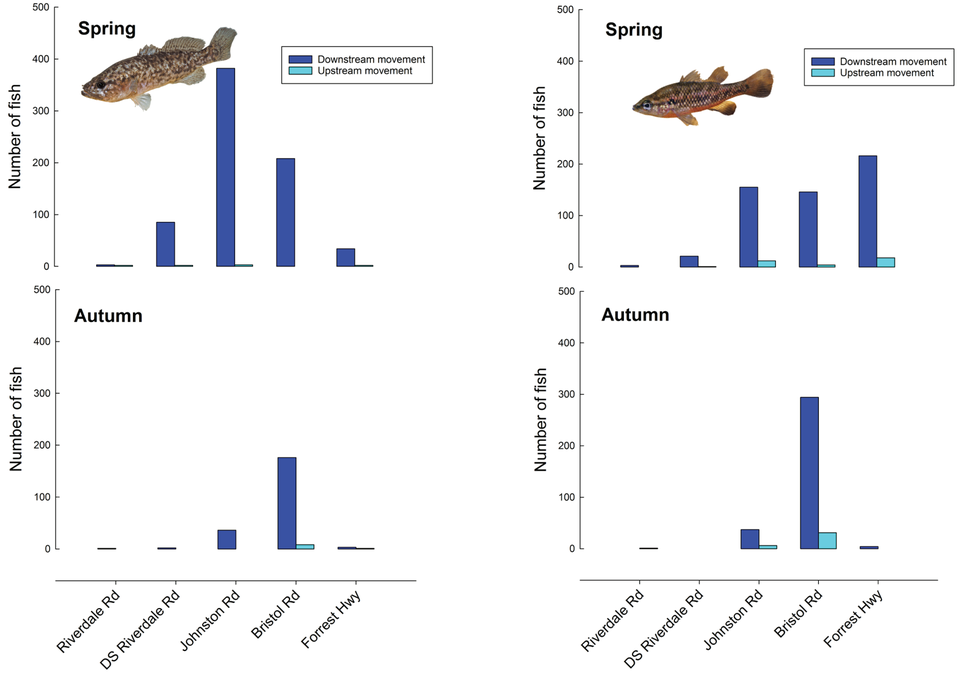


Figure 8: Upstream and downstream migrations of Nightfish (left) and Western Pygmy Perch (right) at the Riverdale sites, Johnston Rd, Bristol Rd and Forrest Highway during spring 2018 and autumn 2019

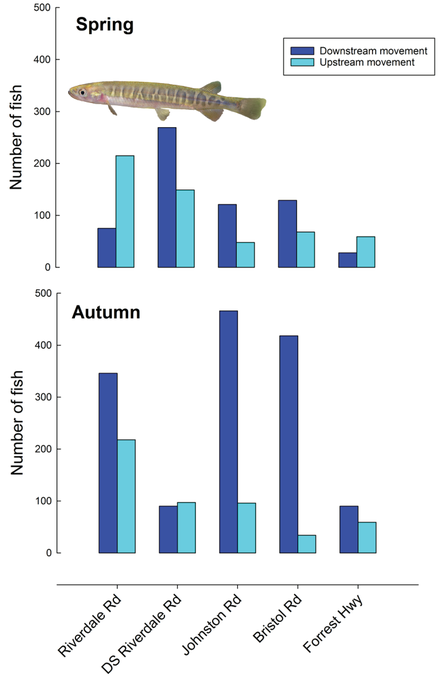


Figure 9: Upstream and downstream migrations of Western Minnows at the Riverdale sites, Johnston Rd, Bristol Rd and Forrest Highway during spring 2018 and autumn 2019

The small pool (inset) at Bristol Rd offers a deep, cooler-water (~1 m) refuge for native fishes to over-summer. This pool contained hunders of native fishes (including juveniles of the 2018 year class of Western Pygmy Perch, Nightfish and Western Minnows). As a strategy to enhance the survivorship of fish in these species, the construction of similar pools through the drainage canals, together with revegetaion of the riparian zone and insertion of large woody debri, would serve to offer a stepping-stone series of refuge pools along an otherwise homogenous habitat, that would reduce water temperatures during summer, and increase habitat for nocturnal species. It would also provide refuge from the high densities of the aggressive Eastern Mosquitofish that patrol the shallow runs of these drains in search of food and conflict.

Key strategies for the conservation of the aquatic fauna in the Harvey River

The massive recruitment events of three of the native endemic freshwater fishes that occured in spring in 2018 were not expected. There does however appear to have been a large amount of juvenile mortaility between spring and autumn. Nonetheless this study has revealed that these species have persisted in the drainage systems of the lower Harvey River despite major degradation of habitat and preceived lack of suitable habitat. It is concluded that habitat restoration has great potential to further enhance the native aquatic fauna by increasing the survival over summer.

The less mobile Smooth Marron, Western Pygmy Perch and Nightfish are useful bioindicator species. The success of future habitat restoration activities could be assessed by monitoring the persistance and survival of these species over time. As an example, it was evident that if fish were within close proximity to deeper pools (>1 m) over summer, relative abundance of new recruits was much greater. This is likely to be due to a number of reasons, including being able to reduce interactions with the invasive and aggressive Eastern Mosquitofish, which would increase in shallower habitats as flow declines. Further, deeper waters provide a buffer against high water temperatures that are experienced during summer; temperatures which are aboth the tolerance level to some species, including Marron.

By directing rehabilitation efforts and resources to the creation of deeper pool habitats along the length of the drains, it may be possible to increase juvenile survivorship. Trialling a number of pools of varying dimensions and depths (e.g. 10 m long, 3 m wide, 1 m depth) should be investigated. Futher rehabilitation of the riparian zone would provide additional shade by reducing direct solar radiation and thus decreasing water temperatures. Additionally, this would lead to leaf litter and other debri creating additional habitat in the three dimensional space with these pools. The insertion of logs or rocks would provide additional habitat for nocturnal species such as Freshwater Cobbler, Nightfish and Marron. Additionally, providing small juvenile Marron with habitat when they are most vulnerable (following detachment from their mother), would assist in their survival. Hollow bricks or rock stacks have been shown to work effectively as hides for small Marron.

Longterm monitoring from the Forrest Road site, the only site to host Marron, Gilgies and Freshwater Cobbler, would provide an insight into the upstream colonisation of these species following large-scale remediation on riparian zones and pool habitats.

Further Reading

BOOKS

Morgan, D.L., Beatty, S.J., Klunzinger, M.W., Allen, M.G. & Burnham, Q.E. (2011). *A field guide to the freshwater fishes, crayfishes and mussels of south-western Australia*. SERCUL, Beckenham, W.A. and Freshwater Fish Group & Fish Health Unit, Murdoch University, Murdoch, W.A.

OTHER PUBLICATIONS

Beatty, S.J. & Morgan, D.L. (2013). Introduced freshwater fishes in a global endemic hotspot and implications of habitat and climatic change. *BioInvasions Records* 2: 1-9.

Beatty, S.J., Morgan, D.L. & Lymbery, A.J. (2014). Implications of climate change for potamodromous fishes. *Global Change Biology* 20: 1794-1807.

Beatty, S.J., Morgan, D.L., McAleer, F.J. & Ramsay, A.R. (2010). Groundwater contribution to baseflow maintains habitat connectivity for *Tandanus bostocki* (Teleostei: Plotosidae) in a south-western Australian river. *Ecology of Freshwater Fish* 19: 595-608.

Beatty, S.J., Morgan, D.L., Rashnavadi, M. & Lymbery, A.J. (2011). Salinity tolerances of endemic freshwater fishes of south-western Australia: implications for conservation in a biodiversity hotspot. *Marine & Freshwater Research* 62: 91-100.

Beatty, S.J., Seewraj, K., Allen, M.G. & Keleher, J.J. (2014). Enhancing fish passage over large on-stream dams in south-western Australia: a case study. *Journal of the Royal Society of Western Australia* 97: 313-330.

Chapman, A, Morgan, D.L., Beatty, S.J & Gill, H.S. (2006). Variation in life history of land-locked lacustrine and riverine populations of *Galaxias maculatus* (Jenyns 1842) in Western Australia. *Environmental Biology of Fishes* 77: 21-37.

Coy, N.J. (1979). *Freshwater fishing in south-west Australia*. Jabiru Books, Perth.

Gill, H.S., Hambleton, S.J. & Morgan, D.L. (1999). Is *Gambusia holbrooki* a major threat to the native freshwater fishes of south-western Australia? In Seret, B. & Sire, J.-Y., (eds). Proceedings 5th Indo-Pacific Fish Conference (Noumea, 3-8 November 1997). pp. 79-87. Paris: Societe Francaise d'Ichtyologie & Institut de Recherche pour le Development.

Morgan, D.L., Chapman, A., Beatty, S.J. & Gill, H.S. (2006). Distribution of the spotted minnow (*Galaxias maculatus* (Jenyns, 1842)) (Teleostei: Galaxiidae) in Western Australia including range extensions and sympatric species. *Records of the Western Australian Museum* 23: 7-11.

Morgan, D.L., Gill, H.S., Maddern, M.G. & Beatty, S.J. (2004). Distribution and impacts of introduced freshwater fishes in Western Australia. *New Zealand Journal of Marine and Freshwater Research* 38: 511-523.

Morgan, D.L., Gill, H.S. & Potter, I.C. (1998). Distribution, identification and biology of freshwater fishes in south-western Australia. *Records of the Western Australian Museum Supplement* No. 56: 1-97.

Morgan, D.L., Hambleton, S.J., Gill, H.S. & Beatty, S.J. (2002). Distribution, biology and likely impacts of the introduced redfin perch (*Perca fluviatilis*) (Percidae) in Western Australia. *Marine & Freshwater Research* 53: 1211-1221.

Morgan, D.L., Unmack, P.J, Beatty, S.J., Ebner, B.C., Allen, M.G., Keleher, J.J., Donaldson, J.A. & Murphy, J. (2014). An overview of the 'freshwater fishes' of Western Australia. *Journal of the Royal Society of Western Australia* 97: 263-278.

Tay, M.Y., Lymbery, A.J., Beatty, S.J. & Morgan, D.L. (2007). Predation by Rainbow Trout (*Oncorhynchus mykiss*) on a Western Australian icon: Marron (*Cherax cainii*). *New Zealand Journal of Marine and Freshwater Research* 41: 197–204.

Unmack, P.J 2013. Biogeography. In: Humphries, P. & Walker, K. (eds), *Ecology of Australian freshwater fishes* pp. 25–48. CSIRO Publishing, Victoria.

Harry Butler Institute
MURDOCH UNIVERSITY

marron, more than a meal
REVIVE OUR RIVERS

HARVEY RIVER RESTORATION TASKFORCE INC.