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Aquatic fauna assessment of fire waterpoints in the Warren region, south-western WA



Report to:



Department of
Parks and Wildlife



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Wildlife, Warren Region



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Front cover photos: Conducting bathymetry of fire waterpoint WP 318, and some of the native freshwater fishes occupying waterpoints surveyed during the study (top to bottom): Nightfish, Western Minnow, Western Pygmy Perch and Balston's Pygmy Perch.

EXECUTIVE SUMMARY

The native freshwater fishes of south-western Australia have suffered major range reductions and population declines with approximately half currently listed, or nominated, as being threatened. The life-cycles of most species involve upstream migration during winter and spring to breed, and retreating to permanent pools or flowing sections of rivers during summer. The species also use artificial habitats as refuge pools, including numerous fire waterpoints throughout the region. Recent evidence has strongly suggested that these waterpoints have the potential to play an important role in maintaining remnant populations of fishes, including threatened species, by offsetting the loss of natural refuge pools that is expected due to a drying climate. Therefore, in the creation of new waterpoints, or the renovation of existing waterpoints, the potential benefits of providing refuge for endemic fishes deserves greater consideration.

The current study undertook an on-ground survey of 12 existing fire waterpoint pools that were scheduled for renovation, in order to determine the resident fish communities and their spatial, biological and physical characteristics. This aimed to assess the conservation value of the pools for native species, and begin to determine those characteristics that are important as dry-season refuge. The data collected from the 12 existing pools, along with distributional information of fishes recently gathered as part of a major State Strategic NRM project, was used to assess the importance of these waterpoints to native fish populations. This assessment helped determine the likelihood that 10 new waterpoints (planned for the Kent, Frankland, and Denmark catchments) would be used as dry season refuges by native fish. The study also aimed to develop recommendations about how the renovation of existing waterpoints could be conducted to enhance the potential for native fish refuge. Recommendations are also made on how to consistently locate and construct new waterpoints to maximise the benefits to native fish conservation, while simultaneously creating additional fire-fighting waterpoints.

Of the existing waterpoints surveyed, 33% housed at least one species of endemic fish and 67% at least one endemic freshwater crayfish. The EPBC listed Balston's Pygmy Perch was present in waterpoint WP299, which also had Western Minnow, Western Pygmy Perch and Nightfish; the greatest diversity of fish of the waterpoints scheduled for renovation, resulting in a high priority ranking for active management. Three other waterpoints that housed native fish were classified as high priority.

While the sample size of surveyed waterpoints was too low for a robust analysis of spatial and environmental factor variability with the presence of endemic fish, some key factors were notable and show potential for further examination. Waterpoints that contained fish were always well connected to a drainage line, generally located closer to a major river, and had a relatively low gradient to that major river compared to waterpoints that did not house fish. Notably, these waterpoints also had sufficient depth to provide refuge of the drier months. While native fish were not collected in waterpoints WP347 and WP334, their proximity to river channels suggests a strong likelihood of becoming fish refuge. Future renovation of these waterpoints to suitable depth and configuration is therefore highly recommended.

The assessment of the potential likelihood of the 10 proposed waterpoints to act as fish refuge identified four that had moderate likelihood given their proximity to natural water

courses and elevation in the landscape. Proposed waterpoint sites 13, 15, 18 and 19 were relatively close to major streams and had a relatively low gradient to the nearest river. The likelihood of native fish colonising an appropriately constructed wetland at these locations was therefore considered to be moderately high.

This report provides a preliminary synthesis of some of the critical factors to be considered in the development of dual purpose waterpoints suited as refuge for south-western Australian fish and water supply for fire-fighting. However, it is important to assess more existing waterpoints to develop a more robust assessment of important spatial, biological and physical characteristics required for native fish refuge.

Recommendations

The analysis of results from the current project helped to generate the following recommendations to manage waterpoint renovations:

- The highest priority waterpoints for the proposed relocation strategy are 299 (four species including Balston's Pygmy Perch), 71 (three endemic fishes), 66 and 141 (each with one endemic fish species).
- Waterpoints 347 and 344 should be renovated to a relatively depth that ensures they remain permanent during the dry season, and any renovation should not cause the waterpoints to become separated from the streamline during peak flow events (e.g., by the creation of a bank or barrier).

Key recommendations to fill knowledge gaps that will ensure a robust design protocol and maximise the conservation benefits of future waterpoints for endemic fishes, include:

- increasing the number of waterpoints that are surveyed to enable robust,
- modelling of those factors correlated with the occurrence of native fishes,
- expansion of the survey will simultaneously increase our current knowledge of the distribution of native fish to more effectively monitor future changes,
- conducting further assessment in the higher flows of winter-spring while fish are attempting to migrate in streams adjacent to proposed waterpoints,
- accessing the depth to groundwater and relative contribution of ground and surface waters be determined in an expanded study (see Ogston et al. 2016).

The study developed a process to ensure that planned renovation of existing waterpoints have minimal impact on native and endangered freshwater fishes and recommendations that include:

- expansion of the survey to include all waterpoints planned to be renovated (recommended above),
- identification of high priority waterpoints likely to provide important native fish refuge,
- developing a systematic relocation program for native fish,
- relocating fish to appropriate alternative refuge pools within the same catchment (based on preliminary criteria identified in the current study),
- confirming the likely re-colonisation of waterpoints by native fish following renovation.

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Background

South-western Australia has the highest proportion of endemism of freshwater fishes than any Australian freshwater fish province with >80% of native fishes found nowhere else. Most of its species have undergone substantial range declines due to secondary salinisation, habitat degradation, river regulation, alien species, and declines in river flow and groundwater levels (Morrongiello *et al.*, 2011; Morgan *et al.* 2014). The majority of species undertake migrations within rivers, and particularly laterally into tributaries, during their winter-spring breeding period. While the maximum migration distances have not yet been determined, species such as the Western Minnow can migrate at least 5 km based on mark-recapture data. These seasonal upstream migrations are then generally followed by a downstream movement to seek out pool habitats (or groundwater maintained flowing habitats) to survive the seasonal dry period (Beatty *et al.* 2014). The relative value of the remaining fresh refuge pool habitats will increase as discharge and flow periods of rivers continues to decline as a result of ongoing reductions in rainfall in the region.

Surveys conducted by the authors and others in south-western Australia over the past ~20 years have suggested that artificial water-points are regularly occupied by native freshwater fishes, including rare and threatened species (see for example Morgan *et al.*, 1998, Beatty *et al.*, 2015). They can represent a considerable proportion of refuge pools in streams on State-managed lands and can mimic naturally occurring permanent pools; acting as important dry-season fish refuges. While their overall relative importance as refuge across the region has not been properly quantified, a recent Strategic State NRM project (#12035) that examined the ecology and threats to three endangered species (Balston's Pygmy Perch, Little Pygmy Perch and Western Trout Minnow) revealed that they can represent up to 50% of dry-season refuge habitat for threatened fishes on certain streams (Beatty *et al.* 2015).

The latter project concluded that, while additional research is required, they have the potential to be an important and relatively cost-effective tool for off-setting the loss of refuge pools under drying climate scenarios; thereby increasing the resilience of declining freshwater fishes of south-western Australia. The study recommended that the specific characteristics of these pools (e.g. location in the landscape, instream and riparian habitat parameters, water quality) that optimises their use as fish refuge be determined by undertaking broad scale assessments. In determining those characteristics, a protocol for the successful creation of new dual purpose waterpoints that can both act as refuge and be used for their major purpose of increasing capacity to fight bushfire could be readily developed.

The Department of Parks of Wildlife (Parks and Wildlife) notified the proponents of their intention to enhance or create a number of fire-fighting pools in the Warren and Frankland regions. Recognising the potential to achieve a win-win in terms of increasing fire-fighting capability while protecting and even increasing the utility of the target pools for fish conservation, Parks and Wildlife requested an on-ground survey be conducted of these 12 existing pools to determine the resident fish communities, and their habitat and water quality characteristics. Additionally, a habitat and spatial assessment was conducted at 10 proposed new waterpoint sites in the Frankland region. Together, these surveys were required to determine how the fire pool enhancement program could be conducted to minimise the impact on resident species, to begin to

determine key characteristics of waterpoints that favour native fishes, and to recommend how the construction of new pools could be undertaken that would enable them to be used by native fishes as refuges while not impeding their core purpose of fighting bushfire.

Aims

Specific aims of the project were to:

- Determine the existing freshwater fish communities and habitat and water quality characteristics of fire-fighting waterpoints in the Warren bioregion that are planned to be upgraded by Parks and Wildlife.
- Assess the likelihood of the proposed waterpoint sites that are to be created in the Frankland region to act as refuge for fishes by undertaking a habitat and spatial assessment of the sites.
- Using the data collected, recommend a protocol to ensure existing waterpoints are upgraded in a way that that minimise the impact of native fish communities.
- Provide a preliminary assessment of the key habitat characteristics of waterpoints that optimise their utility as artificial refuges for endemic freshwater fishes.
- Finally, the project aimed to develop an approach that could be replicated in the future to eventually provide a framework for management and construction of current and future waterpoints for the purposes of both fire control and biodiversity conservation in south-western Australia.

Methods

Site Selection

The list of 12 existing and 10 proposed waterpoint sites that were surveyed in the current study were provided by Parks and Wildlife. Existing waterpoints (i.e. those that were to be renovated by Parks and Wildlife in autumn 2016), were located in the Donnelly, Warren, Gardner and Shannon River catchments (Table 1, Figure 1). An additional waterpoint was also surveyed (LPP Pool, Table 1) as it was known to house two endangered species and its addition in the assessment would add to the database on waterpoint habitat characteristics suitable for fishes.

Table 1: Existing Water Point Sites

Water point	Latitude	Longitude	Access
WP81	-34.5802	116.174124	Hogg Rd (off Middleton Rd)
WP92	-34.4953	116.332059	Lockyer Rd (off SW Highway)
WP224	-34.4435	116.338353	Sutton Road
WP343	-34.4415	116.10023	Munda Bididi just E of Pemberton
WP299	-34.5258	116.410378	Creek Bend Rd (near Curtin Tank Picnic ground)
WP334	-34.521	116.458827	Strachan Rd
WP347	-34.6032	116.407555	off Lower Shannon Rd
WP66	-34.4436	116.131588	Bannister Rd
WP71	-34.4848	116.106105	Collins Rd
WP323	-34.0861	115.894151	Well Rd
WP141	-34.1866	115.915438	Austin Rd
WP318	-34.3992	116.138531	off Vasse Hwy (NE of Pemberton)
LPP Pool	-34.7804	117.136653	Watershed Road

The locations of the proposed new waterpoints that were assessed for the likelihood of becoming refuge for native freshwater fishes are shown in Table 2 and Figure 2. The 10 waterpoints were located in the Frankland, Kent and Denmark catchments.

Table 2: Proposed Water Point Sites

Site	Latitude	Longitude	Access
13	-34.591	116.844246	Hiker Rd
14	-34.6254	116.894885	Durham Rd
15	-34.6853	117.076017	Bevan Rd
16	-34.6964	117.158558	Watershed Rd/Bevan Rd
17	-34.6137	117.177527	Watershed Rd/Biro Track
18	-34.5789	117.159388	Perillup Rd South
19	-34.5982	117.270114	off Clear Hills Rd
20	-34.6177	117.261359	off Clear Hills Rd
21	-34.6479	117.36951	off Pile Rd (behind Prison Farm)
22	-34.7078	117.335691	off Seymour Rd

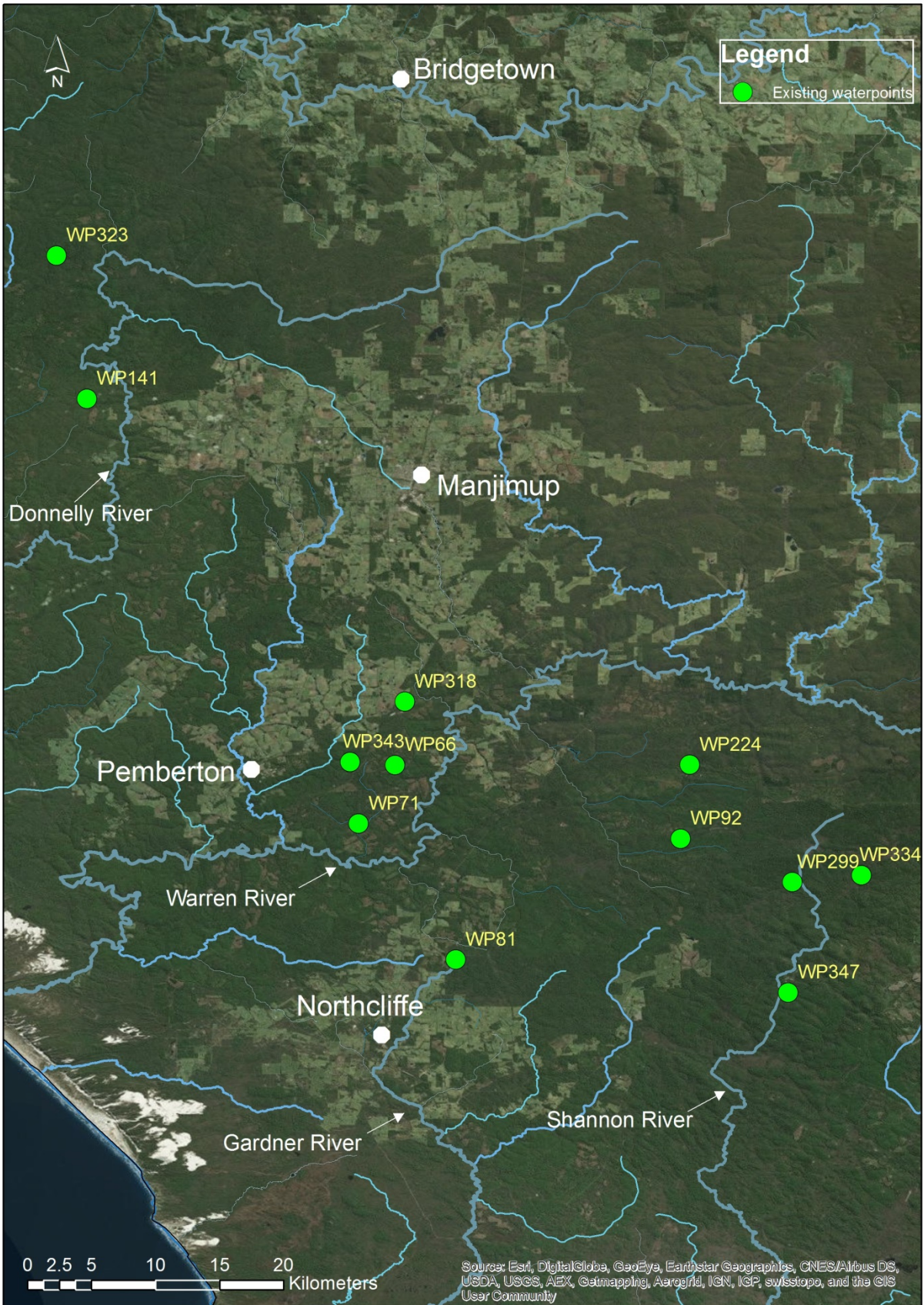


Figure 1: Location of the existing waterpoints that were surveyed for aquatic fauna in April 2016.

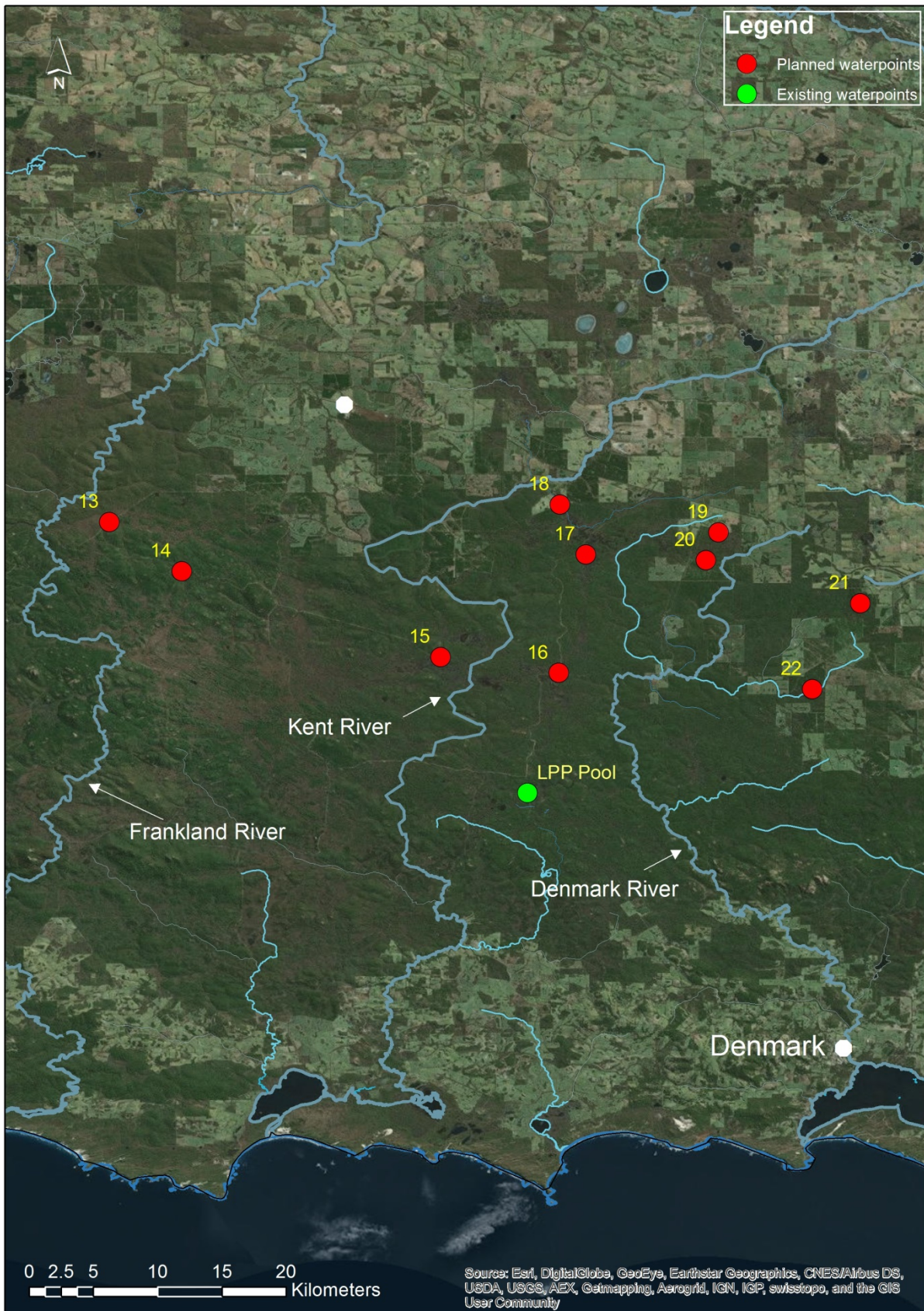


Figure 2: Location of the planned waterpoints that were assessed in April 2016.

Existing waterpoint aquatic fauna surveys

Three seine net (5 m net, 2 mm mesh width) pulls were conducted within each of the 12 waterpoints. All fish and crayfish were identified to species level, measured to the nearest 1 mm (total length (TL) for fish, orbital carapace length (OCL) for crayfish), held in a bucket while all netting was conducted in each pool, and then promptly returned to the water. Other animals captured, including tadpoles, were counted and returned to the water as soon as possible. Introduced fish species were euthanised according to the Murdoch University Ethics protocols disposed.

Mean (\pm 1S.E.) density of fish and crayfishes was calculated in each pool using the specific area of each drag of the net and the total number of individuals captured.

Water quality measurements were made immediately below the water surface, as close to the deepest point in the middle and at the middle depth of each wetland. The physicochemical variables were measured using a YSI™ Professional Plus multimeter (YSI Inc., Yellow Springs, Ohio 45387, USA) and included temperature ($^{\circ}$ C), pH, electrical conductivity (μ S/cm), salinity (ppt), and oxidation reduction potential (ORP).

Habitat features recorded at each site were based on those used in Ogston *et al.* (2016) and included features such as the wetland dimension (length, width, maximum depth, average depth), bank condition (angle of slope, height above the water level, overall condition) and habitat features (proportion of native vegetation, proportion of riparian vegetation shading, substrate composition, proportion of aquatic habitat features).

In addition, the relative location of each site was classified according to its position within the water catchment, by noting the elevation of each water point and the distance and elevation from the nearest major stream. These estimates were obtained by comparing elevation and measuring distances ARCGIS with gradient to the nearest major streamline being calculated (vertical metres per km). While the sampling occurred during the dry season, visual assessment of the connectedness to the streamline adjacent to each waterpoint was ranked using the following scale: 1 (situated with direct connectivity to a streamline), 2 (would connect seasonally during winter/spring), 3 (would connect periodically during flood events) and 4 (unlikely to connect).

For existing waterpoints, a qualitative ranking system was applied to assess the relative priority for management of each existing waterpoint based on their resident fauna. The categories in the system were:

- Very high – housed threatened endemic fishes.
- High – housed endemic fishes.
- Moderate – housed endemic crayfishes but not endemic fishes.
- Low – no endemic fishes or crayfishes present.

Proposed waterpoint surveys

A basic visual habitat and spatial assessment of the 10 proposed waterpoint sites in the Frankland, Kent and Denmark catchments was assessed qualitatively to determine the likelihood of the waterpoints, once created, being used by native fishes as refuge. While crayfish were not included in the ranking system, evidence of crayfish (Koonac) activity was recorded at each site (either live animals or burrows) and we assume those waterpoints would almost certainly be used by Koonacs.

The likelihood ranking system used in the current assessment was:

- Very likely – would have a very high probability of being a refuge for threatened endemic fishes.
- Moderately likely – would have a high probability of being a refuge for endemic fishes.
- Unlikely – would have a low probability of being a refuge for endemic fishes.
- Very unlikely – would have a very low probability of being a refuge for endemic fishes.

It should be noted that this was a preliminary assessment as was based on the authors' opinion underpinned by their knowledge of the movement patterns, life-histories and habitat requirements of the species known within each catchment, along with the previous sampling sites for freshwater fish within the catchments. A synthesis of the results from this study indicates some of the important factors influencing suitable native fish refuge, however recommendations are also provided to enable a more robust process for selecting sites and designing future waterpoints to maximise the probability of use by endemic and threatened fishes.

Results

The complete set of survey data for each site is provided in detail in Appendix A and a summary of results and is provided in the following pages for each of the surveyed locations.

The aim of the summary pages for each site is to outline the status of each wetland by providing a comparison of fish captures photographs of key habitat features, relative condition of water quality, instream habitat and riparian habitat and an overall assessment of the relative priority. In later sections we summarise the overall characteristics of waterpoints that correspond to native fish occurrence and highlight those factors thought to be most critical for suitable refuge habitat.

WP 141: Austin Road (Donnelly River Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
26/04/2016	Western minnow 4	0.15 ± 0.05
	Koonac 24	0.91 ± 0.5



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
85	35	Clay	80	Wood	10
		Sand	10		
		Gravel	10		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
12 x 6	13.5 x 7	1.2	0.8	40	1.0	Moderate (3)

Connectivity							
Local drainage		Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
Connected to Cow Brook		2	Donnelly River	2.5	217.0	27.0	10.8

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
14.5	175	142	7.5	-4

Overall Priority			
Very High	High	Moderate	Low

WP 323: Wells Road (Donnelly River Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
26/04/2016	Marron 83	1.8 ± 0.5
	Koonac 1	0.02



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
75	10	Clay	65	Wood	5
		Sand	30		
		Gravel	5		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
13.6 x 9	19 x 12.5	1.0	0.6	20	1.5	Good (2)

Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
Shallow depression	1	Donnelly River	3.4	290.0	60.0	17.6

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
17.1	108	83	7.9	101

Overall Priority			
Very High	High	Moderate	Low

WP 81: Hogg Road (Gardiner Creek Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
27/04/2016	Koonac 55	1.5 ± 0.9



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
60	0	Clay	85	Wood	10
		Sand	10		
		Gravel	5		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
10.5 x 7.3	13 x 12.6	1.6	1.0	70	1.3	Very Poor (5)

Connectivity							
Local drainage		Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
Not connected to drainage line		1	Gardiner Creek	0.5	166.0	15.0	30

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
14.9	404	325	6.9	157

Overall Priority			
Very High	High	Moderate	Low

WP 71: Collins Road (Warren Creek Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
27/04/2016	Western minnow 1	0.02
	Western pygmy perch 12	0.23 ± 1.0
	Nightfish 2	0.17



Habitat Features				
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)
Native Cover (%)	Shade (%)			
80	30	Clay	65	Wood 30
		Rock	30	Rock 10
		Gravel	5	



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
12 x 7.3	16 x 15	1.6	1.0	30	1.6	Good (2)

Connectivity							
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)	
Connects in winter and spring	3	Warren River	3.8	100.0	30.0	7.9	

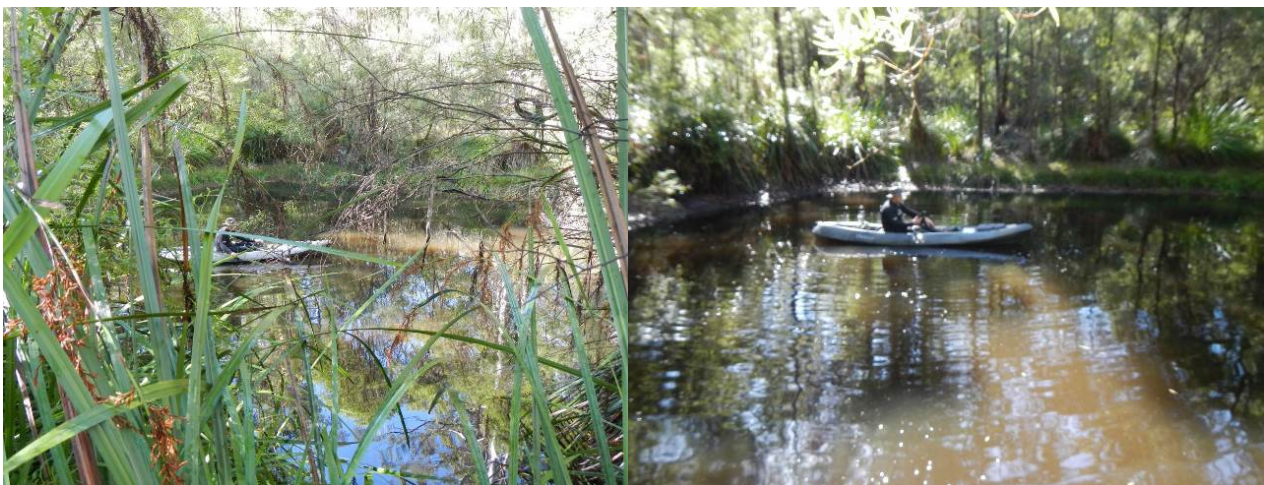
Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
14.5	294	239	7.5	54

Overall Priority			
Very High	High	Moderate	Low

WP 343: Munda Biddi Track (Lefroy Brook Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
27/04/2016	NO CAPTURES	

Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
90	20	Clay	100	Wood	5
				Plants	30



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
16.2 x 15	20 x 18	2.6	21.8	30	1.0	Very good (1)

Connectivity							
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)	
Poor - perched	1	Lefroy Brook	7.4	150.0	65.0	8.8	

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
14.6	204	166	7.4	101

Overall Priority			
Very High	High	Moderate	Low

WP 66: Bannister Road (Warren River Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
27/04/2016	Nighfish 10	0.31 ± 0.08
	Marron 6	0.25 ± 0.07



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
80	20	Clay	70	Wood	50
		Gravel	30		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
59 x 26	60 x 28	2.0	1.4	30, 70	1.8	Very good (1)

Connectivity							
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)	
Connected to tributary	2	Warren River	3.2	140	44	13.8	

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
15	187	150	6.9	121

Overall Priority			
Very High	High	Moderate	Low

WP 318: Off Vasse Highway (Warren River Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
28/04/2016	Marron 45	1.1 ± 0.33



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
95	35	Clay	90	Wood	20
		Gravel	10	Plants	10



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
28 x 15	29.5 x 16	3.3	2.5	80	0.3	Good (2)

Connectivity							
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)	
Connected to minor stream	1	Warren River	4.6	192	86	18.7	

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
14.7	759	611	7	33

Overall Priority			
Very High	High	Moderate	Low

WP 347: Off Lower Shannon Road (Shannon River Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
28/04/2016	Koonac 12	0.53 ± 0.07



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
60	30	Clay	75	Wood	20
		Gravel	25		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
12.5 x 7	21 x 15	0.3	0.2	45, 60	1.8	Poor (5)

Connectivity							
Local drainage		Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
Minor tributary of Shannon R.		2	Shannon River	0.3	160.0	8.0	26.7

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
12.9	116	99	7.2	64

Overall Priority			
Very High	High	Moderate	Low

WP 334: Strachan Road (Shannon River Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
28/04/2016	NO CAPTURES	

Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
95	25	Clay	70	Wood	0
		Sand	20		
		Gravel	10		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
1.8 x 1.2	15 x 12	0.1	0.0	35	1.7	Good (2)

Connectivity							
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)	
Connected to major tributary Shannon R.	3	Shannon River	3.7	198.0	6.0	1.6	

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
DRY				

Overall Priority			
Very High	High	Moderate	Low

WP 299: Creek Bend Road (Shannon River Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
28/04/2016	Western minnow 90	1.61 ± 1.28
	Western pygmy perch 142	2.20 ± 0.10
	Balstons pygmy perch 12	0.43
	Nightfish 29	0.38 ± 0.26
	Marron 71	0.97 ± 0.58



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
95	15	Clay	90	Wood	5
		Gravel	10		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
12 x 8	14 x 10	1.4	0.9	45	1.2	Good (2)

Connectivity							
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)	
Connected to tributary of Shannon R.	2	Shannon River	0.6	191.0	3.0	5.0	

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
13.5	214	176	7.1	74

Overall Priority			
Very High	High	Moderate	Low

WP 92: Lockyer Road (Quinninup Brook Catchment)

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
28/04/2016	Marron 82	2.72 ± 0.33



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
70	15	Clay	60	Wood	5
		Sand	30		
		Gravel	10		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
30 x 11	35 x 13	1.8	1.2	85	0.8	Good (2)

Connectivity

Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
Offstream in upper 6 Mile Brook	1	Quinninup Brook	8.2	200.0	58.0	7.1

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
13.4	168	140	7.2	76

Overall Priority			
Very High	High	Moderate	Low

WP 224: Sutton Road (Warren River Catchment)

Date	Aquatic Biota Captured	Mean Density (no. /m ²)
28/04/2016	NO CAPTURES	

Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
60	10	Clay	60	Wood	5
		Sand	20		
		Gravel	20		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
11 x 8.6	11 x 10	1.1	0.8	45, 90	1.5	Moderate (3)

Connectivity

Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
Perched offstream from Tutors Brook	2	Warren River	8.0	192.0	64.0	8.0

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
13	197	167	7.1	23

Overall Priority			
Very High	High	Moderate	Low

Little Pygmy Creek Refuge Fire Point

Sampling Results		
Date	Aquatic Biota Captured	Mean Density (no. /m ²)
30/04/2016	Western minnow 2	0.17
	Western pygmy perch 58	1.58 ± 0.27
	Balstons pygmy perch 28	0.91 ± 0.25
	Nightfish 29	0.38 ± 0.26
	Little Pygmy Perch 5	0.33



Habitat Features					
Riparian Vegetation		Substrate (%)		Aquatic habitat (%)	
Native Cover (%)	Shade (%)				
30	10	Clay	60	Wood	10
		Sand	30		
		Gravel	10		



Physical Characteristics						
Size (L x W (m))		Depth (m)		Bank Condition		
Current	Full Supply	Maximum	Average	Slope (Degrees)	Height (m)	Condition (1 - 5)
16.5 x 9.5	18 x 11	3.2	1.5	25, 35	0.9	Good (2)

Connectivity

Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
On Drainage line	2	Denmark River	9.0	120.0	6.0	0.7

Water Quality (middle of water column)				
Temp. (°C)	EC (µS/cm)	TDS (mg/L)	pH	ORP (mV)
14.5	496	403	7.7	53

Overall Priority			
Very High	High	Moderate	Low

Proposed waterpoint assessment

The proximity of the proposed waterpoints to the known distribution of native freshwater fishes is shown in Figure 3. It can be seen that most sampling effort has previously occurred in the middle parts of the catchment, however, upper reaches of the Kent and Frankland (not shown) generally contain lower diversity than middle and lower reaches presumably due to increased salinity upstream. Balston's Pygmy Perch, Western Mud Minnow and Little Pygmy Perch are particularly sensitive to salinity and all are relatively restricted compared to the more common and widespread Western Minnow, Western Pygmy Perch and Nightfish. We took the known and presumed distribution of native fishes in the nearest major rivers to the proposed waterpoint sites in each site assessment that follows.

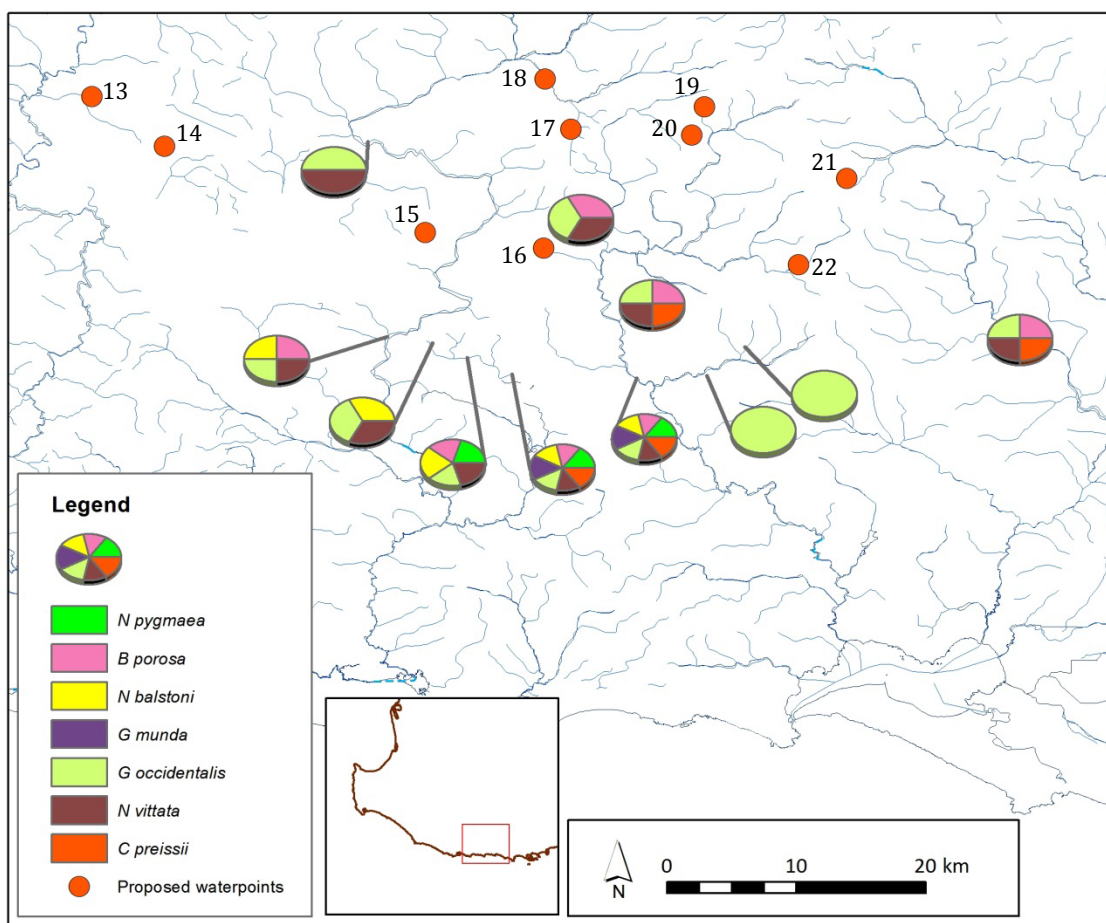


Figure 3: Shows the locations of the planned new waterpoints in relation to the known distributions of native fishes in the area (see Beatty *et al.* 2015).

PWP 13: Hiker Road



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
Upper Tributary	1	Frankland River	4.3	158	6	1.4

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
14.6	77	62	7.8	140

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Has a very low gradient and moderate distance to the Frankland River*
- *Moderate likelihood of the Western Minnow accessing the pool given its migratory ability and tolerance to salinity. It is likely that species uses this tributary for breeding*

PWP 14: Durham Road



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream	Gradient from Stream
Upper Tributary	1	Frankland River	13.9	217	87	6.3

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
15.4	90	72	7.6	126

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Has a relatively low gradient, however, the large distance to the Frankland River reduces the likelihood of use by native fishes*
- *Would be colonised by Koonacs as burrows were present*

PWP 15: Bevan Road



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream	Gradient from Stream
Upper Tributary, indistinct	3	Kent River	4.1	147	10	2.4

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
DRY				

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Confluence of the drainage line with the Kent River is adjacent to important refuge pools for Balston's Pygmy Perch and Little Pygmy Perch*
- *Low gradient to the Kent River increases chances of colonization by native fishes for breeding. (Somewhat indistinct drainage line to the Kent River)*
- *While Little Pygmy Perch has only been demonstrated to seasonally migrate ~3km in the Mitchell River, it utilizes artificial pools that are 9km from the Denmark River. Balston's Pygmy Perch can migrate ~15 km upstream to breed in Milyeannup Brook*
- *Alternative location for the waterpoint (~100 m east along Bevan Rd S 34.685005, E117.077491) may increase connectivity of the site as would be on drainage channel, however, the condition of Bevan Rd there is boggy that may hamper fire access*

PWP 16: Corner of Watershed and Bevan Roads



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream	Gradient from Stream
Upper Tributary, indistinct	1	Kent River	5.8	150	10	1.7

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
14.4	131	105	9.1	59

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Has a relatively low gradient to the section of the Kent River that has good diversity of native fishes*
- *However, aside from the excavated drain dug from the Watershed Rd (pictured), much of the drainage line to the Kent River appears to be indistinct and, along with the distance, may reduce the likelihood of use by native fishes*

PWP 17: Corner of Watershed Road and Biro Track



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream	Gradient from Stream
Upper Tributary, very indistinct	1	Kent River	13.9	200	50	3.6

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
DRY				

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Located close to the Denmark River, but is within the Kent catchment*
- *Very indistinct drainage line, large distance to the Kent River and confluence likely has relatively low fish diversity*

PWP 18: Perillup Road South



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream	Gradient from Stream
On large Upper Tributary	1	Kent River	2.1	193	5	2.4

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
14.4	10308	8390	7.2	71

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Very good connectivity to the Kent River*
- *Likelihood of Western Minnows colonising the waterpoint. However, relatively high salinity would probably prevent other species being present in this stream*
- *Koonac burrows observed*

PWP 19: Off Clear Hills Road



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient from Stream (m/km)
Upper Tributary	1	Denmark River	2.4	235	15	6.25

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
14.7	759	611	7	33

Overall likelihood

Very likely	Mod. likely	Unlikely	Very unlikely

- *Relatively close to the Denmark River*
- *Likelihood of Western Minnows colonising the waterpoint*

PWP 20: Off Clear Hills Road (Adjacent to Blue Gum Plantation)



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream	Gradient from Stream
Shallow Upper Tributary	1	Denmark River	20.4	235	85	4.2

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
12.9	116	99	7.2	64

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Very indistinct drainage line, large distance to the Denmark River*

PWP 21: Off Pile Road



Connectivity						
Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream	Gradient from Stream
Shallow drainage	1	Hay River	2.6	246	23	8.8

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
DRY				

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Very indistinct drainage line*
- *Quite close to upper Hay River, but that has relatively low diversity of fish and the drainage line doesn't appear to enable a migration pathway for fishes*

PWP 22: Seymour Road



Connectivity

Local drainage	Stream Order	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream	Gradient from Stream
Shallow drainage	2	Denmark River	11.7	200	45	3.8

Water Quality (middle of water column)				
Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)
13.5	214	176	7.1	74

Overall likelihood			
Very likely	Mod. likely	Unlikely	Very unlikely

- *Very indistinct drainage line, large distance to the upper Denmark River that has relatively low diversity of fish*

Discussion

Existing waterpoints

Four of the 12 (~33%) of the existing waterpoints scheduled for renovation housed native fishes, and 8 (~67%) housed endemic freshwater crayfishes (Table 3). Native fishes included the three most common south-western Australian endemic fishes the Western Minnow, Western Pygmy Perch and Nightfish. Importantly, WP299 housed the highest diversity of fishes (four species) of the existing waterpoints that are to be renovated and these included the EPBC listed (*Vulnerable*) Balston's Pygmy Perch. The additional waterpoint on Little Pygmy Perch Creek housed the greatest overall fish diversity (five species) including the Balston's Pygmy Perch and the Little Pygmy Perch; the latter of which was recently listed as *Endangered*.

While the limited number of waterpoints surveyed in the current study does not allow a robust analysis of the factors explaining the presence/absence, richness, or density of native fish in those habitats (that would be undertaken using principal components analysis, followed by Generalized Linear Modelling with model averaging (see Ogston *et al.* 2016), some key factors are notable. A simple comparison of means of key factors between those that housed fish and those that did not was undertaken to begin to identify those characteristics that may best explain their use by native species (see Table 4). The mean connectivity ranking of those waterpoints that had native fish present was 1.20 (± 0.2 S.E.) compared to a mean of 2.75 (± 0.45) for those that did not ($F = 6.61$ $p = 0.026$) (Table 4). This reflected the fact that all five waterpoints that housed native fishes (including the refuge on Little Pygmy Perch Creek) had a direct link to the local streamline that would ensure they were connected during periods of flow, rather than being off the channel or potentially only connecting in extreme flood conditions.

The gradient to the nearest major streamline was half as steep for those that housed native fish (i.e., 7.63 ± 2.26 m/km) compared with those that did not (14.81 ± 3.56 m/km) although this difference was not significant ($p = 0.17$). Sites with fish were also slightly deeper, and nearer to major streamlines although these factors were not significant.

We believe that these factors, along with others that may be revealed in a broader, more robust analysis will enable a clear picture of specific design and location criteria that could be used to develop a specific set of guidelines for the renovation and future creation of additional waterpoints that will be colonized and used by endemic fishes as additional dry-season refuge (see recommendations).

Two waterpoints stand out as having potential of becoming useful as native fish refuge (including for the *Vulnerable* Balston's Pygmy Perch) through the renovation process; as they match several of the preliminary key criteria highlighted above. Waterpoint 347 is directly on a streamline, and very close (300m) to the lower Shannon River (that is known to house a high diversity of fishes), and therefore may have high potential to be colonized by native fishes if it had greater depth. It was also impacted by the major bushfires that occurred in January 2015 and a noticeable layer of ash was present in the sediment, increasing the depth through excavation would remove the layer. However, while being close to the Shannon River, 347 also has a considerable gradient to it (~27m/km) that may prevent colonization should natural instream barriers be present in the 300m streamline to the main channel of the Shannon River.

Waterpoint 334, also in the Shannon River catchment, also has good connectivity to a major tributary of the Shannon River and at the time of sampling was almost completely dry. The waterpoint is 3.7 km from the main channel of the Shannon River (approximating the mean distance of other waterpoints that housed native fish) and had a very low gradient (i.e., 1.6 m/km) suggesting that there would not exist any significant instream barriers preventing fish migrating as far as the waterpoint. Should renovation of the waterpoint achieve a depth that ensures it remains permanent, it is likely that it would be colonized by native fish and utilised as a dry-season refuge.

Planned waterpoints

Four of the 10 (~40%) of the planned waterpoints scheduled for creation (site 13, 15, 18, 19) had a moderate likelihood of being colonised by native fishes. Therefore, most were unlikely or very unlikely to be situated in a location that would result in them becoming dual purpose waterpoints. Those that had increased likelihood were classified due to them being relatively connected to a streamline, relatively close to a major river, and having a relatively low gradient to the river.

Future assessments of the likelihood of planned waterpoints sites becoming refuge habitats for native fish should be based on protocols developed by replicating the survey methods undertaken here more broadly, along with undertaking sampling of the planned locations during winter-spring to determine whether fish seasonally migrate to those locations for breeding.

Other considerations

While a suitable water depth of at least greater than 2 m appears to be necessary to maintain sufficient summer refuge, other topographic features may also enhance the habitat features for native fish species. Some of these features may include terraced banks (to provide a higher proportion of shallow habitat), introduction of artificial aquatic habitat (such as large wood or rock structure), planting additional fringing vegetation and enhancing riparian vegetation to provide greater shade.

The density and complexity on aquatic habitat of waterpoints was not found to have a major influence on the presence of native fish in this current study. However, numerous studies (e.g. McNeil *et al.* 2013) have shown that the resilience of suitable refuge habitat is influenced by the amount and diversity of instream habitat features (including complex woody structure and aquatic macrophytes). The assessment of additional waterpoints is likely to demonstrate a higher correlation between native species occurrence and aquatic habitat features.

The relocation of native fish species (particularly threatened species) needs to be undertaken with approval from appropriate state and federal fisheries and conservation organisations. Some of the important considerations will include the known distribution ranges of species, maintaining the genetic integrity of endemic populations and minimising the spread of pests and diseases. A relocation strategy should be developed in liaison with these groups and the relevant catchment managers (e.g. Department of Parks and Wildlife and Natural Resource Management Groups).

Table 3: Summary of the key spatial, habitat and water quality variables of the existing waterpoints surveyed in April 2016.

Site	Number of Native Fish Species	Number of Native Crayfish Species	Protected Species	Full Size (m ²)	Maximum Water Depth (m)	Mean Water Depth (m)	Riparian Coverage (%)	Shade (% coverage)	Aquatic Habitat (% coverage)	Stream Connectivity (1 - 4)	Elevation of Waterpoint (m)	Stream Order	Distance to Major Stream (km)	Gradient to Major Stream (m/km)	Water Quality	Overall Priority
WP141	1	1		95	1.2	0.8	85	35	10	1	217.0	2	2.5	10.8	SUITABLE	High
WP323		2		238	1	0.6	75	10	5	3	290.0	1	3.4	17.6	SUITABLE	Moderate
WP81		1		164	1.6	1	60	0	10	4	166.0	1	0.5	30.0	SUITABLE	Moderate
WP71	3			240	1.6	1	80	30	40	2	100.0	3	3.8	7.9	SUITABLE	High
WP343				360	2.6	1.8	90	20	35	4	150.0	1	7.4	8.8	SUITABLE	Low
WP66	1	1		1680	2	1.4	80	20	50	1	140.0	2	3.2	13.8	SUITABLE	High
WP318		1		472	3.3	2.5	95	35	50	2	192.0	1	4.6	18.7	SUITABLE	Moderate
WP347		1		315	0.3	0.2	60	30	20	1	160.0	2	0.3	26.7	POOR	Moderate
WP334		1		180	0.1	0	95	25	0	1	198.0	3	3.7	1.6	DRY	Moderate
WP299	4	1	Balstons PP	140	1.4	0.9	95	15	5	1	191.0	2	0.6	5.0	SUITABLE	Very High
WP92		1		455	1.8	1.2	70	15	5	3	200.0	1	8.2	7.1	SUITABLE	Moderate
WP224				110	1.1	0.8	60	10	5	4	192.0	2	8.0	8.0	SUITABLE	Low
LPP WP	5		Balstons PP Little PP	180	3.2	1.5	30	10	10	1	120.0	2	9.0	0.7	SUITABLE	Very High

Table 4: Mean values of key parameters of waterpoints where native fish were present and absent in April 2016.

		Mean	SE	Min	Max	F	p value
Max. surface area (m ²)	Absent	286.66	47.990	110.00	472.00		
	Present	470.50	303.388	94.50	1680.00		
	Total	357.37	115.299	94.50	1680.00	.581	.462
Max. depth (m)	Absent	1.48	.386	.10	3.30		
	Present	1.88	.356	1.20	3.20		
	Total	1.63	.270	.10	3.30	.510	.490
Mean depth (m)	Absent	1.01	.292	0.00	2.50		
	Present	1.12	.139	.80	1.50		
	Total	1.05	.182	0.00	2.50	.076	.788
Native riparian (%)	Absent	75.63	5.545	60.00	95.00		
	Present	74.00	11.336	30.00	95.00		
	Total	75.00	5.250	30.00	95.00	.021	.888
Shade (%)	Absent	18.13	4.112	0.00	35.00		
	Present	22.00	4.637	10.00	35.00		
	Total	19.62	3.020	0.00	35.00	.369	.556
Stream connectivity (1-4)	Absent	2.75	.453	1.00	4.00		
	Present	1.20	.200	1.00	2.00		
	Total	2.15	.355	1.00	4.00	6.611	.026
Stream order	Absent	1.50	.267	1.00	3.00		
	Present	2.20	.200	2.00	3.00		
	Total	1.77	.201	1.00	3.00	3.455	.090
Distance to major stream (km)	Absent	4.51	1.117	.30	8.20		
	Present	3.82	1.402	.60	9.00		
	Total	4.25	.842	.30	9.00	.149	.707
Elevation of waterpoint (m)	Absent	193.50	15.324	150.00	290.00		
	Present	153.60	21.915	100.00	217.00		
	Total	178.15	13.314	100.00	290.00	2.368	.152
Elevation to confluence of major stream (m)	Absent	45.25	10.877	6.00	86.00		
	Present	22.00	7.714	3.00	44.00		
	Total	36.31	7.795	3.00	86.00	2.341	.154
Gradient to confluence of major stream (m/km)	Absent	14.81	3.563	1.62	30.00		
	Present	7.63	2.264	.70	13.75		
	Total	12.05	2.496	.70	30.00	2.146	.171
Temperature	Absent	14.37	.554	12.90	17.10		
	Present	14.38	.315	13.50	15.00		
	Total	14.37	.358	12.90	17.10	.000	.996
Conductivity (μS/cm)	Absent	279.43	88.170	108.00	759.00		
	Present	217.50	26.772	175.00	294.00		
	Total	256.91	55.992	108.00	759.00	.262	.621
TDS	Absent	227.29	70.554	83.00	611.00		
	Present	176.75	21.982	142.00	239.00		
	Total	208.91	44.860	83.00	611.00	.272	.614
pH	Absent	7.24	.125	6.90	7.90		
	Present	7.25	.150	6.90	7.50		
	Total	7.25	.092	6.90	7.90	.001	.972
ORP (mV)	Absent	79.29	17.277	23.00	157.00		
	Present	61.25	25.889	-4.00	121.00		
	Total	72.73	13.951	-4.00	157.00	.362	.562

Recommendations

The current study represents the first step in developing dual-purpose waterpoints that can act as crucial dry-season refuge for endemic south-western Australian fishes, while also increasing fire-fighting capacity in the regions by creating new water sources.

The methodology developed here enabled an efficient assessment of the aquatic fauna within waterpoints along with key factors that need to be assessed in order to develop design and construction protocols to create new dual purpose waterpoints. A proposed process and timeline for developing a robust protocol for future waterpoints is presented in Figure 4.

The analysis of results from the current project helped to generate the following recommendations to manage waterpoint renovations:

- The highest priority waterpoints for the proposed relocation strategy are 299 (four species including Balston's Pygmy Perch), 71 (three endemic fishes), 66 and 141 (each with one endemic fish species).
- Waterpoints 347 and 344 should be renovated to a relatively depth that ensures they remain permanent during the dry season, and any renovation should not cause the waterpoints to become separated from the streamline during peak flow events (e.g., by the creation of a bank or barrier).

Key recommendations to fill knowledge gaps that will ensure a robust design protocol and maximize the conservation benefits of future waterpoints for endemic fishes, include:

- increasing the number of waterpoints that are surveyed to enable robust modelling of those factors correlated with the occurrence of native fishes.
- expansion of the survey will simultaneously increase our current knowledge of the distribution of native fish to more effectively monitor future changes.
- conducting further assessment in the higher flows of winter-spring while fish are attempting to migrate in streams adjacent to proposed waterpoints.
- accessing the depth to groundwater and relative contribution of ground and surface waters be determined in an expanded study (see Ogston *et al.* 2016).

The study developed a process to ensure that planned renovation of existing waterpoints have minimal impact on native and endangered freshwater fishes and recommendations that include:

- expansion of the survey to include all waterpoints planned to be renovated (recommended above).
- identification of high priority waterpoints likely to provide important native fish refuge.
- developing a systematic relocation program for native fish.
- relocating fish to appropriate alternative refuge pools within the same catchment (based on preliminary criteria identified in the current study).
- confirming the likely re-colonisation of waterpoints by native fish following renovation.

Dual purpose waterpoints: design and renovation strategy

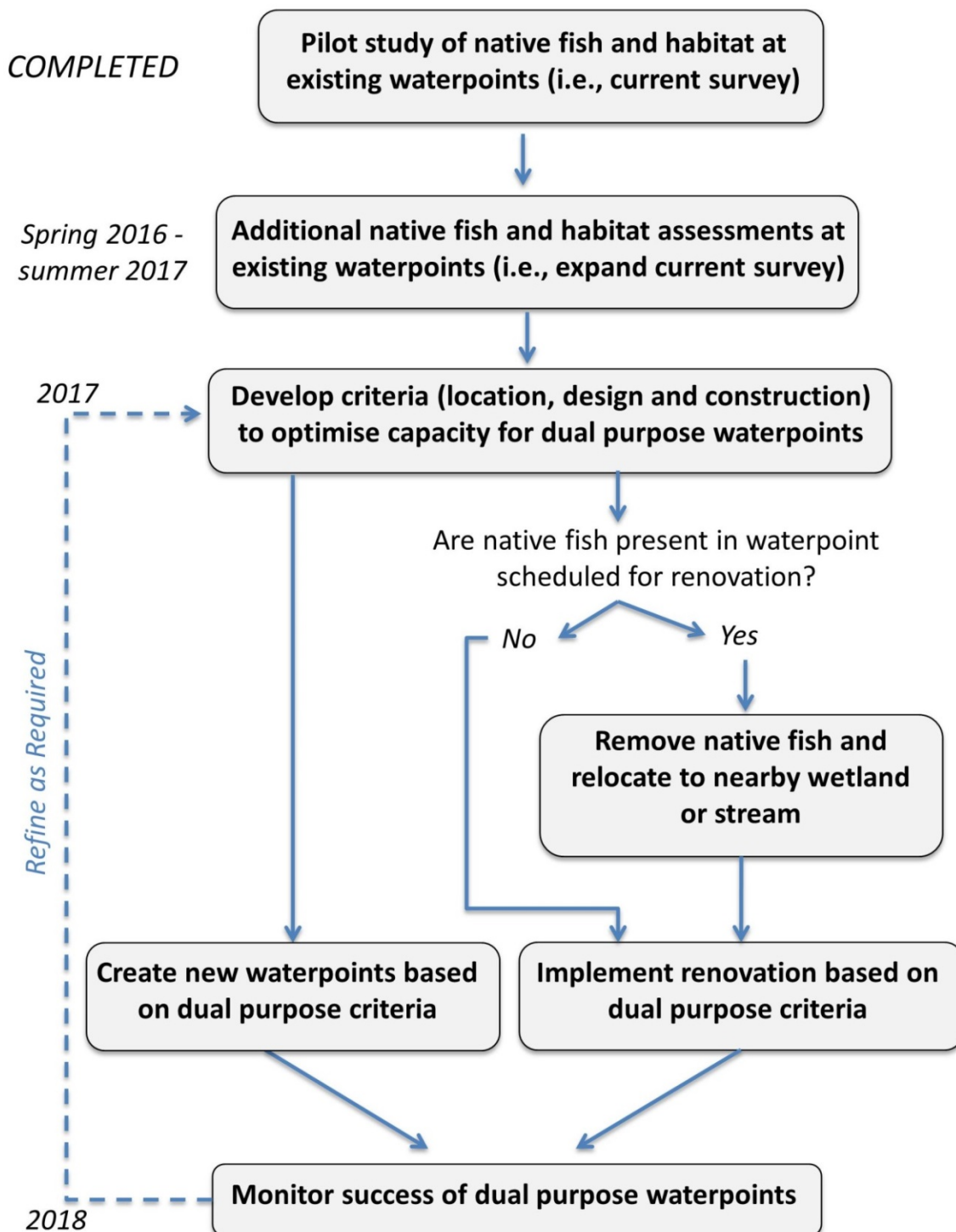


Figure 4: Proposed process for developing a robust protocol to design, create, manage and monitor dual purpose waterpoints for aquatic refuge and fire-fighting in south-western Australia.

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Appendix 1: Faunal, spatial, habitat, and water quality data from existing waterpoints surveyed in April 2016.

Water Point	Date	Native fish captured							Native crayfish captured				Waterbody Size		Water body depth		Bank profile and condition			Riparian Vegetation		Substrate (%)				Aquatic habitat (%)		
		Native fish present (1 = y, 0 = n)	Number of native fish species	Western minnow	Nightfish	Western pygmy perch	Balston's pygmy perch	Little pygmy perch	Native crayfish species	Number of native crayfish	Koonac	Smooth marron	Full Supply (m)	Surface Area (m2)	Maximum (m)	Average (m)	Slope (Degrees)	Height (m)	Bank Condition (1 - 5)	Native Cover (%)	Shade (%)	Clay	Sand	Gravel	Rock	Wood	Rock	Plants
WP141	26/04/2016	1	1	4				1	1	24		13.5 x 7	94.5	1.2	0.8	40	1.0	Moderate (3)	85	35	80	10	10		10			
WP323	26/04/2016	0	0					1	2	1	83	19 x 12.5	237.5	1.0	0.6	20	1.5	Good (2)	75	10	65	30	5		5			
WP81	27/04/2016	0	0					1	1	55		13 x 12.6	163.8	1.6	1.0	70	1.3	Very Poor (5)	60	0	85	10	5		10			
WP71	27/04/2016	1	3	1	2	12		0	0			16 x 15	240	1.6	1.0	30	1.6	Good (2)	80	30	65		5	30	30	10		
WP343	27/04/2016	0	0					0	0			20 x 18	360	2.6	21.8	30	1.0	Very good (1)	90	20	100				5		30	
WP66	27/04/2016	1	1		10			1	0		6	60 x 28	1680	2.0	1.4	30, 70	1.8	Very good (1)	80	20	70		30		50			
WP318	28/04/2016	0	0					1	0		45	29.5 x 16	472	3.3	2.5	80	0.3	Good (2)	95	35	90		10		40		10	
WP347	28/04/2016	0	0					1	1	12		21 x 15	315	0.3	0.2	45, 60	1.8	Poor (5)	60	30	75		25		20			
WP334	28/04/2016	0	0					0	0			15 x 12	180	0.1	0.0	35	1.7	Good (2)	95	25	70	20	10		0			
WP299	28/04/2016	1	4	90	29	142	12	1	1		71	14 x 10	140	1.4	0.9	45	1.2	Good (2)	95	15	90		10		5			
WP92	28/04/2016	0	0					1	1		82	35 x 13	455	1.8	1.2	85	0.8	Good (2)	70	15	60	30	10		5			
WP224	28/04/2016	0	0					0	0			11 x 10	110	1.1	0.8	45, 90	1.5	Moderate (3)	60	10	60	20	20		5			
LPP WP	30/04/2016	1	5	2	29	58	28	5	0	0		18 x 11	180	3.2	1.5	25, 35	0.9	Good (2)	30	10	60	30	10		10			

Appendix 1. (Cont.) - Faunal, spatial, habitat, and water quality data from existing waterpoints surveyed in April 2016)

Water Point	Date	Waterbody Connectivity with local catchment								Water Quality					Description
		Local drainage	Stream Order	Connectivity Category (1-4)	Nearest stream	Distance (km)	Elevation (m)	Elevation from Stream (m)	Gradient (m/km)	Temp. (oC)	EC (uS/cm)	TDS (mg/L)	pH	ORP (mV)	
WP141	26/04/2016	Connected to Cow Brook	2	1	Donnelly River	2.5	217.0	27.0	10.8	14.5	175	142	7.5	-4	On stream wetland In good condition. Lacking aquatic habitat.
WP323	26/04/2016	Shallow depression	1	3	Donnelly River	3.4	290.0	60.0	17.6	17.1	108	83	7.9	101	Off stream wetland in good condition. Lacking aquatic habitat.
WP81	27/04/2016	Not connected to drainage line	1	4	Gardiner Creek	0.5	166.0	15.0	30.0	14.9	404	325	6.9	157	Off stream wetland in good condition. Lacking aquatic habitat.
WP71	27/04/2016	Connects in winter and spring	3	2	Warren River	3.8	100.0	30.0	7.9	14.5	294	239	7.5	54	Off stream wetland in good condition with good aquatic habitat
WP343	27/04/2016	Poor - perched	1	4	Lefroy Brook	7.4	150.0	65.0	8.8	14.6	204	166	7.4	101	Off stream wetland in good condition with excellent aquatic habitat
WP66	27/04/2016	Connected to drainage line	2	1	Warren River	3.2	140.0	44.0	13.8	15	187	150	6.9	121	On stream wetland In good condition with excellent aquatic habitat
WP318	28/04/2016	Connected to minor stream	1	2	Warren River	4.6	192.0	86.0	18.7	14.7	759	611	7	33	Deep offstream wetland In good condition
WP347	28/04/2016	Connected to minor trib of Shannon	2	1	Shannon River	0.3	160.0	8.0	26.7	12.9	116	99	7.2	64	Full of silt and due to fire runoff
WP334	28/04/2016	Connected to major tributary Shannon R.	3	1	Shannon River	3.7	198.0	6.0	1.6	DRY					With extra capacity would provide good refuge for upper catchment
WP299	28/04/2016	Connected to tributary of Shannon R.	2	1	Shannon River	0.6	191.0	3.0	5.0	13.5	214	176	7.1	74	On stream wetland In good condition. Supporting abundant and diverse native fish population.
WP92	28/04/2016	Offstream in upper 6 Mile Brook	1	3	Quinninup Brook	8.2	200.0	58.0	7.1	13.4	168	140	7.2	76	Off stream wetland in good condition with good aquatic habitat
WP224	28/04/2016	Perched offstream in upper Tutors Brook	2	4	Warren River	8.0	192.0	64.0	8.0	13	197	167	7.1	23	Off stream wetland in good condition with good aquatic habitat
LPP WP	30/04/2016	On LPP Creek	2	1	Denmark River	9.0	120.0	6.0	0.7	14.5	496	403	7.7	53	On stream wetland In good condition. Supporting abundant and diverse native fish population.