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Indigenous cultural and ecological values of the Donnelly River and their water requirements

Part B: Review of the literature

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Acknowledgement of Country

We acknowledge the Traditional Owners of Country throughout Australia and their continuing connection to and stewardship of land, sea and community. We pay our respects to them and their cultures and to their Ancestors, Elders and future leaders. Our Indigenous research partnerships are a valued and respected component of National Environmental Science Program research.

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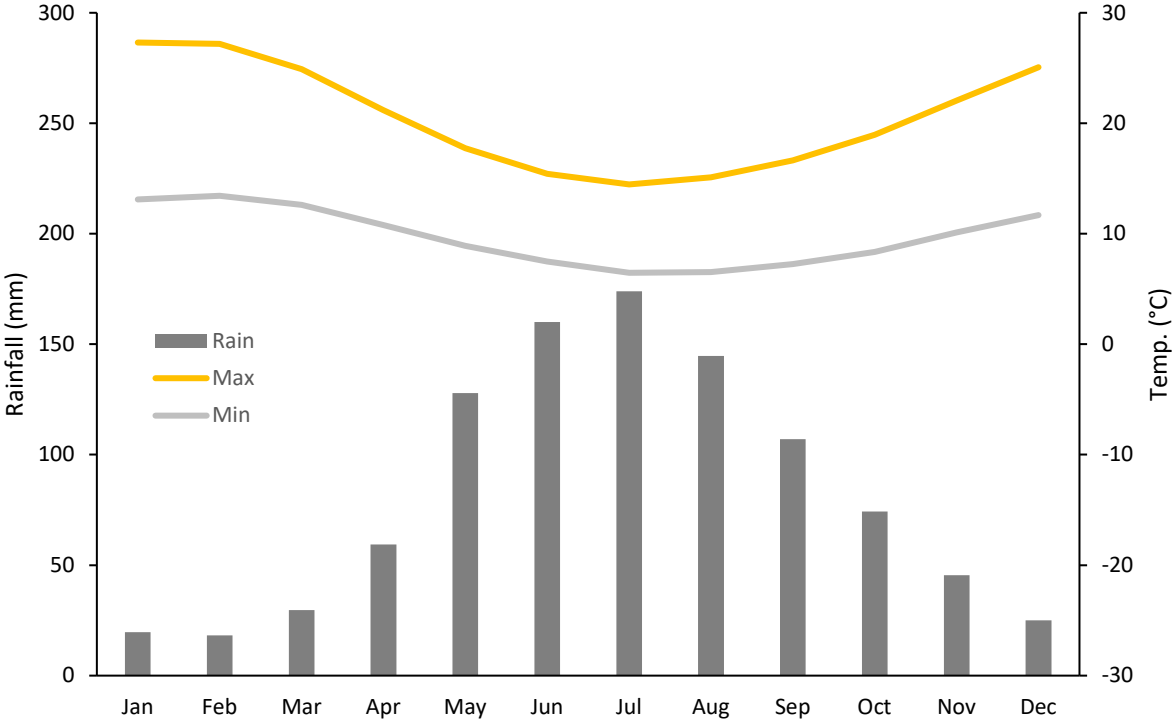


1 Introduction

This report is Part B of a report on the Indigenous cultural values and ecological values associated with the Donnelly River. Part A of the report details an approach developing a conceptual hydro-socio-ecological (HSE) model and principles and considerations for water managers seeking to understand and protect Indigenous cultural and ecological values supported by freshwater flows. Here, in Part B, we provide a review of the literature supporting the HSE model and principles and considerations.

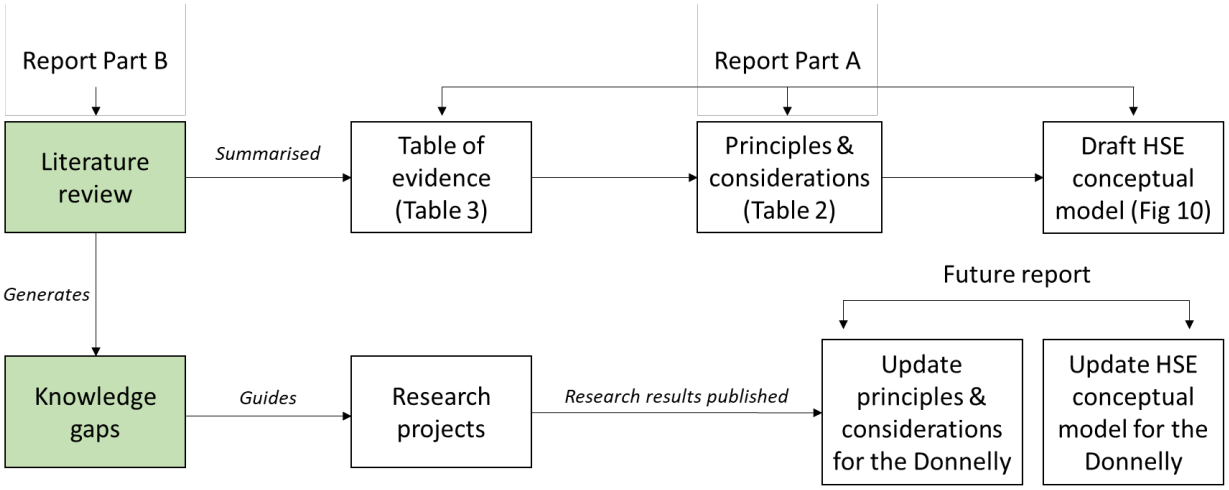


Figure 1. Workflow showing the components of the current report (Parts A and B) and how they inform on-going work.

For the literature review we followed the process used to develop the original HSE model for the Fitzroy River (Douglas et al., 2019). Information was sourced from discoverable literature, primarily published studies. Evidence was sought at 3 spatial scales: the Donnelly River itself (local), the Warren Bioregion (regional) and elsewhere. Elsewhere includes other areas in south-west Western Australia (SWWA). For each value we identify key knowledge gaps.

Specifically, we report on the following:

- Background information on the physical setting of the Donnelly River.
- A review of discoverable information for Indigenous cultural values relating to flows of the Donnelly River or nearby catchments where applicable.
- A review of discoverable, peer-reviewed and published information on the flow-ecology relationships for ecological values of the Donnelly River.
- Knowledge gaps for each value.

Our focus was on flowing riverine environments that are impacted by changes in river flows. Therefore, information derived from lakes and wetlands not connected to rivers, and estuarine and adjacent coastal marine ecosystems was not included in our review.

2 Physical setting

Climate and hydrology

The Donnelly River catchment has a Mediterranean-type climate, with highly seasonal rainfall and temperatures (Figure 2). Average maximum temperature is 27.3 °C in January, with cooler temperatures in winter with an average maximum of 14.5 °C in July. The majority of rainfall is in the winter months, with 72% of rainfall occurring between 1 May and 30 September, with an average monthly rainfall of 18.2 in February and 174 mm in July (BOM, 2025a). Rainfall varies considerably across the catchment, with the north-east section near Yornup receiving an annual average of 645 mm, the area east of Manjimup ~ 980 mm, and the south-east part receiving ~1100 mm (average annual rainfall from Bureau of Meteorology (BoM) interpolated dataset). The majority of the catchment receives approximately 980 mm.

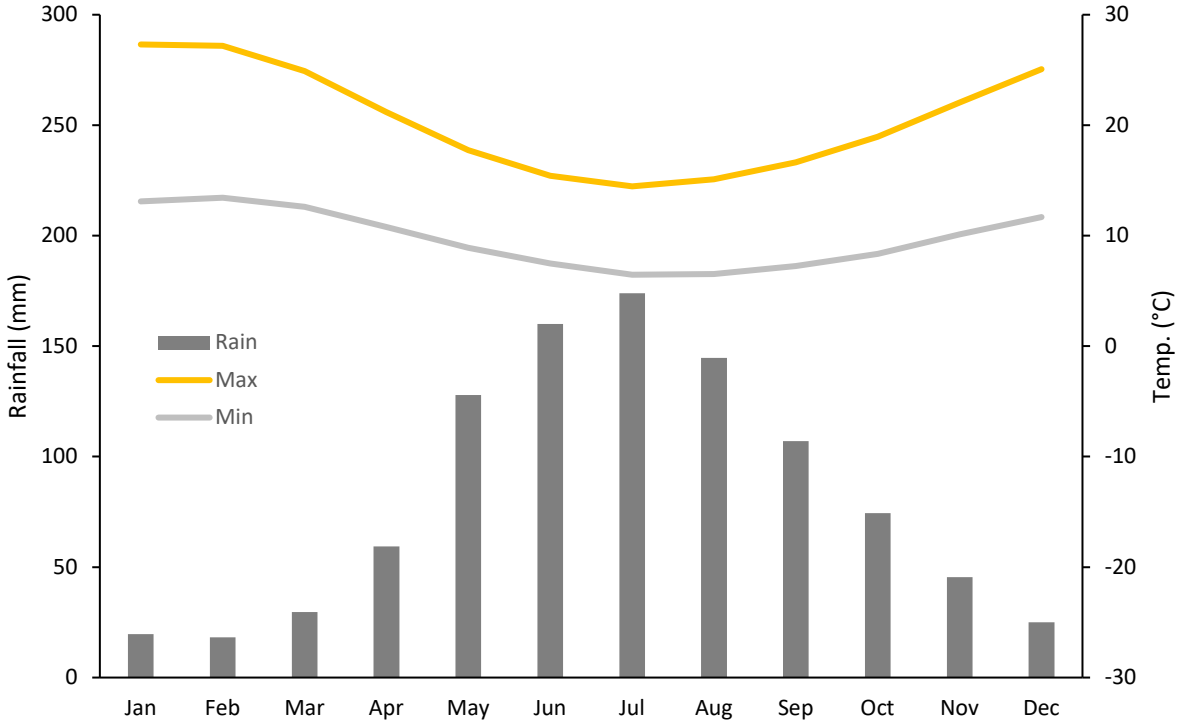


Figure 2. Monthly rainfall and minimum and maximum temperature. Values are the mean and data are from the Manjimup gauge (No. 9573) for the years 1936 to 2022.

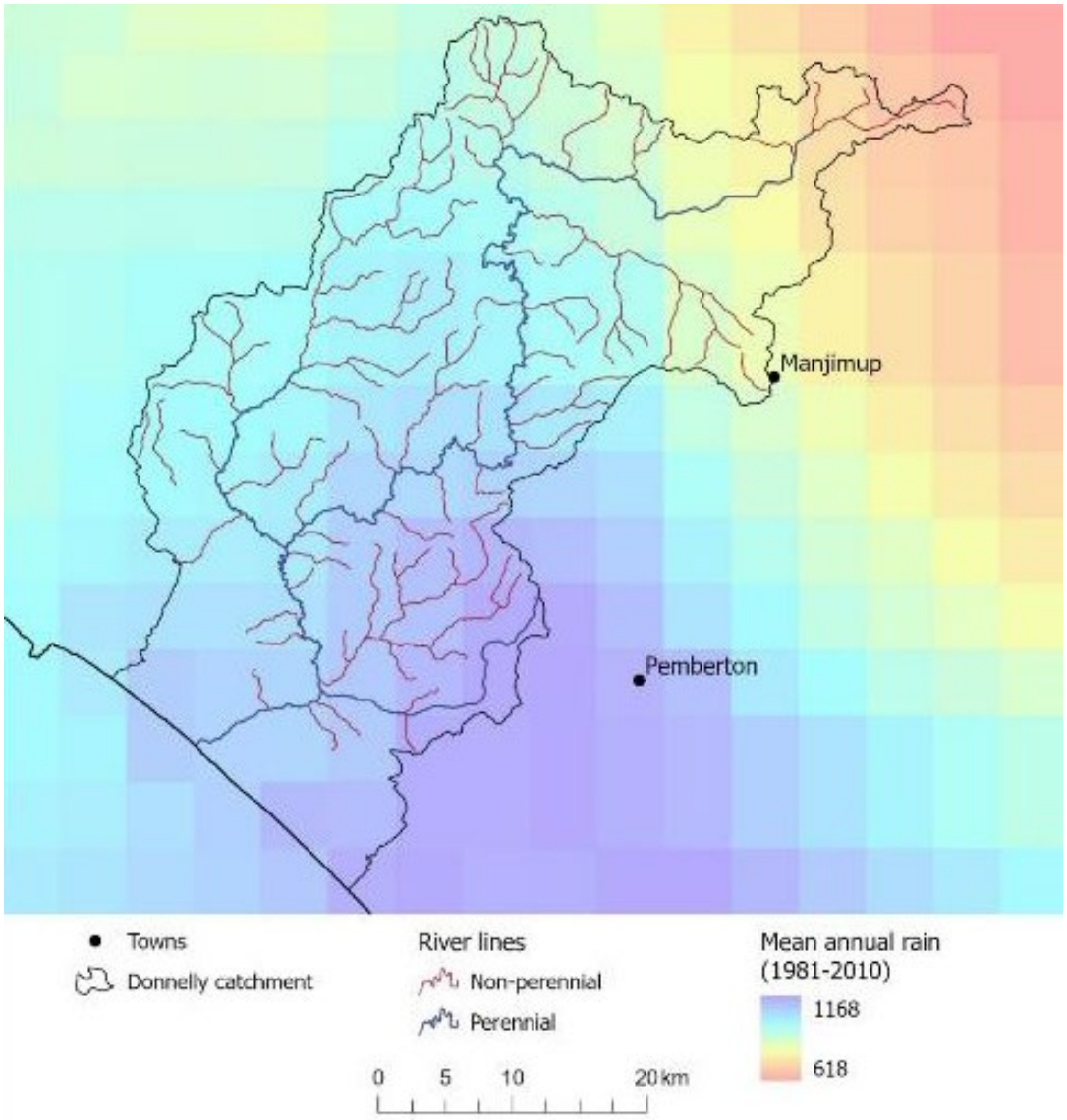


Figure 3. Gridded rainfall data across the Donnelly catchment. Data are the mean annual rainfall from 1981 to 2010 and were accessed from http://www.bom.gov.au/jsp/ncc/climate_averages/rainfall/index.jsp.

Streamflow in the Donnelly River

Streamflow in the Donnelly is predominantly 'predictable winter highly intermittent' (Kennard et al., 2010), as classified for Strickland gauge on the Donnelly and Barlee Brook at Upper Iffley (Figure 4). Peak flows occur in late winter or early spring and provide longitudinal connectivity in the intermittent reaches of the Donnelly. There is limited information on the duration of connectivity, which can be critical for the movement of aquatic biota.

Lower in the catchment on Carey Brook (Staircase Rd gauge) and Fly Brook (Boat Landing Rd) flow was characterised as 'Class 2 - stable winter baseflow', which indicates a perennial stream or river

with the majority of runoff occurring in winter (Kennard et al., 2010). It is notable that these 2 tributaries of the Donnelly were 2 of only 14 reaches found to be perennial in the 136 reaches in WA assessed by Kennard et al. (2010), highlighting how uncommon this flow type is Western Australia.

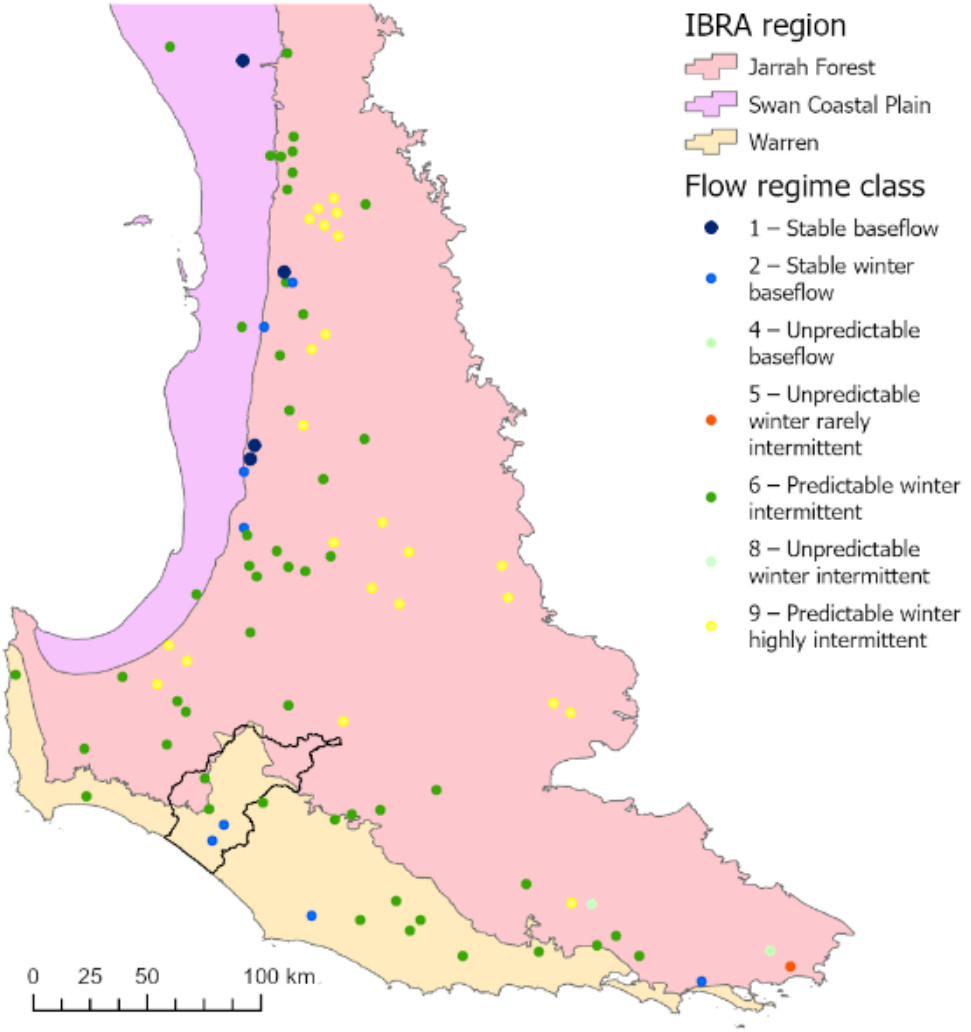


Figure 4. Flow regime class determined by Kennard et al (2010) mapped for river sites across southwest Western Australia. IBRA Bioregions are shown using coloured polygons with the cream colour indicating the Warren Bioregion. The black traced line indicates the edge of the Donnelly River catchment.

Knowledge gaps

Increasingly attention is being directed towards how to manage freshwater systems in an era of climate change or non-stationarity, in particular to protect ecological and Indigenous cultural values into the future (Horne et al., 2019, Horne et al., 2017). The Donnelly catchment is experiencing a

decline in rainfall and streamflow (see section 3.1.2 in Part A of this report). Thus, research is required to better predict how flow is likely to change in response to the climate.

Specific knowledge gaps identified are:

- Improve predictions of streamflow in a changing climate, in particular:
    - Return interval of overbank flows
    - Duration of bankfull flows
    - Changes to groundwater baseflows
    - Changes to the timing and duration of 'no flows'

Physiography and hydrogeology

The Donnelly catchment spans the Yilgarn Craton (consisting of both the Yilgarn Craton granites and the south-west terrane greenstones) to the north, and the Warnbro group to the south of the catchment (Figure 5). The most northerly part of the catchment is approximately 260 m AHD (Australian Height Datum, or the height of a point above sea level), declining to less than 100 m AHD closer to the coast (Munro, 2006). The Barlee Brook catchment includes an area on the Blackwood Plateau, which is gently undulating and composed of laterite and sand at the surface (Munro, 2006). The mouth of the Donnelly River is situated on the Scott Coastal Plain, a low-lying swampy plain, which includes permanent freshwater lakes and swamps (Munro, 2006).

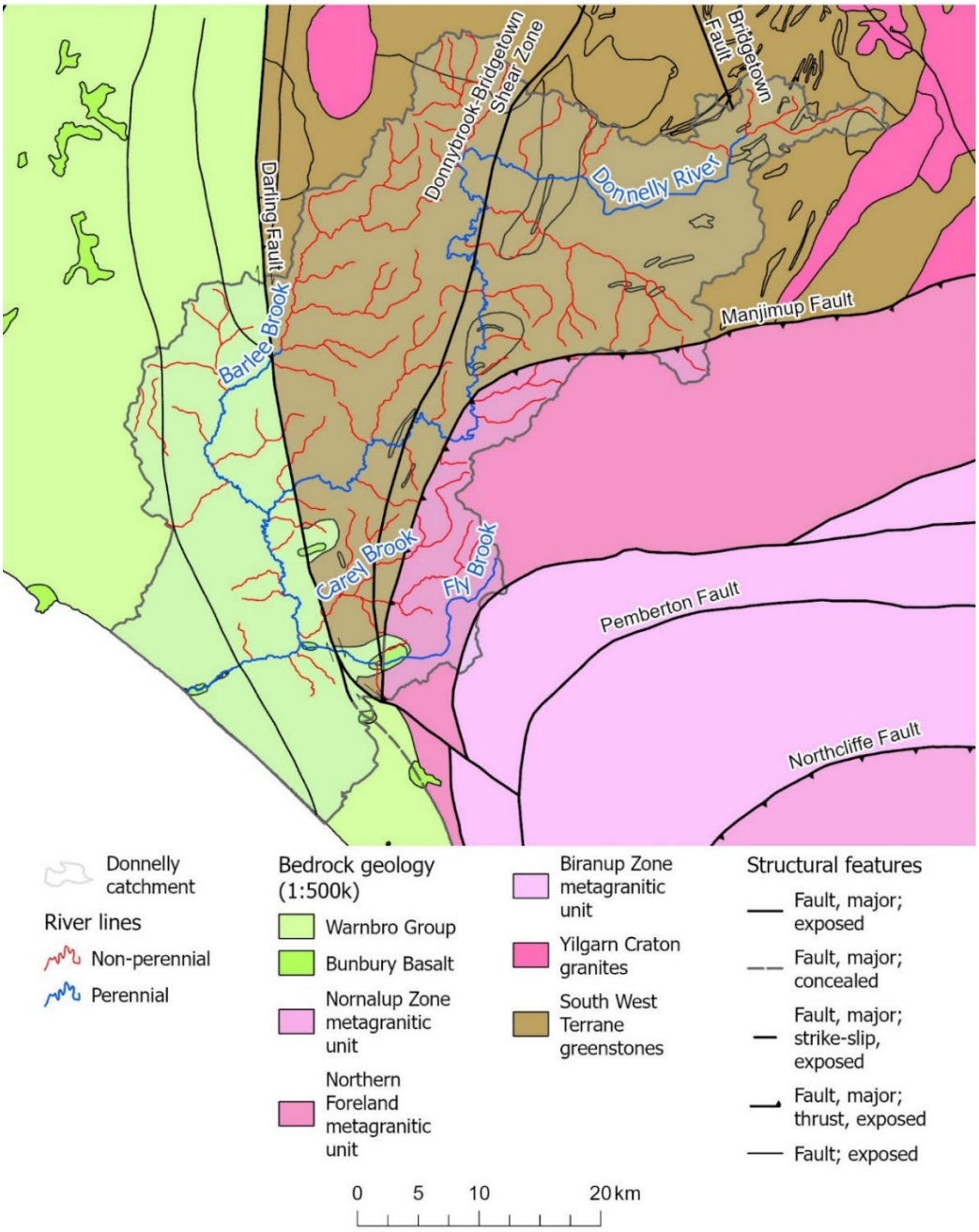


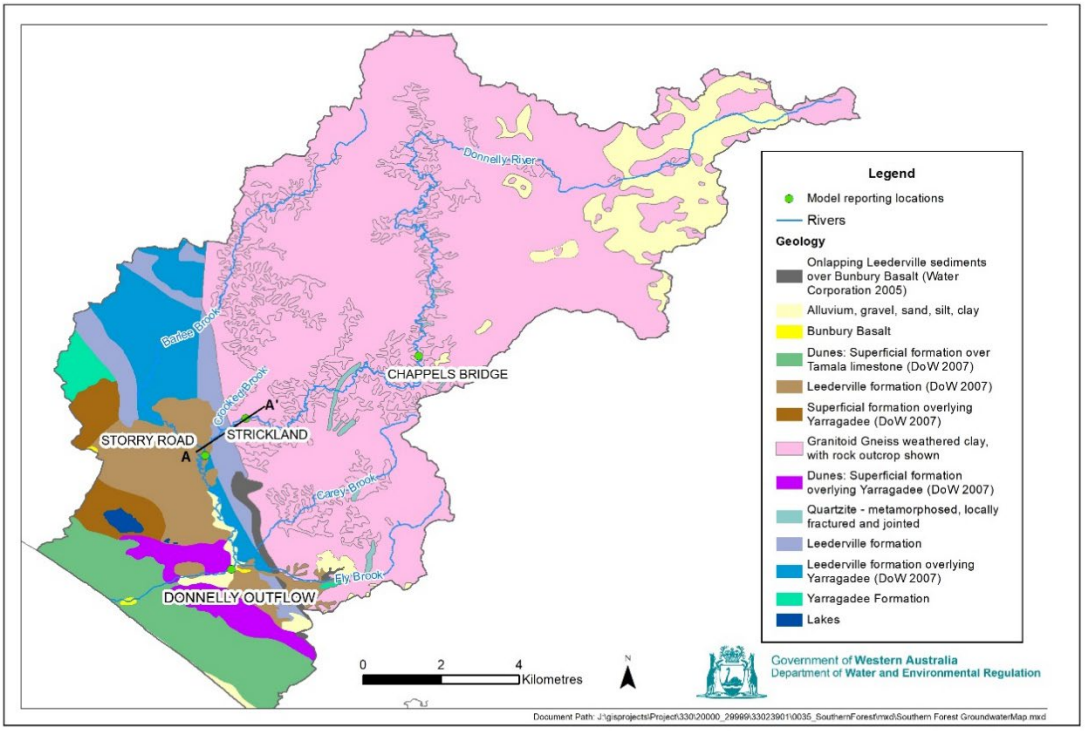
Figure 5. Bedrock geology and faults in the Donnelly catchment. Note that the classification of 'non-perennial' and 'perennial' are indicative only and analysis of hydrographs from relevant gauges is required to confirm.

There are a number of fault-lines in the catchment (Figure 5) which are thought to influence connectivity to regional and local aquifers, thus river flow. The primary fault is the Darling Fault, which runs in an approximate north-south direction and bisects the Donnelly River main stem, and Barlee and Carey Brooks (Figure 5).

Upstream of the fault the river occurs on the Balingup Complex of the Yilgarn Craton (De Silva, 2004), which is characterised by shallow basement rock overlain by a highly weathered regolith (Figure 6). Groundwater exists mainly in the weathered profile and in the fractures and joints of the granitic and gneissic basement rocks (De Silva, 2004). These form aquifers commonly referred to as the weathered-rock aquifers and, may be locations of groundwater upwelling, which can support refuge pools in intermittent sections of the catchment, although further investigation is required.

Downstream of the fault there is a marked increase in groundwater discharge where the river intersects the sediments of the southern Perth Basin as the river intersects the Leederville formation (Perrin, 2018)(Figure 6). Groundwater pressure gradients in the Leederville aquifer and radon testing in the river indicate that groundwater from the Leederville formation is discharging to the river (Perrin, 2018). The Leederville formation also provides groundwater discharge to Barlee Brook (Water Corporation, 2005) and is likely to support the lower Carey Brook (Perrin, 2018). It may also support the lower end of Crooked and Fly brooks based on their intersection with the Leederville aquifer.

As the river moves westwards over the Scott Coastal Plain it intersects the superficial formations. These contain an unconfined groundwater flow system that is recharged by direct infiltration of rainfall and potentially by discharge from the underlying Leederville and Yarragadee aquifers (Rockwater Pty Ltd, 2004, Water Corporation, 2005, DoW, 2007). The superficial formations are likely to be a source of baseflow to the river, and combined with Leederville and Yarragadee discharge, contribute to permanent flow on the lower reaches and the estuary on the Scott Coastal Plain.



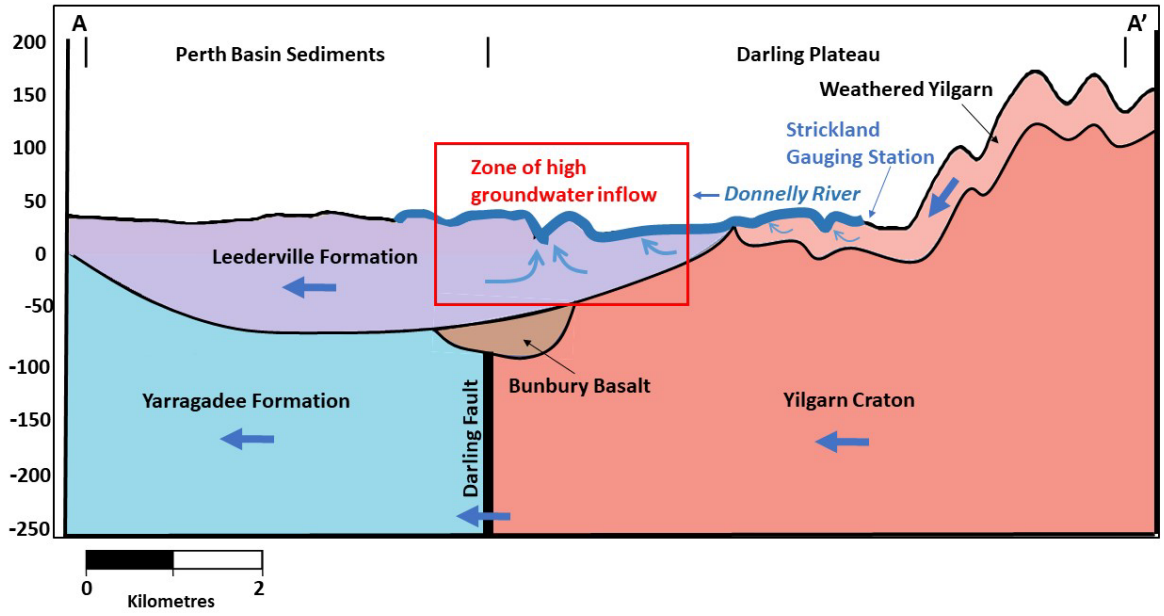


Figure 6 Top panel: Hydrogeology of the Donnelly River catchment (Adapted from De Silva (2004)). Note that the top panel shows the transect line marked A to A', which is shown in the bottom panel as a conceptual model of groundwater contributions to the lower Donnelly River (adapted from Perrin (2018)). Diagrams courtesy of DWER.

Knowledge gaps

There is currently limited hydrogeological information in the literature to support the conceptual separation of perennial and intermittent channels as habitat in the Donnelly River; however, it is supported by personal observations of groundwater upwelling. Research by a UWA PhD student is currently investigating groundwater inputs of the lower Donnelly River. As new information is collected it will be incorporated into our conceptual understanding of the system.

- Locations of groundwater upwelling that support perennial reaches / pools.
- Relative contribution of different groundwater (alluvial and regional) to dry season flows.

3 Threatening processes

While the objective of this report was to identify the currently known Indigenous cultural and ecological values of the Donnelly River and summarise the literature related to water requirements, it is important to recognise that water management does not occur in isolation and that numerous threatening processes co-occur. Here we briefly introduce threats, citing key literature. Key threatening processes for SWWA, including the Donnelly River, are:

Climate change. The south-west region, including the Donnelly catchment, is experiencing a drying climate characterised by reduced rainfall, higher temperatures, declining groundwater levels and reduced river flow. The change in rainfall and streamflow for the Donnelly River is discussed in detail in Part A, section 3.1.2 'A freshwater refuge in a drying climate'.

The ecological threats of a drying climate have been discussed broadly for the region by numerous authors, see Davis et al. (2010); Barron et al. (2012); Pettit et al. (2015); and, Allen et al. (2017). They have also been discussed in detail for specific biotic groups such as fishes (Beatty et al., 2014, Stewart et al., 2022, Allen et al., 2017), mussels (Benson et al., 2019, Benson et al., 2021), crayfish (Emery-Butcher, 2023), macroinvertebrates (Stewart et al., 2013) and plants (Froend and Sommer, 2010, White et al., 2021).

Water development. Freshwater is an important resource for economic development, for example supporting irrigated agriculture; however, extraction of freshwater from rivers and aquifers can negatively impact ecological values. In the Lefroy Brook Catchment, a tributary to the Warren River, research in the mid 2000s estimated that farm dams have reduced annual streamflow by 22% on average and that dams intercepted approximately 85% of summer flows (Fowler, 2008). Currently, water take for agriculture occurs predominantly in the upper eastern section of the catchment, and there have been plans for increased water development as discussed in Part A Section 3.1.3 'Management setting'. The impact of water extraction on Indigenous and ecological values are the basis of the HSE conceptual model and are discussed in detail in Part A Section 4.3 'HSE model'.

Land use change for agriculture, forestry or other reasons is known to have a negative impact on the ecological values of river systems in SWWA (Trayler et al., 1996). In the Donnelly River there is evidence that clearfelling for forestry impacts macroinvertebrate assemblages via increased sedimentation (Growns and Davis, 1994a). In the neighbouring Warren River forestry has been found to also impact hyporheic invertebrates, although the mechanism is unclear (Trayler and Davis, 1998). Currently, water quality remains relatively good in the Donnelly River, due to most of the catchment being managed as either state forest (46%) or National Park (31%; see Part A Section 3.1.1. 'Location'). Water quality may deteriorate if further land-clearing occurs or if agricultural development intensifies. The biggest water quality threat is likely to be secondary salinity, which is widespread across SWWA (Clarke et al., 2002), and impacts the ecology of most river catchments in

the region (Halse et al., 2003). Elevated nutrients (nitrogen, phosphorous) also pose a threat to fish if they lead to algal blooms and associated oxygen crashes (McComb and Davis, 1993).

Non-native species. Non-native species, such as introduced fish and weeds, are present in the Donnelly River. Non-native fish include Rainbow Trout (*Oncorhynchus mykiss*), Brown Trout (*Salmo trutta*), Redfin Perch (*Perca fluviatilis*), and Eastern Gambusia (*Gambusia holbrooki*) (Morgan and Beatty, 2008). Research in SWWA indicates that non-native species negatively impact native fish and crayfish via predation and competition for food and space (Morgan et al., 2004, Beatty and Morgan, 2013), although no studies have assessed these impacts in the Donnelly River. Redfin perch and eastern gambusia have been identified as particularly problematic, the former because of its aggressive nature and propensity to feed on fish and crayfish (Morgan et al., 2002), the latter because of its fin-nipping (Gill et al., 1999). Riparian weeds of concern in the Donnelly River are common blackberry (*Rubus anglocandicans*), arum lily (*Zantedeschia aethiopica*), watsonia (*Watsonia* sp.) and olives (*Olea europaea*) (Munro, 2006). Blackberry is of considerable concern, being relatively widespread and forming large thickets.

Inappropriate fire regimes can alter the structure and composition of vegetation, as well as impact terrestrial fauna, reviewed for SWWA by Bradshaw et al. (2018). Short fire intervals may not allow sufficient time for obligate seeder species to reproduce, leading to a decline in abundance. In a drying climate, changes in fire regime may interact with other factors such as reduced seed production and lower seedling survival, thus a reduction in populations (Enright et al., 2015, Souto-Veiga et al., 2024).

Acid Sulphate Soils. The drying of coastal wetlands can lead to the oxidation of iron-rich soils which release high concentrations of metals, acid and sulphur to water upon rewetting (Kilminster and Cartwright, 2011). These soils, termed 'Acid Sulphate Soils' (ASS), have been implicated in fish kills and other ecological impacts in Australia (Sammut et al., 1995). The lower Donnelly River, particularly wetlands along the Scott Coastal Plain are most at risk as they contains a variety of ASS (Miller et al., 2010).

Phytophthora cinnamomi is a soilborne plant pathogen that infects plant roots, killing plants and ultimately altering plant communities and reducing biodiversity in SWWA (Shearer et al., 2007). The pathogen is spread through the movement of soil (for example on vehicles or shoes) and moves naturally through water flows. There are mapped locations of dieback within the Donnelly Catchment (Figure 7), and movement within these areas is avoided during wet conditions to limit spread.

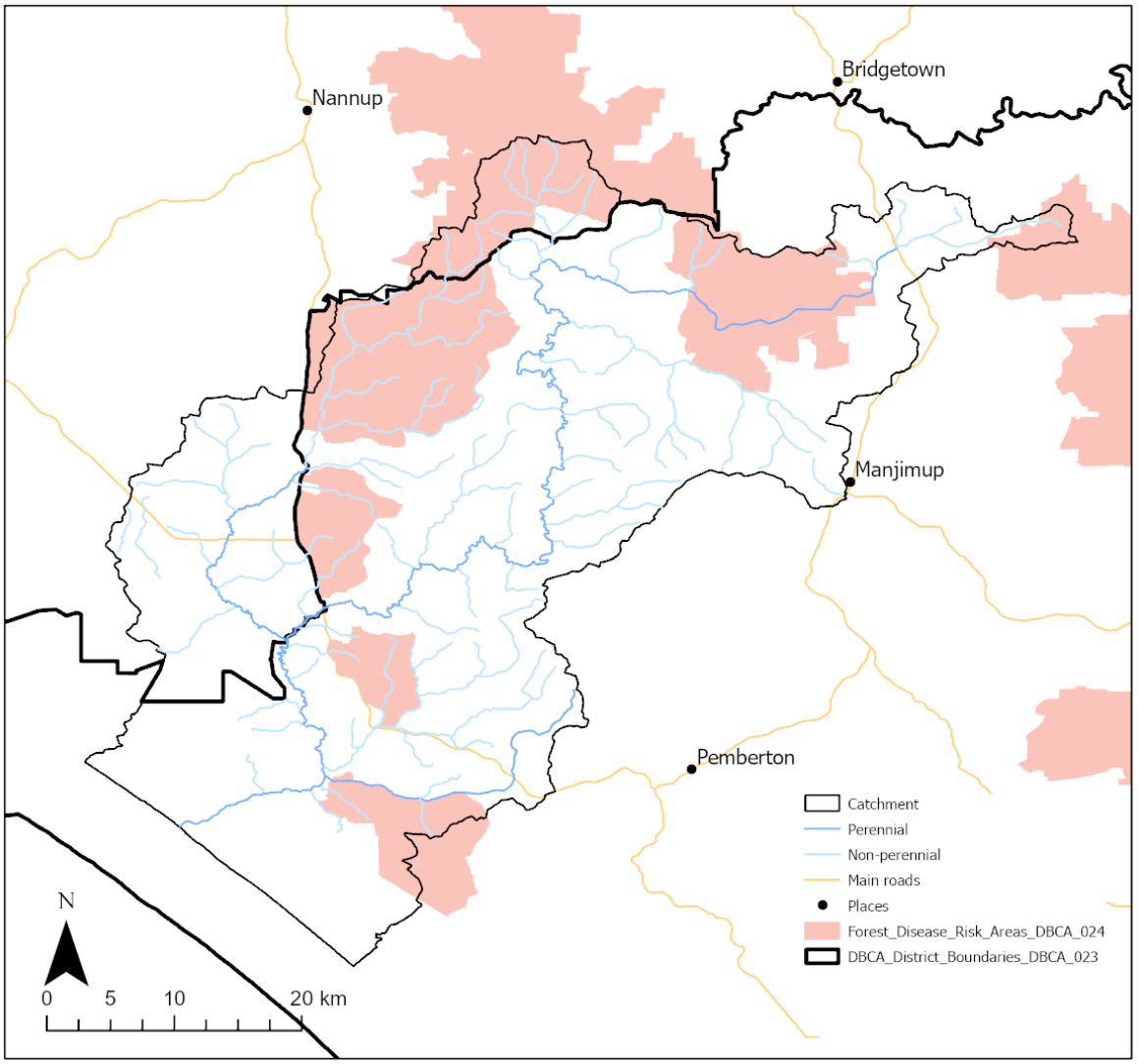


Figure 7. Mapped locations of forest disease risk areas (locations known to be infested with *Phytophthora cinnamomi*)

4 Indigenous cultural values

4.1 Scope of review on Indigenous heritage

To inform the interim HSE model and to highlight knowledge gaps we reviewed publicly available information on the Indigenous cultural values relating to the Donnelly River. For the river and riparian zone, we summarised documented Indigenous heritage sites and use of species by Noongar people. Our review was limited to the riverine environment of the Donnelly and its tributaries. It does not include Lake Jasper and Gingilup Wetland systems, springs and other freshwater habitats not directly connected to the Donnelly River, although we recognise that these places are significant.

We found no published literature or reports on the Indigenous cultural values associated with the Donnelly River and its riparian system. Instead, the values recorded in neighbouring areas may provide some indication of the importance of the river spiritually, culturally and as a resource. We therefore drew on reports from neighbouring catchments, as well as books that include species-based information that may be relevant to the Donnelly. Specifically, our review was based on:

- A search and reports from the WA Aboriginal Cultural Heritage Inquiry System (ACHIS).
- Anthropological reports from catchments neighbouring the Donnelly River.
- The Noongar seasonal calendar.
- Published books on Noongar bush food and bush medicine.

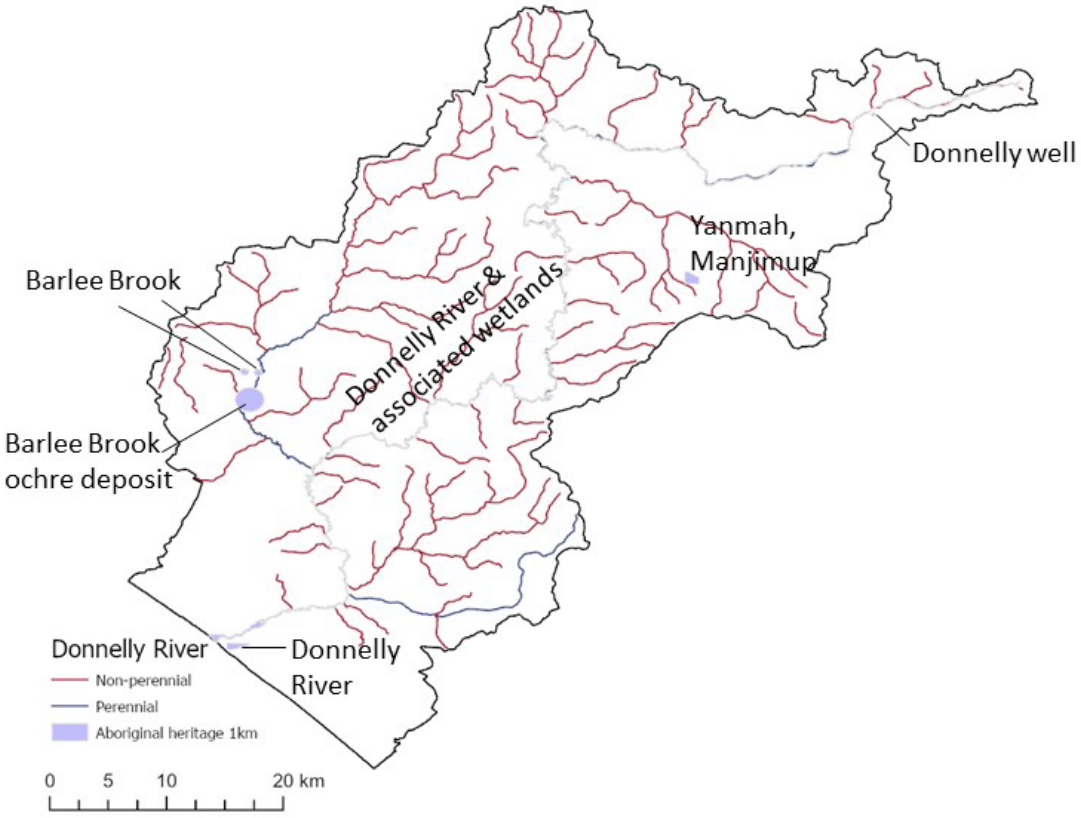
Further consultation and collaboration with cultural knowledge holders are required to appropriately represent the Indigenous cultural values associated with the flows of the Donnelly River.

The values reviewed relate to Indigenous perspectives on freshwater and river flows, and the plants and animals they support. Policies and research relating the legitimacy and diversity of Indigenous rights, interests, knowledge and responsibilities and their governance principles and structures are discussed further in ‘Section 4.4 Principles and Considerations’ in Part A of the main report.

4.2 Summary of search results from the ACHIS

To identify documented cultural heritage sites we undertook a search of the ACHIS (DPLaH, 2023) in August 2023 for registered Aboriginal heritage places within a 1 km buffer (i.e. 500 m of the mid-line) along the Donnelly River and its tributaries. Seven Aboriginal heritage sites were returned from the inquiry (Figure 8). Access to the reports was provided by WA Department of Planning, Lands and Heritage, with the exception of site 5278, which is a closed file (it is recorded as an artefact and burial site). The listed Aboriginal heritage places were camps, water sources or locations with artefacts or scatter. For example, stone artefacts were found at Barlee Brook (site ID 4562), which ‘appears to be a waterside camp’. Donnelly Well (site ID 17977) is believed to be a traditional water source and camp for Aboriginal people, which has been used as a water source for stock after colonial settlement. Notably, the Donnelly River and associated wetlands are recorded in the ACHIS for their

mythological values relating to the Waugal (the great, serpent-like Dreamtime spirit), however these places are not currently registered sites. There is an ochre deposit recorded on Barlee Brook. Our review of the ACHIS records shows the location of some culturally important places, including places associated with freshwater values. However, the information contained in the ACHIS reports was limited, and not collected in relation to informing water requirements.



ID	Name	Status	Type
5724	YAN MAH, MANJIMUP.	Lodged	Artefacts / Scatter, Camp
17977	DONNELLY WELL	Lodged	Camp, Water Source
17979	DONNELLY RIVER & ASSOCIATED WETLANDS	Stored Data / Not a Site	Mythological
5278	DONNELLY RIVER	Registered Site	Artefacts / Scatter, Skeletal Material / Burial
22925	Barlee Brook Ochre Deposit	Lodged	Ochre
4562	BARLEE BROOK	Lodged	Artefacts / Scatter
5656	BARLEE BROOK.	Registered Site	Camp, Water Source

Figure 8. Places listed in the Aboriginal Cultural Heritage Inquiry System along the Donnelly River and its tributaries. The search was limited to a 1 km buffer of the river.

4.3 Cultural water values reports

Reports relating to cultural values connnected to freshwater have been prepared by anthropologists contracted by WA's Department of Water and Environmental Regulation (DWER) as part of water allocation planning processes for the Blackwood River, the neighbouring catchment to the west of the Donnelly (Goode and Irvine, 2006). The Indigenous cultural values relating to the south-west Yarragadee aquifer have also been investigated in response to a water allocation plan that included significant groundwater take for domestic water supply (Goode, n.d.).

Goode (n.d.) report that the Waugal (a mythological being) resides in the freshwater places of the southwest, including Lake Jasper and the Blackwood River. 'As the Yarragadee aquifer recharges the Blackwood River near Darradup the Aboriginal people consulted considered that the aquifer was 'of the same spiritual energy as the Blackwood River', that the aquifer was associated with the Waugal (Goode, n.d. p52).' The report recommended that the Donnelly River (and the Scott River) and its associated tributaries should be registered as a site of mythological significance in association with Waugal beliefs.

Glen Kelly, an interviewee in Goode (n.d.) noted the significance of water for Noongar people. 'Water has sacred religious significance. Water is fundamental to life, our heritage and culture. Nyungar (Noongar) traditional mythologies taught people a code of 'values' and instituted (*created / instilled)* a system of respect for this resource in order that it was used in a sustainable way. We did not take more than we needed and did not interfere with the waters natural flow across the landscape, which would deny other species the use of water' (Goode, n.d. p47).

Rivers and wetlands in SWWA have significant use values for Noongar people. In particular, summer river pools are important places and 'traditionally Nyungar people used these pools when traveling to the coast in summer along a path running adjacent to the Blackwood River. Mrs. Vilma Webb stated that these pools were important campsites where fish and marron could be caught. Mrs. Webb stated that fishing and marroning were still of great importance to Nyungars today' (Goode, n.d. p49). Frogs and gilgies (freshwater crayfish) were also a food source, and the presence of frogs can indicate that a place is 'good country' (Goode and Irvine, 2006). There is some evidence of freshwater mussels being a food source for Noongar people in SWWA, with shells found in Devil's Lair, an important archeological site south of Margaret River (Dortch, 1974). Both freshwater and marine molluscs are food sources elsewhere in Australia, however it is uncertain if they were a regular or important food in SWWA (Dortch et al., 1984).

Although there are currently no records of fish traps on the Donnelly River, there is evidence of traps in neighbouring systems. For example, Dortch and Gardner (1976) describe a wooden fish trap on a freshwater creek near Point D'Entrecasteaux, near Northcliffe. There is also a record of fish traps on the Lefroy River, a tributary to the Warren River, approximately 3 km south of Pemberton (WA Aboriginal Cultural Heritage Inquiry System (ACHIS) ID 4570). Wooden weir of slot type fish traps were often used to trap migrating fish and were widely recorded by early settlers, as described by Dix

and Meagher (1976), cited in Goode and Irvine (2006). However, there is limited archaeological evidence of them, as the wood degrades over time.

The values highlighted in the reports demonstrate some of the spiritual, cultural and use values for Noongar people in the Blackwood region. However, there is a knowledge gap for the Donnelly River, with limited cultural values recorded in available reports.

4.4 Noongar seasonal calendar

Aboriginal seasonal calendars provide insight into the relationship between regular weather patterns, the resulting changes in the environment and the activities and belief of Aboriginal people. There is not a seasonal calendar specific to the Donnelly area, and we have instead drawn on information from a calendar described by Jason Barrow in partnership with the Bureau of Meteorology (BOM, 2025b) for Noongar Country. Noongar people recognise 6 seasons, determined by weather patterns, which indicate which plants and animal resources are available. These 6 seasons are: *Bunuru, Djeran, Makuru, Djilba, Kambarang* and *Birak*. From the calendars we have highlighted the Noongar values related to river flows.

> *Birak* (season of the young) is when 'rains ease up and warm weather really starts to take hold'. It the time when frogs develop into adults.
>
> *Bunuru* (season of adolescence) is the hottest time of year with little to no rain. It is an important time of year for fishing and freshwater foods (as well as seafood) are important at this time of year.
>
> *Djeran* (season of adulthood) is when the really hot weather starts to break, and nights become cooler. Freshwater foods are important at this time of year, for example *yanget* (bullrushes), freshwater fish, frogs and turtles.
>
> *Makuru* (season of fertility) is the coldest and wettest part of the year. 'As the waterways and catchments started to fill, people were able to move about their country with ease.' *Mali* (black swans) moved to rivers and lakes to prepare for nesting and breeding.
>
> *Djilba* (season of conception) is a transitional time of year with some sunny days in the transition from the wet, cold weather. Food sources are primarily from the land.
>
> *Kambarang* (season of birth) has the weather warming up again, with longer dry periods. There are many wildflowers and reptiles come out of hibernation.

The Noongar seasonal calendar summarised here does not include extensive information relating cultural values to river flows. Another knowledge gap is that the information is derived from outside of the Donnelly catchment and Warren Bioregion and more information is required to develop a seasonal calendar specific to the study area.

4.5 Indigenous plant uses

Plants have been an important food and medicine source for Noongar people for ~45,000 years (Hansen and Horsfall, 2016, Hansen and Horsfall, 2019). Specific information on the plants used by Noongar people in the Donnelly Catchment has not been recorded. However, there are 2 published books that record Indigenous uses of plants: 'Noongar Bush Medicine: Medicinal plants of the south-west of Western Australia' (Hansen and Horsfall, 2016); and 'Noongar Bush Tucker: Bush food plants and fungi of the south-west of Western Australia' (Hansen and Horsfall, 2019). These books cover Noongar boodja (Country) which extends across the entire south-west corner of Western Australia from north of Jurien Bay to the southern coast, east of Esperance.

To create a list of plants with cultural uses along the Donnelly River we firstly identified species recorded in Hansen and Horsfall (2016) and Hansen and Horsfall (2019) that are likely to occur in the riparian zone, as determined by their habitat description in Florabase or Atlas of Living Australia included the words 'riparian', 'wet', 'river' or 'damp' (www.florabase.dpaw.wa.gov.au and https://www.ala.org.au/ respectively, accessed 4 July 2023). We then reduced the list to only include species with records in the Donnelly Catchment, as recorded on Florabase or ALA. This process produces a list of 31 species (Table S1), however not all species are strictly riparian, and are known to occur elsewhere in the wetter parts of the karri and marri forest (C. Canham pers. comm.). Therefore, the list was further revised to species known to the authors to be riparian or wetland specialists (that are dependent on river flows), which identified 3 tree species and 2 herb species (Table 4-1). These species and their Noongar names and uses are discussed in the text below.

For the majority of species, their distribution in relation to the river and the water requirements is not known, and this is a limitation in identifying riparian species with cultural values. There is also a knowledge gap for specific information on plant uses by Noongar people along the Donnelly River.

Trees

Flooded gums (*E. rudis* subsp. *rudis*) occur along the Donnelly River, and are used in similar ways to other common eucalypts (e.g. *E. megacarpa, E. patens,*); crushed leaves are used as antibacterial poultices and for congestion relief, gum is used as an ointment for sores and to treat dysentery, and leaves can be used as bedding (Table 4-1 & S1; (Hansen and Horsfall, 2016)). Stout paperbark (*Melaleuca preissiana*) is a common wetland and riparian species. The young leaves of *M. preissiana* can be crushed and used to treat sinusitis, headaches and colds, and its bark used to bandage wounds, as well as to wrap food and for sanitary purposes. The swamp Banksia (*Banksia littoralis*) is endemic to SWWA, commonly occurring in wetland and riparian environments. Its flowers can be infused and used to treat coughs and sore throats, and infused flower spikes may be consumed as a sweet refreshing drink (Table 4-1).

Herbs

Our review identified 2 herb species commonly found in riverine and wetland environments that occur along the Donnelly River, and that have Noongar bush medicine or food uses. The roots or

tubers of the aquatic herb *Cycnogeton huegelii* can be eaten raw or roasted, as is the case for other upland herb species that occur in the catchment (e.g. *Daucus glochidiatus, Anigozanthos flavidus, Haemodorum spicatum,* and many species of the Orchidaceae family). *Centipeda cunninghamii* is common in areas with still water and plants can be decocted and used as eyewash or distributed around campsites at night so the pungent odour of the plant would deter ants (Table 4-1).

Table 4-1. Riparian plants that are both (i) known to occur in Donnelly River riparian habitat based on ALA, and (ii) have a recorded use by Noongar. Noongar names and Indigenous uses are from Hansen and Horsfall (2016) and Hansen and Horsfall (2019).

Life Form	Family	Scientific name	Noongar name	Indigenous uses	Distribution
Tree	Myrtaceae	*Eucalyptus rudis* subsp. *rudis*	Moitch (Abbott 1983)	**Bush medicine** Crushed leaves; antibacterial poultices, congestion relief. Ground gum; sore ointment and to treat dysentery. **Bush tucker** Sugary substance (manna) produced by mites that live on the base of the leaves can be eaten. **Other uses** Leaves; bedding.	endemic to SWWA
Tree	Myrtaceae	*Melaleuca preissiana*	Moonah	**Bush medicine** Crushed young leaves; to treat sinusitis, headaches, colds. Bark; to bandage wounds. **Bush tucker** Nectar; consumed as sweet drink. **Other uses** Bark; sanitary paper, food wrap.	endemic to southern WA
Tree	Proteaceae	*Banksia littoralis*	Pungura, Boora, Boorarup, Mimidi	**Bush medicine** Flower infusions; cough and sore throat relief. **Bush tucker** Flower spike infusions; sweet refreshing drink.	SWWA
Herb	Asteraceae	*Centipeda cunninghamii*	Unknown, but other Aboriginal name Gukwonderuk (Koori)	**Bush medicine** Decoctions; eyewash. **Other uses** Plants distributed around campsites at night to deter ants.	widespread in central and southern Australia
Herb (aquatic)	Juncaginaceae	*Cycnogeton huegelii*	unknown	**Bush tucker** Edible tubers; raw or roasted.	endemic SWWA

4.6 Knowledge gaps

This desktop review highlighted a lack of documented knowledge on Indigenous cultural values of the Donnelly River, including the use of plants and animals.

Specific knowledge gaps identified are:

- Indigenous cultural water values specific to the Donnelly River
- Information on cultural values of aquatic animals and riparian and aquatic plants, and the flows required to maintain them.

We recommend this information be expanded through collaboration with appropriate people as identified by the Karri Karrak Aboriginal Corporation's Cultural Advice Committee.

5 Water dependent ecological assets

5.1 Literature review and collation

Background and scope

Flow-ecology relationships

Water management decisions that seek to minimise negative impacts on ecological values are underpinned by an understanding of the relationship between flows, species, and ecological processes. Flow-ecology relationships quantify how species or ecological processes respond to particular components of the flow regime (Chen and Olden, 2018, Poff and Zimmerman, 2010). Thus, the information required to determine a flow-ecology relationship requires quantification of both the biotic and hydrological factors.

We considered using an 'eco-evidence' approach (Webb et al., 2012a) to systematically assess the existing published literature to determine the statistical strength of flow-ecology relationships. This approach, developed by Norris et al. (2012), combines evidence from the literature in a rigorous and transparent way to test 'cause-effect' hypotheses (Webb et al., 2012b). However, this approach requires sufficient published flow-ecology data to support it which are often not available. For instance, Davies et al. (2014) reviewed the published literature from Australia that included the keywords 'environmental flow' or 'environmental water', and found that of the 156 papers identified only 18% investigated a flow-ecology relationship (Davies et al., 2014). Further, a recent synthesis of flow-ecology for the wet-dry tropics of northern Australia found that of the 213 research articles identified only 24% of studies directly assessed flow-ecology, i.e. they measured a flow metric (e.g. discharge, velocity, duration of inundation) and statistically evaluated its relationship with a biota or process of interest (Beesley et al., 2024). We therefore applied a more conventional 'narrative' literature review approach.

For our review of the Donnelly River, we include studies that report on flow-ecology relationships. Studies that solely report on biota with no data on hydrological metrics are largely omitted.

Sources of information

Today, there is increasing expectation that environmental management decisions are informed by 'best available science' to ensure that decisions are transparent and defensible (Ryder et al., 2010). However, the diversity of approaches to science makes identifying the 'best' science difficult (Ryder et al., 2010). Bisbal (2002) identified 3 types of information that could be used to inform the management of salmon, which is broadly applicable to an understanding of best available science more generally. The 3 types of information, as cited in Ryder et al. (2010) are:

1) '**scientific information** emerges from a process of observation, identification, description and testing of hypotheses or the satisfaction of provisions for peer review and validation;

2) **suggestive information** is rich in empirical data, detailed observations, or reasonable estimates, but these data do not necessarily explain the causal mechanisms behind the observations; and

3) **supplementary information** is local knowledge or expert opinion.'

For the Donnelly River and SWWA more generally there has been a long history of research on riverine biota which has generated a wealth of information. Research has been undertaken by researchers from Murdoch University, University of Western Australia, Edith Cowan University, DWER, the WA Department of Biodiversity, Conservation and Attractions (DBCA) and CSIRO. This research has documented species, their distributions and biology. It has also investigated threats including salinity, non-native species, habitat degradation / land clearing, barriers to fish movement, and altered river flow. This knowledge has much merit, but when viewed from a strict flow-ecology perspective much of it is suggestive or supplementary (as outlined above). Further, the information can be difficult to discover as it sits inside government or university reports.

Our review of flow-ecology knowledge focussed on published scientific information that details quantitative flow-ecology relationships, the strictest standard of 'best available science' (as categorised by Bisbal, 2002). In general, peer-reviewed scientific journal articles were the preferred source of information, however grey-literature (e.g., government reports) was used if there was an important link between flow and ecological values and this information was not available in the peer-reviewed literature and the report was readily discoverable. Our collation of grey literature was not exhaustive, with some reports referenced by published journal papers, found through internet searches, or known by the study authors.

Our literature review focussed on biotic groups and riverine functions with strong links to flow, including:

- riparian and aquatic vegetation
- fish
- crayfish
- mussels
- macroinvertebrates
- hyporheic invertebrates
- ecosystem function (i.e. food web, primary production & metabolism)

For these groups, we searched the published literature using SCOPUS, Web of Science and Google Scholar.

Biotic groups with important but weaker links to flows, such as mammals, birds and frogs, are included in our review, but searches for these groups were not as rigorous. For these groups, information was not summarised by spatial scale (for more detail on spatial scope see below).

Spatial scope

Following the process used to develop the HSE model for the Fitzroy River (Douglas et al., 2019), we undertook a review of the literature on flow-ecology, seeking evidence at 3 spatial scales: the Donnelly River itself (local), the Warren Bioregion (regional) and elsewhere, described below.

Local. Includes information collected from the Donnelly River.

Regional. Includes information derived from rivers that traverse the Warren Bioregion. For instance, studies conducted in the mid Blackwood River, a river whose lower stretches pass through the Warren Bioregion, are included as 'regional' knowledge even though the sites technically sit outside the bioregion. This approach is used as bioregions are terrestrially based categorisations that do not consider riverine catchments and are often a poor fit to aquatic patterns (Turak and Koop, 2008, Davies and Stewart, 2013, Marchant et al., 2000).

Elsewhere. Includes knowledge from outside the Warren Bioregion. We prioritise information from SWWA as it should be most transferable to the Donnelly River; however, we also included evidence from elsewhere in Australia and overseas where local and regional knowledge is absent. Information from 'elsewhere' is not included in our synthesis unless there is a conceptual expectation that this relationship may hold for the Donnelly River.

Our focus was on flowing riverine environments that are impacted by changes in riverine flow. Therefore, information derived from lakes and wetlands not connected rivers, and estuarine and adjacent coastal marine ecosystems was not included in our review.

5.2 Riparian & aquatic vegetation

5.2.1 Woody riparian vegetation

Vegetation assemblages in the Donnelly River catchment differ moving north to south, or from upstream to downstream (Beard et al., 2013). The northern extent of the Donnelly River catchment is dominated by dry sclerophyll jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) forest (Lyons et al., 2000) (Figure 9). Lower lying parts of the catchment along the Donnelly River and its tributaries are dominated by wet sclerophyll karri (*E. diversicolor*) forest. The southern part of the catchment, on the Scott Coastal Plain, is dominated by an acacia-teatree (*Melaleuca* spp.) – *Allocasuarina* alliance (Figure 9). Many species that are common on the Donnelly River, for example *Trymalium odoratissimum* subsp *trifidum* and *Taxandria juniperina* have limited information available on Florabase (florabase.dbca.wa.gov.au) and in the published literature, especially in relation to their water requirements.

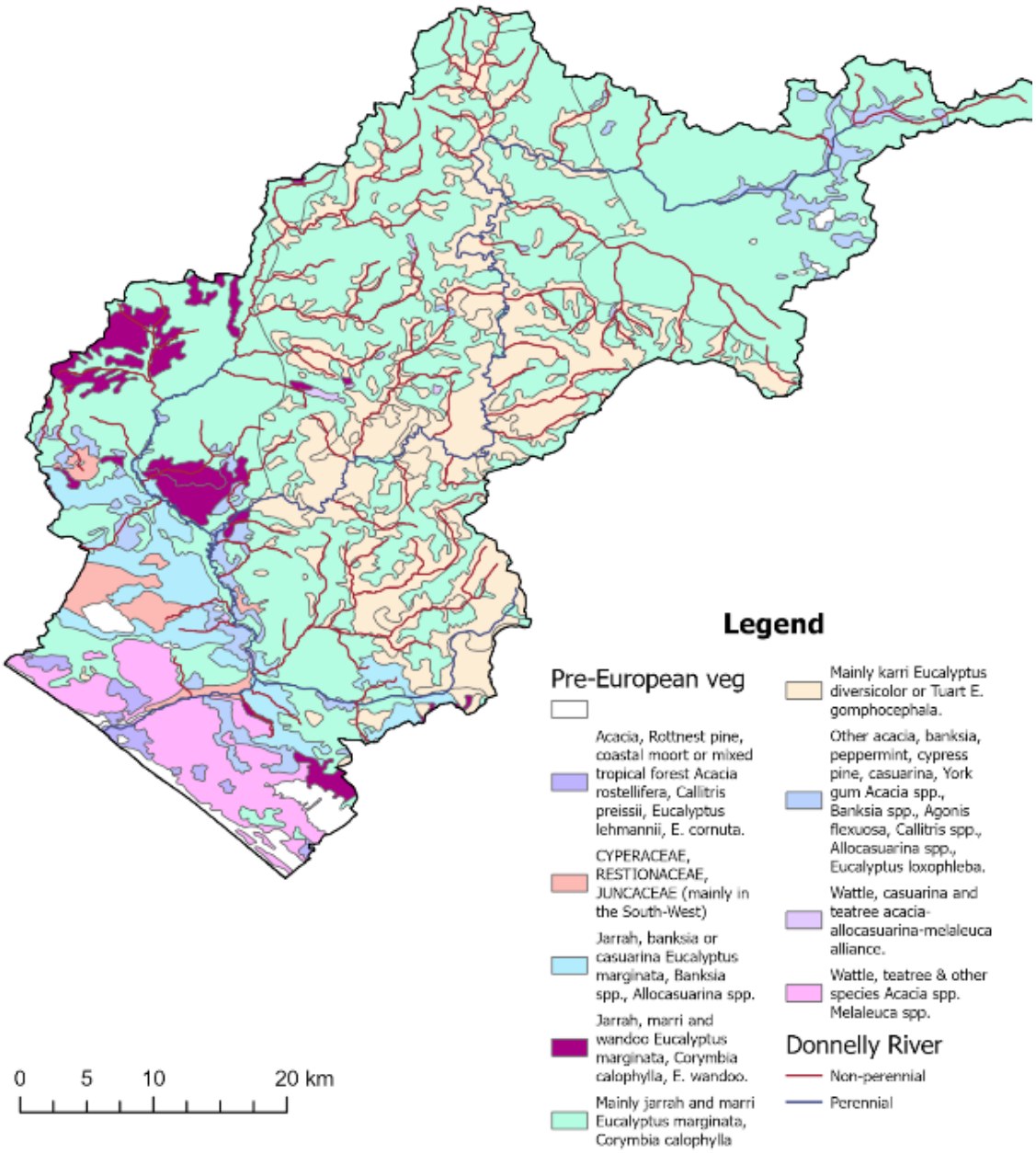


Figure 9. Pre-European vegetation mapping after Beard (1981).

Studies on the water requirements of woody riparian species from the Donnelly River

We found no published studies on the flow-ecology relationships of riparian trees in the Donnelly River.

Studies on the water requirements of woody riparian species from the Warren Bioregion

Three studies have assessed community composition and structure of riparian vegetation in the Warren Bioregion, all in the Warren River catchment (Pettit and Froend, 2001b, White et al., 2021, Yeatman et al., 2016). An additional 3 studies investigated reproductive phenology, recruitment and gene flow of specific riparian tree species within the Warren Bioregion (Pettit and Froend, 2001a, Hopley and Byrne, 2022, Hopley and Byrne, 2018). All studies related riparian vegetation to overbank flows, although the linkages were sometimes indirect. For example, Yeatman et al. (2016) found that, in the Warren River catchment, the riparian zone has a denser midstorey and a different assemblage of species compared with upland sites higher in the landscape. The assessment of vegetation was a secondary aim of the study, which was investigating the distribution of vertebrates (Yeatman et al., 2016), and position in the landscape implies a link between overbank flows and riparian vegetation.

Overbank flows are linked to the cover of exotic species (annual herbs and grasses) in the Blackwood River catchment, with a positive relationship to duration and frequency of inundation (Pettit and Froend, 2001b). Species richness was found to decrease with increased duration and frequency of flooding, although this relationship was weaker (Pettit and Froend, 2001b).

The metric of inundation duration has been used to categorise species as either obligate riparian, facultative riparian or upland species, based on field surveys and a surface water model for the Warren River (White et al., 2021).

Obligate riparian species were defined as species that only occur along river and tributary channels and were more common in locations that were inundated at least once in most years (White et al., 2021). Six obligate riparian species were identified:

- *Taxandria juniperina*
- *Melaleuca viminea*
- *Melaleuca rhaphiophylla*
- *Melaleuca cuticularis*
- *Eucalyptus rudis*
- *Astartea leptophylla*

Facultative riparian species are more common along water channels, but also occur in areas that are not inundated. Four facultative riparian woody species have been identified on the Warren River (White et al., 2021):

- *Hakea oleifolia*
- *Callistachys lanceolata*
- *Banksia seminuda*
- *Agonis flexuosa*

These species occurred in areas with less than 50 % probability of inundation in a year, and generally experienced less than 5 days of inundation per year (White et al., 2021). It should be noted that *A. flexuousa* is a widespread, common species, including in terrestrial habitats. Its classification as a

facultative riparian species may be revised in future research (it may be more appropriately classified as an upland species). In addition, *Taxandria linearifolia* is a small tree or tall shrub that is restricted to wet environments that experience seasonal inundation (Hopley and Byrne, 2022), and is recorded along the Donnelly River according to the Atlas of Living Australia (2023). The species was not assigned a category by White et al. (2021), but genetic analysis suggests adaptation or phenotypic plasticity of the species to winter water availability (Hopley and Byrne, 2022). Given the species distribution in seasonally inundated environments, *T. linearifolia* may be considered a facultative riparian species.

Upland species includes species that are common in the riparian zone, but that also occur in the adjacent, drier upland areas. White et al. (2021) identified 7 upland species in the Warren catchment:

- *Trymalium odoratissimum* subsp*. trifidum*
- *Melaleuca incana*
- *Leucopogon propinquus*
- *Leucopogon obovatus* subsp*. revolutus*
- *Hovea elliptica*
- *Hibbertia cuneiformis*
- *Acacia pulchella*.

Upland species are considered terrestrial and widespread and are not constrained to riparian habitats. However, in high rainfall zones of the lower Warren and Donnelly catchments a subset of species classified as 'upland' may be considered as riparian species in drier parts of the south-west. For example, *Trymalium odoratissimum* subsp*. trifidum* occurs throughout the karri forest but is considered a riparian species along the Darling Scarp closer to Perth (Hancock et al., 1996, White et al., 2021). Other upland species, for example *A. pulchella*, are widespread terrestrial species, that also occur in riparian areas.

Figure 10 shows a cross-section of the approximate distribution of species following the classification of White et al. (2021) , for the Warren River. It is currently not clear if the same species occur along the Donnelly River, and if their distribution reflects similar flow preferences.

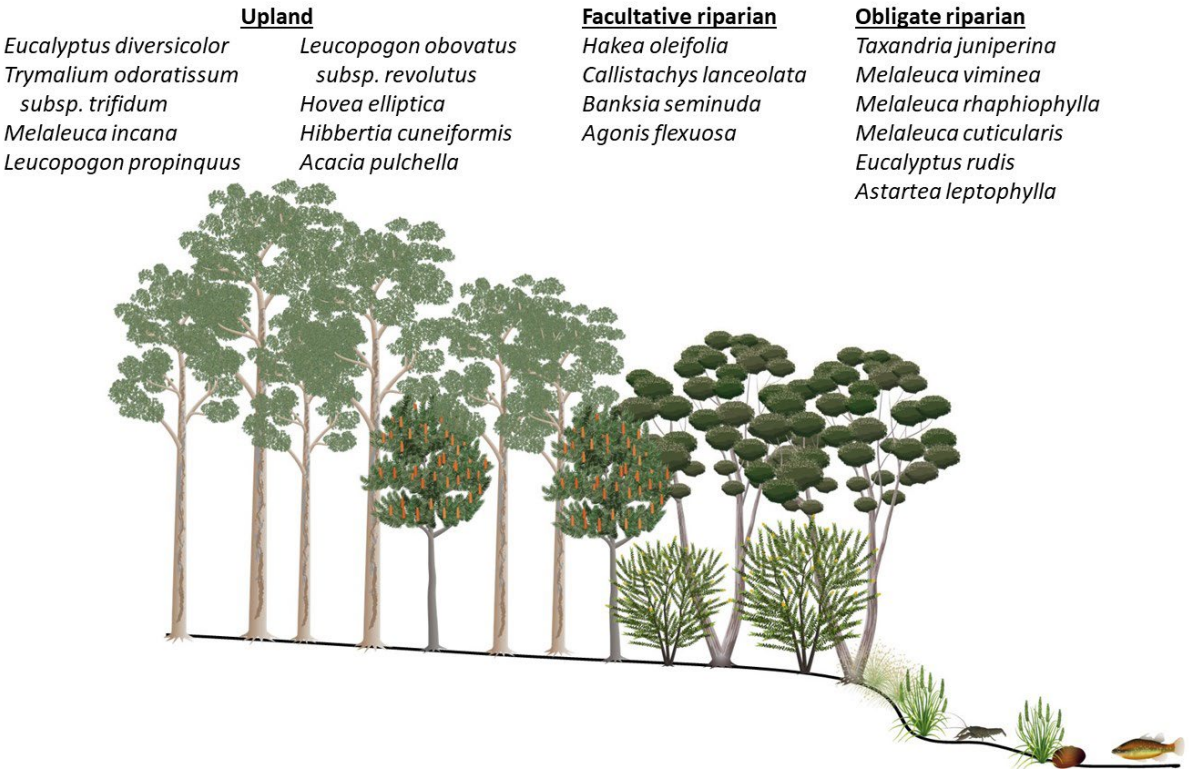


Figure 10. Cross-section of a river channel showing the approximate distribution of common obligate and facultative riparian and upland woody species, as classified by (White et al., 2021). Cross-section also shows instream macrophytes and fringing sedges.

Overbank and within-bank flows can be important for the recruitment of riparian plants and the distribution of propagules (Nilsson et al., 2010). However, for *M. rhaphiophylla* and *E. rudis* (2 obligate riparian trees (White et al., 2021)), there are limited relationships between flow and reproductive phenology (Pettit and Froend, 2001a). Both species retain seed in the canopy for more than 12 months, and *M. rhaphiophylla* appears to release seed after disturbance, such as when branches are broken off (Pettit and Froend, 2001a). *Eucalyptus rudis* had a peak period of seed release after the winter wet season, from August to December, although some seedfall was observed throughout the year (Pettit and Froend, 2001a). For *E. rudis* and *M. rhaphiophylla*, within-bank flows do not appear to provide an important dispersal mechanism (hydrochory), with *E. rudis* seeds beginning to sink after one day, and *M. rhaphiophylla* after 6 days (Pettit and Froend, 2001a). A separate study found that there was an even distribution of size classes of trees on the Blackwood River, indicating continual recruitment likely related to more predictable overbank flows of the temperate system (Pettit and Froend, 2001b).

Studies of geneflow between plant populations can show if hydrochory is an important dispersal mechanism. However, evidence from the Warren River indicates that river flows do not influence patterns of genetic diversity for 2 species with contrasting hydrological preferences (obligate riparian

vs upland species) (Hopley and Byrne, 2018). Instead, vegetation type and reduced habitat connectivity (either by habitat fragmentation or changes in vegetation type) had more impact on genetic diversity and structure (Hopley and Byrne, 2018). There was, however, some evidence of a relationship between climate variables and allele frequencies for *Taxandria linearifolia*, although the study did not investigate the influence of flow specifically.

From the reviewed studies it may be inferred that river flows do not have a strong influence on the recruitment and genetic flow for woody riparian species in the Warren Region. This may be related to the higher rainfall experienced in this region, however there is very limited information available and further research is needed to understand the relationship between flows and woody riparian vegetation.

Studies on the water requirements of woody riparian species from elsewhere

The distribution of woody riparian species reflects hydrological conditions, such as number of days of inundation (per year), due to different species having different physiological adaptations to drought stress and inundation (Jansson et al., 2019). Flows that inundate the riparian zone are important for the recruitment of riparian species, as they transport seed and provide suitably moist conditions for germination and establishment (Naiman and Décamps, 1997, Jansson et al., 2019).

Groundwater may be an important water source for riparian trees (Pettit and Froend, 2018), and availability of groundwater over dry summer months can reflect a species vulnerability to water stress (Canham et al., 2009). However, it is unclear if groundwater (either alluvial or regional) is a significant water source for riparian trees along the Donnelly River. Although the region experiences a prolonged period with limited rain, overall rainfall is high, and the soil has a high water-holding capacity. This may mean riparian trees are less reliant on groundwater, although research is required to quantify relative groundwater-use, particularly in late summer and autumn.

Knowledge gaps

Knowledge gaps on woody riparian vegetation are incorporated below, in the aquatic plant section.

5.2.2 Aquatic plants

There is inconsistent terminology for defining aquatic plants, with the terms aquatic plants, macrophytes and riparian herbs used interchangeably by various authors (Mackay and James, 2016). We use the term aquatic plants which includes the following:

- Aquatic macrophytes which are ‘aquatic vascular flora (i.e. plants with conductive tissues) that grow in or on water, or on waterlogged soils’ (Mackay and James, 2016). We include floating, submerged and emergent species that do not tolerate drying, following Lyons et al. (2004) cited in Davies and Stewart (2013).

- Riparian herbs, which are herbaceous 'amphibious and terrestrial plants in riparian habitats during damp or dry phases in the absence of standing or flowing water (although these plants sometimes persist during wet phases as well) (Capon, 2016)'.

In SWWA there are 100 species of aquatic plants from 28 families, with 11 species that are threatened or near threatened (Davies and Stewart, 2013). Of these, the WA Herbarium database (florabase.dbca.wa.gov.au) shows that only *Ornduffia submersa* has been recorded in the Donnelly catchment. This is not necessarily an accurate depiction of threatened species occurrence in the Donnelly given the paucity of records for aquatic plants.

Aquatic plants are poorly understood, with few records for the Donnelly River or other rivers in the region.

Studies on the water requirements of aquatic plants from the Donnelly River

We found no published studies on the flow-ecology relationships for aquatic plants in the Donnelly River.

Studies on the water requirements of aquatic plants from the Warren Bioregion

We found no published studies on the flow-ecology relationships for aquatic plants in the Warren Bioregion.

Studies on the water requirements of aquatic plants from elsewhere

Studies on the water requirements of aquatic plants in broader SWWA are limited to emergent macrophyte species and not linked to specific flow components. In the Geographe region 6 native macrophyte species occur in surveyed rivers and creeks: *Cycnogeton huegelii, Liparophyllum lasiospermum*, *Potamogeton drummondii, P. ochreatus*, *Ottelia ovalifolia* and *Isolepis* sp. (Paice et al., 2017). A maximum of 3 species was found in a given reach and assemblages were influenced predominately by riparian condition (vegetation condition and stream stability) rather than flow (Paice et al., 2017). Recent declines in rainfall and flow had reduced the hydroperiod in the studied reaches, which may have influenced macrophyte assemblage (Paice et al., 2017), and this is an important consideration for SWWA more generally.

In wetlands on the Swan Coastal Plain near Perth, water regime (water depth and seasonal variability) was related to reproductive phenology and above-ground productivity for the emergent macrophyte species *Baumea articulata* (a sedge) and *Typha orientalis* (a rush) (Froend and McComb, 1994). *Baumea articulata* has greater flowering, seed production and aboveground productivity in wetlands with a greater mean water depth and did not flower at all in the driest site. *Typha orientalis* occupies areas with a similar water regime as *B. articulata*, and in some instances displaces the sedge species due to the high number of seeds produced (Froend and McComb, 1994).

The emergent macrophyte *Cycnogeton* spp. (formerly *Triglochin*) is found at 2 Donnelly River locations, with specimens of *C. hueglii* and *C. lineare* collected in the Donnelly with vouchers in the WA Herbarium. *Cycnogeton* spp. is widespread in Australia, and demonstrates adaptability to hydrological changes, responding swiftly to inundation, exhibiting rapid growth, and photosynthesising underwater (Rea and Ganf, 1994, Deegan et al., 2007). Chessman et al. (2008) investigated the impact of water abstraction on aquatic macrophytes in northeastern NSW, including *Cycnogeton* spp., noting their general resilience. However, the study investigated minimal water-take (4% of mean annual flow), leaving uncertainty about the impacts of larger flow alterations on Cycnogeton spp. and the applicability of findings to the Donnelly River (Chessman et al., 2008).

Aquatic plant species have important functional roles beyond their inherent biodiversity value. Emergent macrophytes, particularly sedges, provide a critical role in the maintenance of river channels, nutrient cycling, and provide important food and habitat for birds, mammals and aquatic fauna (Barrett, 2013). Submerged macrophytes provide habitat and food substrate (e.g. biofilms) for macroinvertebrates (Paice et al., 2017, Humphries, 1996) and fish (Bond and Lake, 2003). Humphries (1996) examined macroinvertebrates living on macrophytes in a Tasmanian river to determine if plant-macroinvertebrate associations varied with water level. Water depth was correlated with the abundance and richness of macroinvertebrates living in macrophytes, but the type of association varied among macrophyte species. For instance, a positive relationship with depth existed for the structurally complex species that inhabited shallow water (*Myriophyllum* spp.), but negative relationships existed for the structurally simple species found in deeper water (*Triglochin* spp. and *Eleocharis* spp.). This highlights the complexity of flow mediated animal-macrophyte relationships (Humphries, 1996).

Knowledge gaps

There is limited published information available on the water requirements for woody riparian and aquatic plant of the Donnelly River and SWWA.

Specific knowledge gaps identified are:

- The distribution of woody riparian species and the community composition of riparian vegetation along the Donnelly River.
- The water requirements of woody riparian vegetation or individual species.
- The phenology, ecology and ecophysiology for many woody riparian species.
- The distribution of aquatic plants and the water requirements for species occurrence.

5.3 Riverine fish

The Donnelly River catchment supports 12 species of fish (9 species endemic to SWWA) that wholly, or partly, inhabit freshwater (Morgan and Beatty, 2008, DWER, 2018), as shown in Table 5-1 .

Table 5-2 Fish species that occur in the Donnelly River Catchment, showing the threatened status listing under the *Commonwealth EPBC Act 1999* and the *WA Biodiversity Conservation Act 2016*. Species shown in grey are most likely to occur in non-flowing habitats, and are therefore not a focus of this report.

Species	Common name	Commonwealth listing	WA listing
Galaxias occidentalis	Western minnow	Not listed	Not listed
Nannoperca vitatta	Western pygmy perch	Not listed	Not listed
Galaxiella munda	Western dwarf galaxias/ Western mud minnow	Currently under consideration	Vulnerable
Bostockia porosa	Nightfish	Not listed	Not listed
Tandanus bostocki	Freshwater cobbler	Not listed	Not listed
Afurcagobius suppositus	South-western goby	Not listed	Not listed
Pseudogobius olorum	Blue-spot goby	Not listed	Not listed
Leptatherina wallacei	Western hardyhead	Not listed	Not listed
Nannatherina balstoni	Balston's pygmy perch	Vulnerable	Vulnerable
Geotria australis	Pouched lamprey	Not listed	P3 Poorly-known
Lepidogalaxias salamandroides	Salamander fish	Not listed	Endangered
Galaxiella nigrostriata	Black-striped dwarf galaxias	Endangered	Endangered

The salamander fish and the black-striped minnow are aestivating species that are restricted to swamp and lake habitats in the lower sandplain region (Scott Coastal Plain) of the Donnelly catchment (Morgan and Beatty, 2008). These habitats are influenced more by rainwater-groundwater interactions than river flow, therefore the species were omitted from our review below. The Western hardyhead was included, as while this species is strictly speaking estuarine, and to date has been collected only from the lower reaches of the Donnelly River, it occurs in inland reaches of other SWWA rivers.

Recent genomic research on the Western pygmy perch indicates that 2 genetically distinct species exist in SWWA (Buckley et al., 2024). One of these species (putative species B) is more closely related to the little pygmy perch (*Nannoperca pygmaea*), a species listed as Endangered by the EPBC Act. Like the little pygmy perch, putative species B has a narrow distribution and is likely of greater conservation concern (Buckley et al., 2024). While individuals from the Donnelly River were not included in the genetic analysis, lineage distribution modelling suggests that both species may be present in the Donnelly (Buckley et al., 2024 Supplementary Tables S8, S9).

Flow-ecology studies on fish in the Donnelly River

One study has directly assessed a flow-biota relationship for fish in the Donnelly River, examining larval lamprey (ammocete) abundance at 6 sites along Carey Brook, finding that larval lamprey (ammocete) preferentially use low velocity habitats (Potter et al., 1986). In addition to this direct flow-biota relationship, distributional studies in the river provide insight into broad water requirements. For instance, freshwater cobbler and pouched lamprey are more likely to occur in downstream perennial reaches of the Donnelly River (Morgan and Beatty, 2008, DWER, 2018) suggesting that these species are more reliant on year-round flows, or some covarying aspect of habitat. Cool, low salinity groundwater is also considered important for the survival of larval lamprey (Morgan and Beatty, 2008).

The Western mud minnow is the only species more likely to occur in the upper intermittent reaches rather than the lower, perennial reaches of the Donnelly River (Morgan and Beatty, 2008, DWER, 2018). This species, which is currently undergoing EPBC assessment (DCCEEW, 2024), is unable to survive complete drying of the river channel, so its persistence in the upper catchment is reliant on refuge pools. Recent sampling by the Western Australian Department of Water and Environmental Regulation (DWER) indicates that farm dams on Ephraim gully (a gully that feeds into Manjimup Brook) may provide summer refuge (Tim Storer pers. comm.). It is likely that mud minnows, which only survive for one year (Morgan et al., 1998, Pen et al., 1991) gain a survival advantage in intermittent tributaries due to the absence of larger predatory species, including the several species of alien fish that are present in the lower catchment (Morgan and Beatty, 2008). The remaining 4 common species (Western minnow, nightfish, Western pygmy perch, and freshwater cobbler) appear to be flow generalists, occurring in both intermittent and perennial reaches (Morgan and Beatty, 2008).

Flow-ecology studies on fish in the Warren Bioregion

Information on the flow-ecology of fish from the Warren Bioregion is limited to 4 papers on fish movement, which highlight the importance of key flow components.

The earliest study examined the movement of adult lamprey crossing the Pemberton Weir on the Warren River and found that upstream movement was strongly related to rising river discharge but not water depth (Potter et al., 1979). Winter high flows (bankfull) not only facilitate the passage of lamprey over instream barriers, but also likely play an important role in the migration of adults into rivers (Stewart et al., 2011, Sorensen and Vrieze, 2003) and the return migration of juveniles to the ocean (Potter et al., 1979).

A more recent study by Beatty et al. (2010) in the mid Blackwood River, investigated the influence of groundwater inflows on the movement of freshwater cobbler. They found that during the dry season, longitudinal movements through riffles (shallow turbulent areas) increased with the magnitude of baseflow discharge, indicating that declines in low flow/groundwater will likely limit the movement of freshwater cobbler (Beatty et al., 2010). Reduced movement, in turn, is likely to impact foraging opportunities (Beatty et al., 2010) which may reduce body condition and reproductive fitness.

Another study by Beatty et al. (2014) on the mid-Blackwood River, investigated the link between river discharge and spawning migrations for smaller-bodied native fish. They found that many fish species, including the Western minnow, nightfish, Western pygmy perch, and Balston's pygmy perch, moved between main channel and tributary habitats. The timing of movement varied among species, but in general fish moved upstream into tributary creeks during winter (June to August) and young-of-year fish moved downstream in tributaries towards the main channel in spring and early summer (October to December). This finding indicates that many species are using seasonally available tributaries as spawning habitat – a conclusion supported by a recent study on the little pygmy perch (*Nannoperca pygmaea*) in the Hay River (Allen et al., 2020). The timing of fish return movements changes according to the persistence of the tributary. Fish move earlier (late winter/early spring) in ephemeral creeks and later (autumn) in perennial creeks (Beatty et al., 2014). This suggests that fish time their movement out of tributary habitats using recessional flows, to avoid stranding in drying habitats. Within-bank flows are likely to cue movement of fish, with a positive relationship between discharge and the number of Western pygmy perch, nightfish, Western minnows moving upstream in tributary habitats (Beatty et al., 2014). The relationship between discharge and directional movement remains uncertain for the Western mud minnow, with Beatty et al. (2014) finding a weak positive association between discharge and upstream movement, and recent observations in the Donnelly River report it moving rapidly downstream on the flood front of connecting winter flows (Tim Storer pers comm).

Flow influences water quality, particularly salinity and temperature. In the salinized inland reaches of the Blackwood and Warren Rivers there are diminished populations of many native species, including

Western pygmy perch, nightfish, and Western mud minnows (Morgan et al., 2003). Many inland river reaches are now dominated by estuarine species, such as the Western hardyhead, blue-spot goby and south-western goby, or by non-native species tolerant of salinity, such as *Gambusia* (Morgan et al., 2003, Rashnavadi et al., 2014, Beatty et al., 2006). Some native species are considerably more sensitive to salinity than others, as determined by EC50, that is the salinity level that causes 50% mortality of individuals. For instance the threatened species, Balston's pygmy perch, has an EC50 of 8.2 g L^{-1} whereas the Western minnow and Western pygmy perch have an EC50 of 14.6 g L^{-1} (Beatty et al., 2011b). Although not currently an issue for the Donnelly River, changes in salinity levels could impact its fish species.

Flow-ecology studies on fish from elsewhere

Studies conducted elsewhere in SWWA reinforce the importance of flow for freshwater cobbler, showing increased movement with larger flows in the Harvey, Brunswick and Canning Rivers (Storer et al., 2021, Beesley et al., 2019). The studies also revealed nuanced flow-biota relationships with cobbler passively displaced several hundred metres downstream by the rising limb of winter flow pulses, but returning 'home' on the falling limb (Beesley et al., 2019). Low flows and instream barriers reduced the size of the daily home range (Beesley et al., 2019) and the general distance travelled (Beesley et al., 2019, Storer et al., 2021), but cobbler still migrated upstream presumably to spawn during spring (October) (Beesley et al 2019).

Studies on Western minnow, nightfish and Western pygmy perch in the Collie River during the 1990s support the findings of Beatty et al. (2014) in the Blackwood. Species are migrate into tributary creeks when they start to flow, and spawn in winter/spring when discharge is high and temperature and daylength begin to increase (Pen and Potter, 1991a, Pen and Potter, 1991c, Pen and Potter, 1990). We could find no studies that directly examine if river discharge acts as a cue for spawning. However, Allen et al. (2017 p17) state 'seasonal flows that provide spawning cues' in their review of threatened aquatic fauna, including fish, of the Cape to Cape region.

There is a strong association between air temperature and instream water temperature, indicating that ambient changes to the atmosphere will translate into the aquatic environment (Beatty et al., 2014). The thermal tolerances of fish have been assessed by Beatty et al. (2013) and indicate that some species (e.g. Western mud minnow) have much lower thermal tolerances than others (e.g. Western minnow). However, it should be noted that these predictions were determined using field detection and non-detection data, and laboratory trials are needed to formalise these associations. Currently, there is little direct evidence that changes in temperature will impact the spawning migrations of SWWA species. A negative relationship between temperature and movement has been found for Western pygmy perch (Beatty et al., 2014), but this may reflect seasonal patterns rather than thermal constraints. Research in south-eastern Australia on water temperature during the Millennium drought (2000-2012) found that fish species with small maximum size, early maturation, low fecundity, demersal eggs and protracted spawning during low temperatures were most impacted by warmer temperatures (Chessman, 2013). These traits are common to most fish in SWWA (Beatty

et al., 2014) and these findings may be transferable to the Donnelly. In the face of a drying climate, rivers in the vicinity of the Donnelly have been identified as regional climate refugia for fish, due to their cooler water temperatures (Stewart et al., 2022).

Knowledge gaps

Although there is limited information on flow-biota relationships for the Donnelly River, we consider information from elsewhere in SWWA to be broadly transferable. Identified knowledge gaps are therefore more targeted to support management of threatened species and to address specific management questions relating to the management of water in the intermittent upper Donnelly. Identified knowledge gaps are:

- A detailed current distribution of fish species, including threatened species, in the Donnelly River.
- The link between environmental variables (pool size/ depth, river km, habitat etc) and fish presence and/or abundance.
- The location and attributes (size, depth, shading, etc) of refuge pools in the upper Donnelly catchment and the freshwater fish populations they support.
- The importance of flow (discharge) as a spawning cue for native fish.
- Understanding the importance of early and late wet season flows for fish dispersal and retreat across the catchment.
- The dispersal capacity of different fish species, and the length of flow connectivity needed to facilitate fish movement.

5.4 Crayfish

All freshwater crayfish in SWWA are endemic, and the Donnelly River supports 4 species:

- smooth marron (*Cherax cainii*)
- koonac (*Cherax preissii*)
- gilgie (*Cherax quinquecarinatus*)
- restricted gilgie (*Cherax crassimanus*)

Obligate burrowing crayfish, for example *Engaewa* sp., are also present in the catchment and while they may inhabit riverine habitats (i.e. riparian zone, tributaries) (Horwitz, 1997, Burnham et al., 2012) they spend virtually all of their life underground. They have been omitted from this review because they are generally considered terrestrial (Burnham, 2014) and influenced more by groundwater than river flow.

Although crayfish, particularly marron, are iconic SWWA freshwater species, researchers comment on how little investigation has taken place in the wild. For instance, De Graaf et al. (2010) state '*Strangely, following such significant findings substantiating the threatened nature of marron as a*

species in the wild, no follow up research was conducted after the 1973/74 study Morrissy (1978) until the present. Conservation of the species has been left to rudimentary recreational fisheries regulations…this has persisted even though the seasonal marron catch continues to decline, and community recognition of the marron's vulnerability increases'. This highlights the lack of quality information on freshwater crayfish to inform decision-making that protects them, not only for the Donnelly but more broadly for SWWA.

Flow-ecology studies on crayfish in the Donnelly River

We found no published studies on the flow-ecology relationships for crayfish in the Donnelly River.

Flow-ecology studies on crayfish from the Warren Bioregion

There is limited published information on crayfish from the Warren Bioregion, and the role of specific flow components have not been investigated. However, in the Blackwood river, Beatty et al. (2006) refer to a positive relationship between marron catch and river flow, citing unpublished Fisheries data. Similarly, Nickoll (1996) reports greater catch of marron following higher rainfall years. Beatty et al. (2006) posit that increased flows promote recruitment due to increased habitat availability and food resources. Flow, along with temperature, is also believed to drive the highly variable growth rate observed among, and within, marron populations (De Graaf et al., 2010, Beatty et al., 2011a).

Aside from flow, information exists about the vulnerability of freshwater crayfish to poor water quality. Secondary salinisation of surface and groundwater in SWWA is thought to have reduced the upstream distribution of marron in the Blackwood River (De Graaf et al., 2010, Morrissy, 1978), with several field studies stressing how vulnerable marron are to elevated salinity (De Graaf et al., 2010, Bunn and Horwitz, 1980).

Flow-ecology studies on crayfish from elsewhere

Studies from elsewhere in SWWA highlight the importance of flows for freshwater crayfish species. Persistent surface water during summer is most important to smooth marron, a species that constructs shallow, poorly-formed burrows (Koenders and Horwitz, 2006) and was historically confined to the high rainfall/flow region between the Harvey and Hay Rivers (Morrissy, 1978). The species is most abundant in areas with perennial flow and largely absent from areas with ephemeral flow (Austin and Knott, 1996, Beatty et al., 2006, Morrissy, 1978). Gilgies and koonacs are much better adapted to intermittent flows, as they create well-constructed deep burrows that can reach the water table (Koenders and Horwitz, 2006), which act as refuge during the summer dry season. Their ability to tolerate channel drying, combined with reduced competition with smooth marron, may explain why gilgies and koonacs are most abundant in small seasonally flowing streams (Austin and Knott, 1996). A mesocosm study revealed that gilgies from a seasonally flowing stream burrowed less during waterbody drying, but had a higher rate of survival than those from a perennially flowing stream (Emery-Butcher, 2023). This finding suggests adaptation to local flow conditions, which may imbue a population with a degree of resilience to drying.

There is no evidence that winter flows trigger breeding in crayfish, with studies indicating that temperature and daylength cue reproductive development (Mosig, 1998); however, winter flows influence recruitment via the provision of habitat. For instance, adult gilgies migrate into tributary habitats during winter high flows to breed, before retreating to the main channel (Beatty et al., 2006, Koenders and Horwitz, 2006), indicating that winter flows create critical nursery habitat for this species.

An unpublished study by Fisheries WA on smooth marron in Wellington Dam, in the Collie River, found that river discharge was a significant predictor of marron catch 1, 2 and 3 years later (De Graaf et al., 2010). Interestingly, discharge had a curvilinear relationship with catch and changed depending on temporal context. For instance, moderate river flows were associated with higher catch of marron one year later but were associated with lower catches after 2 or 3 years (De Graaf et al., 2010). The study did not account for changing catchability with flow / dam fullness, and it seems probable that high catches during low water levels were simply the product of increased catchability rather than abundance. If this is the case, then a positive relationship between flow and abundance may exist.

Information from elsewhere in SWWA shows the impact of salinity on crayfish. Laboratory trials indicate that growth and survival decline if salinity exceeds 4 g L^{-1} (De Graaf et al., 2010) to 8 g L^{-1} (Morrissy, 1974, Morrissy et al., 1990), and mortality occurs when levels exceed 20 g L^{-1} (Morrissy et al., 1990) (note seawater is 35 g L^{-1}). Marron are also thought to be unable to tolerate low dissolved oxygen (DO); however, much of this knowledge comes from aquaculture studies (Morrissy, 1992, Lawrence and Jones, 2001, but see Beatty et al., 2019 as an exception). Preliminary data from the Donnelly River suggest that marron in the wild may be able to tolerate low dissolved oxygen levels with healthy numbers found in late dry season pools with oxygen levels of ~ 2 mg L^{-1} (DWER, 2018).

Knowledge gaps

There is limited published information available on the flow-ecology relationships of crayfish not only for the Donnelly but more broadly for SWWA.

Specific knowledge gaps identified are:

- Distribution of crayfish species, including threatened species, in the Donnelly River.
- The relationships between environmental variables (pool depth, river km, habitat etc) and crayfish presence and/or abundance.
- The relationship between flow and the recruitment of freshwater crayfish, particularly marron.
- The influence of local and landscape factors, (e.g. water quality, pool depth/size position in the catchment, flow persistence) on marron recruitment.

5.5 Mussels

Until recently, one species of freshwater mussel was thought to exist in SWWA, Carter's mussel (*Westralunio carteri*). However, recent genetic studies identified 3 evolutionarily significant units that correspond to geographic locations: west coastal, southwestern and southern coastal drainages (Klunzinger et al., 2021, Klunzinger et al., 2022, Benson et al., 2022). Today 3 species are now recognised: *W. carteri*, *Westralunio inbisi meridiemus*, and *Westralunio inbisi inbisi* (Klunzinger et al., 2022). This species complex is endemic to the region and is listed as Vulnerable under the EPBC Act 1999 and WA Biodiversity Conservation Act 2016. Mussels in the Donnelly River belong to the south coast evolutionary unit (*W. i. inbisi*) and have the greatest genetic affinity to those in the Blackwood River – south-west corner (Benson et al., 2022, Klunzinger et al., 2022). Carter's mussel has undergone a dramatic 49% reduction in range over the last 50 years (Klunzinger et al., 2015) with key threats considered to be a drying climate and secondary salinisation (Lymbery et al., 2021). Carter's mussel attains maturity after 4 to 6 years and can live for more than 50 years (Klunzinger et al., 2014). Its slow growth rate, delayed maturation, long generation time and relatively sedentary nature make this species, like other mussels, particularly vulnerable to disturbance (Ma et al., 2022, Brainwood et al., 2006, Galbraith et al., 2010).

Flow-ecology studies on mussels from the Donnelly River

No published studies focus on the flow-ecology relationships of mussels in the Donnelly River; however, sites from the Donnelly are included in a regional study that examined the influence of flow and water quality on distribution through time. Mussel occurrence was greater in perennial waterways and low to absent in non-perennial ones (Klunzinger et al., 2015). Salinity is also a strong driver of mussel distribution with mussels absent from waterways with salinity > 1.62 mg L^{-1}, supported by laboratory trials (Klunzinger et al., 2015); however a more recent study by Ma (2018) suggests salinity tolerance is higher with an LC50 of 5.9 g L^{-1}.

Flow-ecology studies on mussels from the Warren Bioregion

No published studies focus on the flow-ecology relationships of mussels in the rivers of the Warren Bioregion. However, the impact of salinity to Carter's mussel has been examined in the Kent River, a salt and acid-affected river approximately 110 km to the east of the Donnelly (Benson et al., 2019). Mussels were more likely to occur in permanently flowing riverine sections and were absent from river locations affected by salinity or acidity. The authors postulate that perennial flows promote survival of mussel populations where fresh groundwater dilutes salinity (Benson et al., 2019). Thus, it appears that river reaches with high connectivity to regional groundwater provide water-quality refugia for this species.

Flow-ecology studies on mussels from elsewhere

Evidence from elsewhere in SWWA shows that Carter's mussel, like other mussel species, have physiological and behavioural adaptations that allow it to survive periods of surface water drying

(Lymbery et al., 2021, Archambault et al., 2014, Gough et al., 2012). In the Collie River, Carter's mussels tracked receding water levels and burrowed into the sediment (Lymbery et al., 2021). Laboratory trials indicate that the species can survive at least 62 days without surface water and even longer if the channel is well shaded and mussels burrow into a wet substrate (Lymbery et al., 2021). Given this information it seems likely that the species can survive seasonal drying. Thus, it seems counterintuitive that the species is largely absent from many intermittent waterways in SWWA. Its absence may be due to a synergistic effect of the stress of secondary salinisation and protracted periods of drought due to climate change. Elevated temperatures associated with low flows, climate change and reduced riparian shading also likely play a role. For instance, a recent study examining mussels from the Harvey River, found that under laboratory settings mussels had an LC50 of 32.8 °C (Perera, 2023). These temperatures were regularly exceeded *in situ* in the Harvey River during the summer, particularly in locations where riparian stream shading was minimal (Perera, 2023).

There is little discussion in the literature about the importance of winter flows to Carter's mussel. It is possible that within-bank flows cue spawning as male mussels spawn during the high flow winter months. However, as females brood larvae from August to December, after which they attach to a general fish host for 4 to 6 weeks (Klunzinger et al., 2012), flow pulses likely play a negligible role in the subsequent stage of their life history (fish dispersal aside). Low flows during January and February are also likely critical for fully formed juveniles to settle into the sediment.

Knowledge gaps

Knowledge of Carter's mussel has increased greatly over the last decade, with information pertinent to flow (Klunzinger et al., 2015, Benson et al., 2019), genetics (Benson et al., 2022, Klunzinger et al., 2021, Klunzinger et al., 2022), behaviour (Lymbery et al., 2021), distribution (Klunzinger et al., 2015, Benson et al., 2019), microhabitat preferences (Ma et al., 2022), life history (Klunzinger et al., 2014, Klunzinger et al., 2013) and population demographics (Ma et al., 2022). This new information greatly expands knowledge about the species; however, gaps remain.

Specific knowledge gaps identified are:

- The relationship between winter flows and the cue to spawn.
- The influence of shading by riparian vegetation and the ability for mussels to survive summer drought.
- The distribution of the mussel in the Donnelly River and the relationship between site factors including water persistence, shade, substrate, wood, fine sediment and water quality.

5.6 Macroinvertebrates

Aquatic macroinvertebrates are an important component of aquatic and riparian food webs, and their community composition is often used as an indicator of river hydrology and water quality

(Chessman, 2003, Brooks et al., 2011, Smith et al., 1999). Compared with other regions in Australia, SWWA has a relatively depauperate macroinvertebrate assemblage at both a family and species level (Smith et al., 1999, Bunn and Davies, 1990, Davies and Stewart, 2013). There are particularly few algal grazing species and few cold-water species known to have limited thermal tolerances (e.g. insect orders Ephemeroptera, Plecoptera, Trichoptera; often referred to as EPT) (Bunn and Davies, 1990). Like fish, many of SWWA's macroinvertebrates are endemic or have Gondwanan affinities, although surprisingly few are listed as threatened (Davies and Stewart 2013); this would likely change if they were assessed against IUCN categories and criteria (Davies and Stewart, 2013).

Flow-ecology studies on macroinvertebrates from the Donnelly River

Two studies conducted in the 1980s by Growns and Davis (1994a, b) highlight the influence of flows on macroinvertebrate assemblages in the Donnelly River. In Carey Brook, a permanently flowing tributary of the Donnelly, most macroinvertebrate taxa occurred where mean velocity and substrate roughness was highest (Growns and Davis, 1994b). Both flow-avoider and flow obligate species were abundant in turbulent areas with high shear stress, with the authors postulating that flow-avoiding species seek refuge in interstitial areas while benefiting from high oxygen and influx of fine organic matter (i.e., food) (Growns and Davis, 1994b). A second study found that the assemblage structure of macroinvertebrates changed seasonally (Growns and Davis, 1994a). They also found reduced macroinvertebrate species richness and abundance during high winter flows at logged (clear felled) sites with inorganic suspended sediments, however, the assemblage recovered through time as sedimentation from vegetation removal abated (Growns and Davis, 1994a).

The ecology of macroinvertebrates and the importance of flow and other environmental factors has been investigated in large spatial scale studies in SWWA, with several studies including sites from the Donnelly. A study of 51 sites (4 from the Donnelly) over a 10-year period (2004-2013) across forested streams in SWWA found that hydrology and connectivity of water bodies were the best predictors of macroinvertebrate species turnover (beta diversity) (Pennifold and Pinder, 2011). The 2 best predicting flow metrics were coefficient of variation (CV) for monthly total runoff and CV for annual maximum monthly runoff, which suggests that macroinvertebrates in intermittently flowing systems (high CV) are very different from those in perennial flowing systems (low CV) (Pennifold and Pinder, 2011). Further analysis of a subset of this data (2005-2008) revealed that macroinvertebrate assemblages in the Donnelly were relatively species rich compared with many other river systems and were in good health (Pennifold and Pinder, 2011). Rivers and streams situated in Karri Forest supported higher species richness of EPT families than Jarrah Forest (Pennifold and Pinder, 2011), which suggests that the mid to lower parts of the Donnelly catchment which have a Karri overstorey should be more speciose than upper Jarrah forested sections. Such patterns haven't been confirmed for the Donnelly, and it remains possible that forest type is a good predictor merely because it is correlated with rainfall/flow. Pennifold and Pinder (2011) also found evidence that dams and low flow cause stress to macroinvertebrate communities, with reduced EPT richness at sites downstream of dams, reduced species richness during a year with low rainfall/flow, and higher macroinvertebrate richness in streams with higher maximum flow. The study found inconsistent patterns with logging

and fire, but a strong negative association between macroinvertebrates species richness and water conductivity (a correlate of salinity).

Flow-ecology studies on macroinvertebrates from the Warren Bioregion

Studies undertaken in the Warren Bioregion contain information relevant to the flow-ecology of macroinvertebrates. In the Warren River it was found that the macroinvertebrate assemblage was in relatively poor health, with low macroinvertebrate SIGNAL scores, an index of EPT species (Beatty and Morgan, 2010). However, SIGNAL scores were highest in the mid reaches, i.e., the location of fresh groundwater upwelling. The authors postulate that strong groundwater-surface water connectivity in the lower reaches of the river may provide refugia from secondary salinisation for macroinvertebrates much like it does for freshwater fish.

A desktop study documented the aquatic biodiversity of the Warren Bioregion by compiling published literature and museum records (Trayler et al., 1996). They found that 17% of aquatic invertebrate species were locally restricted, however, the assessment included lakes and wetlands. The study highlighted that altered land use, dams, sedimentation, secondary salinisation, habitat destruction and introduced fish species (e.g. Gambusia, rainbow trout etc) are key threats to the region's aquatic fauna (Trayler et al., 1996).

Negative effects of increasing temperature and salinity on macroinvertebrates of SWWA have been reported by many other studies in SWWA (Bunn and Davies, 1992, Horwitz et al., 1997, Kay et al., 2001, Halse et al., 2003, Halse et al., 2007, Edward et al., 2000); however, at least one longitudinal study along the Blackwood River failed to find any link with salinity (Williams et al., 1991).

Flow-ecology studies on macroinvertebrates from elsewhere

Studies conducted elsewhere in SWWA provide an insight into the flow-ecology of macroinvertebrates, their habitat associations, water quality tolerances, and the impacts of land use change. The importance of flow is highlighted in some studies. In the upper Canning River near Perth there is correlative evidence that flow impoundment shifts the assemblage of macroinvertebrates from species typically associated with flowing water to those more common in standing water (Storey et al., 1991). In streams of the northern Jarrah Forest (Wungong catchment), close to Perth, an increase in flow intermittency was associated with a decline macroinvertebrate shredders i.e. species of caddisflies and stoneflies (EPT Gondwanan relicts) to widespread resilient desert-adapted taxa (i.e. certain chironomids) (Carey et al., 2023). An earlier study in the same region found strong associations between water velocity and depth and temporal changes in the macroinvertebrate assemblage, with the diversity of taxa decreasing markedly during summer low flows (Bunn et al., 1986). However, flow-related changes may not be noticeable if salinity has already impacted the assemblage. For instance, Bunn and Davies (1992) found no association between the macroinvertebrate assemblage and flow, and little association with other environmental parameters (width, temp, substrate heterogeneity, organic matter, nutrients, water quality), in a study of the Hotham River and an adjoining intermittent tributary – a system with highly saline waters (>3 g L^{-1})

and a low diversity macroinvertebrate assemblage. Studies in the northern Jarrah Forest and coastal plain around Perth also highlight the importance of riparian vegetation to macroinvertebrates, particularly the diversity of shredder and EPT species (Armstrong et al., 2005, Gwinn et al., 2018), and studies from wetlands highlight the importance of riparian shade to macroinvertebrates during periods of drought (Strachan et al., 2016).

Knowledge gaps

We found no published studies on macroinvertebrates in the main stem and upper tributaries of the Donnelly River. However, the WA Department of Biodiversity, Conservations and Attractions surveyed several sites in this area as part of the Forest Streams Monitoring Program which ran from 2008 to 2016 (Adrian Pinder pers. comm.).

Specific knowledge gaps identified are:

- Information about pool temperatures along the Donnelly during summer low flows to ascertain the thermal threat to macroinvertebrates.
- Information about the movement ability of semi-aquatic insects in SWWA to better understand the implications of different configurations of refuge pools across a riverscape.

5.7 Hyporheic invertebrates

Rivers and streams with porous bed substrates, such as gravel and sand, commonly experience considerable surface water-groundwater exchange (Boulton, 1993). This area, termed the 'hyporheic zone' occurs beneath the channel bed and adjacent to the channel (White, 1993) and supports tiny biota that live in the interstitial spaces. Hyporheic biota include species that also occupy surface waters, such as microcrustaceans, worms and midge larvae, as well as specialised species only found in the hyporheic zone, e.g. certain copepods, isopods and syncarids (Williams, 1984).

Flow-ecology studies on hyporheic invertebrates from the Donnelly River

We found no published studies on the flow-ecology relationships for hyporheic invertebrates of the Donnelly River.

Flow-ecology studies on hyporheic invertebrates from the Warren Bioregion

There are 2 studies assessing hyporheic invertebrates in the Warren Bioregion, although they were not related to flow requirements (Trayler and Davis, 1998, Boulton, 2007). Hyporheic invertebrate communities of sandy SWWA streams were first described for the headwaters of the Warren and Gardner Rivers, with the aim of determining the impact of clear fell logging Karri on hyporheic invertebrate assemblage (Trayler and Davis, 1998). Logging markedly altered the hyporheic assemblage and reduced species richness in the riverbed sediment below 5 cm. However, logging had no impact on invertebrates in the very shallow sediment – where the majority of the hyporheic

individuals occurred. The decline of species richness at depths > 5 cm may be due to the greater depth and current velocity in logged catchments (Trayler and Davis, 1998). If true, this suggests that scouring flashy flows associated with land use change impact the hyporheos.

Boulton et al. (2007) examined the relationship between hyporheic invertebrates and salinity in 13 south-west rivers including a handful that traversed the Warren Bioregion. No relationship was found between salinity and the hyporheic invertebrate community (Boulton et al., 2007), and specialised groundwater invertebrates (stygofauna) were only found in several rivers, one being the Warren, and the Tone which discharges into the Warren.

Flow-ecology studies on hyporheic invertebrates from elsewhere

Few studies have examined the link between flow and hyporheic invertebrates elsewhere in SWWA, but a considerable amount is known from around the world. Research indicates that reduced stream water depth reduces the penetration of surface water into the hyporheic zone, which reduces the amount of habitat available for hyporheic invertebrates (see review by Hancock 2002). Reduced stream flow also increases sediment infilling of interstitial spaces and alters nutrient and chemical processing – together impacting the quantity and quality of habitat for hyporheic invertebrates (see reviews by Boulton and Hancock and Hancock 2002). Studies have found that sites with high flow permanence (reaches that receive groundwater) supported greater species richness and more distinct hyporheic invertebrates (Daltry et al., 2007, Smith et al., 2003).

Knowledge gaps

There is limited published information on the flow-ecology relationships for hyporheic invertebrates in the Donnelly, the Warren Bioregion, and SSWA more broadly.

Specific knowledge gaps identified are:

- The relationship between flow and hyporheic invertebrates in the Donnelly, Warren Bioregion and SWWA more broadly.
- The species of stygofauna that occur in the Donnelly River has not been determined.

5.8 Ecosystem function

Although not a biotic group *per se*, knowledge about ecosystem function, aquatic food webs, leaf litter breakdown and stream metabolism are pertinent to our review because they provide an insight into how rivers function.

Flow-ecology studies on ecosystem function from the Donnelly River

We could find no published studies on ecosystem function for the Donnelly River.

Flow-ecology studies on ecosystem function from the Warren IBRA

There are no published studies on leaf litter breakdown in the Donnelly River. However, one study has examined leaf breakdown at a single location in the neighbouring Warren River, but the only published results of this study are a single data point in a large global study (Boyero et al., 2021b, Boyero et al., 2021a), thus are of limited use. However, preliminary unpublished results suggest that the breakdown of leaf litter from common tree species (karri, jarrah, peppermint) is accelerated by elevated instream nitrogen concentrations (Middleton et al., 2016). There have been no published studies on stream metabolism.

Flow-ecology studies on ecosystem function from elsewhere

Studies from SWWA provide an insight into the food web and energetics of rivers in the region. Research on streams of the northern Jarrah Forest south of Perth showed that benthic invertebrates predominantly consume riparian leaf litter (Bunn et al., 1999), and that detritivores are the dominant macroinvertebrate taxa in these forest streams (Bunn, 1986's). Energetic subsidies from the terrestrial to the aquatic environment likely extend beyond leaf litter, as gut content studies indicate that several species of fish (e.g. Western minnow, mud minnow) consume terrestrial fauna on the water surface (Pen and Potter, 1991b, Pen et al., 1991). Evidence also exists of energetic subsidies in the opposite direction, i.e. from the aquatic to the terrestrial environment, with a stable isotope study by Hunt et al. (2020) finding that energy flowed from instream macroinvertebrates to spiders in the riparian zone. This study, conducted in 4 perennial streams near Albany, also found that the condition of riparian vegetation mediated the transfer of energy - with less energy flowing as riparian condition declined.

Given the importance of leaves to the energetics of heavily shaded waterways, knowledge about leaf litter breakdown is important as it provides an insight into food availability and its incorporation into the food web. Studies on leaf litter breakdown in SWWA rivers come from the northern Jarrah Forest and the coastal plain near Perth. Research in the early 1980s (from 1982 to 1983) on headwater streams of the North Dandalup found that that although most litter fall occurs during summer and autumn, that litter breakdown is very slow and occurs predominantly during winter (Bunn, 1988a). Sedimentation from land clearing reduces breakdown by burying leaves (Bunn, 1988a, Bunn, 1988b). A recent study by Carey et al. (2021) in the Wungong River investigated the influence of flow reduction (i.e. stream drying) on leaf litter breakdown by studying contemporary perennial and intermittent streams and comparing breakdown in perennial streams today (2018-19) with those studied by Bunn in the early 1980s. The study found that a shift in flow regime from perennial to intermittent changed the types of shredder macroinvertebrates but did not alter leaf breakdown, largely because one type of shredder was replaced by another (i.e. functional redundancy in the shredder community). Another study across the Swan Coastal Plain found no association between leaf litter breakdown and flow stress, as measured by catchment imperviousness, but identified a positive association with total nitrogen concentration (Middleton, 2015).

There is limited published research on stream metabolism in SWWA with only one study undertaken in the northern Jarrah Forest. This study found that streams were heterotrophic, i.e. net respiration was greater than net primary production (Bunn et al., 1999), indicating that they consumed more energy than they create. This finding supports the findings from food web studies that indicate that streams are predominantly fuelled by riparian leaf litter.

Knowledge Gaps

We found no published studies on the flow-ecology relationships of stream metabolism, the food web or leaf litter breakdown in the Donnelly River.

Specific knowledge gaps identified are:

- Testing the assumption that leaf litter is the dominant source of energy sustaining the food web of the Donnelly River.
- The impacts of agricultural land use on flow and nutrients and subsequent impacts of the river's energetics.

5.9 Amphibians & reptiles

There are 9 frog species that occur in the Donnelly catchment, as recorded by Atlas of Living Australia records:

- *Crinea georgiana* (Tschudi's froglet)
- *Geocrinea rosea* (karri frog)
- *Litoria adelaidensis* (slender tree frog)
- *Meacrinia nichollsi* (Nicholl's toadlet)
- *Crinia glauerti* (Glauert's froglet)
- *Litoria moorei* (motorbike frog)
- *Limnodynastes dorsalis* (Western banjo frog)
- *Geocrinia leai* (Lea's frog)
- *Heleioporous psammophilus* (sand frog)

Some species, such as the motorbike frog occur in the main channel of the Donnelly or its adjacent riparian zone (Tim Storer pers. comm.). Other species, such as the karri frog, Sand frog and Nicholl's toadlet, are found predominantly in terrestrial habitat, such as karri forest (Wardell-Johnson and Roberts, 1993, Wayne et al., 2001), while the Western banjo frog is common in the lake/swamp habitat of Scott Plain (Cogger, 2015). Research on the water requirements of species that utilise the main channel and riparian zone is limited; however, distributional studies provide some insight. A study in the intermittent headwaters of the Warren River found more individuals of *Helioporous* and *Crinia* species in riparian than midslope or ridge habitats (Yeatman et al., 2016), suggesting that overbank flows which support riparian areas may be important for some frog species.

Although numerous reptiles inhabit the Donnelly River catchment, only the south-western turtle (*Chelodina colliei,* previously known as *Chelodina oblonga*) is considered strongly associated with freshwater habitats (Davies and Stewart, 2013). This turtle is endemic to SWWA but is widely distributed across the region and is habitat generalist, occupying wetlands and lakes as well as flowing riverine habitats (Cogger, 2015). No studies have examined the flow ecology of *C. colliei* in the Donnelly or elsewhere in SWWA.

Knowledge Gaps

While there are no targeted studies assessing the water requirements of amphibians and reptiles in the Donnelly River, such studies are not considered a priority because the link between river flow and populations is not as strong as for other biotic groups.

5.10 Terrestrial vertebrates

5.10.1 Mammals

The Donnelly River and its riparian zone provide important habitat to rakali (*Hydromys chrysogaster*) and quokka (*Setonix brachyurus;* listed as Vulnerable under the EPBC Act 1999 and WA BC Act 2016). Although riparian vegetation is not used exclusively, it is also significant habitat and food source for the Critically Endangered (EPBC Act 1999 and WA BC Act 2016) Western ringtail possum (*Pseudocheirus occidentalis*), as well as quenda (*Isoodon obesulus fusciventer*).

Rakali are a semi-aquatic water rat and are habitat specialists, preferring dense, low lying (<30cm) vegetation cover and narrow streams (Speldewinde et al., 2013). Although rakali are widespread across Australia, their populations have been in decline, and the species is listed by as Priority 4 (rare, near threatened and other species in need of monitoring) under the WA BC Act 2016. Rakali require permanent water bodies, intact riparian vegetation and stable banks (Smart et al., 2011). Greater habitat diversity has also been associated with a higher abundance of rakali (Smart et al., 2011). Specific water requirements to support rakali populations have not been determined for SWWA; however, flows that maintain permanent pools will be critical, as flows that maintain riparian vegetation will be important.

The southern forests, including the Donnelly catchment, support a population of quokka with other mainland populations found in the northern jarrah forest and in reserves around Albany (Bain et al., 2019). Riparian vegetation provides important corridors for movement of quokkas between primary habitats (Bain et al., 2019), particularly in years following fire (Bain et al., 2023). Although riparian vegetation is not used exclusively by quokkas, sedges (e.g. *Lepidosperma effusum* and *Anarthria scabra*) and the small tree *T. linearifolia* have been associated with mainland quokka populations (De Tores et al., 2007).

The southern forest population of the critically endangered Western ring tail possum *(Pseudocheirus occidentalis)* occurs in jarrah, marri or karri dominated forests and adjacent riparian vegetation,

which often has an overstorey of *E. rudis* (DPaW, 2017). Intact riparian vegetation provides important habitat for ringtail possums, for both food and habitat (DPaW, 2017).

Quenda, also known as the Southern brown bandicoot, are distributed throughout SWWA. Dense riparian vegetation provides important habitat for quenda, providing protection from predators (Burrows and Christensen, 2002).

Water requirements for quokka, ringtail possums and quenda are related to the maintenance of adequate riparian vegetation to provide habitat and food. We could find no studies in the Donnelly that examined the extent to which mammals utilize riparian habitat. However, a study by Yeatman et al. (2016), in the intermittent headwaters of the neighbouring Warren River, examined the extent to which mammals utilised riparian, midslope and ridge habitats. They report a trend towards more individuals of Western pygmy possum (*Cercartetus concinnus*) in riparian than midslope or ridge habitats (Yeatman et al., 2016), but in general, found that mammals were most abundant in non-riparian habitats which were more floristically diverse and had more habitat (leaf litter, rock cover, fallen logs). However, the study only collected 3 mammal species (Western pygmy possums, grey-bellied dunnarts *Sminthopsis griseoventer*, and the non-native house mouse *Mus musculus*), with water rats, quokkas, bandicoots or ring-tailed possums not found.

Knowledge gaps

Knowledge gaps on mammals are incorporated in the section below, on birds.

5.10.2 Birds

The Donnelly River may provide food and habitat for birds that associate with freshwater environments. While we could find no studies for the Donnelly, a study by Davies and Stewart (2013) note that 92 species of birds associate with freshwater in SWWA. While none of these birds are endemic, the Australasian Bittern (*Botaurus poiciloptilus*) is listed as Endangered under the EPBC Act 1999 and WA BC Act 2016. Changes to flow regimes and drought are listed as key threats for the Bittern, however this refers primarily to wetland rather than riverine environs (NESP, 2019).

In addition to birds that associate with freshwater, riparian vegetation supports a greater density of terrestrial birds than the surrounding forest (Christensen, 1975, Christensen et al., 1985, Abbott and Heurck, 1985, Abbott and Burrows, 1999). Three species of threatened black cockatoo occur in the Donnelly catchment: Carnaby's (*Zanda latirostris*), Baudin's (*Zanda baudinii*) and red-tailed black (*Calyptorynchus banksia naso*). Reductions in eucalypt habitat and water points are threatening processes for both species (DPaW, 2013). Although there are no studies making a direct link between riparian vegetation and the species, intact riparian zones may provide important resources, such as tall trees for night roosts, and for safe watering points.

Knowledge gaps

There have not been systematic surveys of the mammals and birds that occupy the riparian vegetation of the Donnelly River.

Specific knowledge gaps identified are:

- The relationship between flows, riparian vegetation and mammal species, particularly listed threatened species (quokka, western ringtail possum) and rakali, which require freshwater habitats.
- The relative importance of riparian vegetation for bird populations, particularly riparian zones as refuges in a drying climate.

6 Summary

Our review of the literature identified that the Donnelly River is an important freshwater system that supports a wide variety of Indigenous cultural and ecological freshwater values. The findings of our literature review underpin the HSE model shown in Part A of the current report. Specifically, the findings of our literature review directly inform the following components of Part A:

- Figure 10, the HSE conceptual model. Supporting information is indicated as numbering which refers to the table of supporting information (Table 3).
- Table 3, the table of supporting information, that informs management principles / considerations, organise by the spatial scale that the information was collected.
- Section 4.4, which summarises the principles and considerations for water management, including reference to key literature.

Our review also identified that there are gaps in the information available on the relationships between flows and Indigenous cultural values and ecological values. Knowledge gaps were identified for each value, and priority knowledge gaps for further research are identified in Table 4 in Part A of this report.

Supplementary material

Table S1. List of plants that are most common in damp environments and found in the Donnelly River Catchment and their Indigenous uses. Plants that are known to be riparian species that occur on the Donnelly River are highlighted in blue and are also in Table 1. This table summarises information in Hansen & Horsfall (2016; 2019) cross referenced with Florabase records (www.florabase.dpaw.wa.gov.au accessed 4 July 2023). Noongar names from Hansen & Horsfall (2016; 2019) unless otherwise stated. Distribution information from Atlas of Living Australia (www.ala.org.au accessed 4 July 2023).

Life Form	Family	Scientific name	Noongar name	Indigenous uses	Distribution
Tree	Myrtaceae	*Corymbia calophylla*	Kurrden, Marree, Marril (Abbott 1983)	**Bush medicine** Powdered resin; reduce bleeding, treat upset stomachs, mouthwash, disinfectant, anti-inflammatory agent, to treat eczma. Seeds; treat diarrhoea and constipation. Crushed leaf vapour; inhaled for headaches, sinusitis and colds. Heated leaves; to treat colds. Flower infusions; blood purifiers and diabetes. Leaf smoke; respiratory complaints. **Bush tucker** Soaked flowers; sweet drink. **Other uses** Smoked leaves; insect repellent Powdered resin; tanning agent for kangaroo skins.	South-west WA

Life Form	Family	Scientific name	Noongar name	Indigenous uses	Distribution
Tree	Myrtaceae	*Eucalyptus megacarpa*	Bullich	**Bush medicine** Crushed leaves; antibacterial poultices, congestion relief. Ground gum; sore ointment and to treat dysentery. **Other uses** Leaves; bedding.	South-west WA
Tree	Myrtaceae	*Eucalyptus patens*	Dwutta (Abbott 1983)	**Bush medicine** Crushed leaves; antibacterial poultices, congestion relief. Ground gum; sore ointment and to treat dysentery. **Other uses** Leaves; bedding.	Endemic to south-west WA
Tree	Myrtaceae	*Eucalyptus rudis* subsp. *rudis*	Moitch (Abbott 1983)	**Bush medicine** Crushed leaves; antibacterial poultices, congestion relief. Ground gum; sore ointment and to treat dysentery. **Bush tucker** Sugary substance (manna) produced by mites that live on the base of the leaves can be eaten. **Other uses** Leaves; bedding.	Endemic to south-west WA
Tree	Myrtaceae	*Melaleuca preissiana*	Moonah	**Bush medicine** Crushed young leaves; to treat sinusitis, headaches, colds. Bark; to bandage wounds. **Bush tucker** Nectar; consumed as sweet drink. **Other uses** Bark; sanitary paper, food wrap.	Endemic to south WA

Life Form	Family	Scientific name	Noongar name	Indigenous uses	Distribution
Tree	Proteaceae	*Banksia littoralis*	Pungura, Boora, Boorarup, Mimidi	**Bush medicine** Flower infusions; cough and sore throat relief. **Bush tucker** Flower spike infusions; sweet refreshing drink.	Endemic south-west WA
Tree	Podocarpaceae	*Podocarpus drouynianus*	Koolah (Abbott 1983)	**Bush tucker** Edible fruit; good dietary supplement, but bland taste.	South-west WA
Shrub	Fabaceae	*Acacia extensa*	unknown	**Bush tucker** Seeds; ground for flour to make damper.	South-west WA
Shrub	Fabaceae	*Acacia pulchella*	Mindaleny	**Bush tucker** Seeds; ground for flour to make damper.	Endemic (WA)
Shrub	Myrtaceae	*Beaufortia sparsa*	unknown	**Bush tucker** Nectar; sucked directly or flowers soaked in water to make a sweet drink.	South-west WA
Shrub	Rhamnaceae	*Trymalium odoratissimum* subsp. *trifidum*	Djop Born	**Bush medicine** Leave, twigs & flowers; decoctions to treat rheumatism and back pain, swollen joints. **Other uses** Parts of the plants placed into waterholes so animals become groggy after drinking the water, making them easier to club. Leaves; used as soap.	South-west WA
Shrub	Sapindaceae	*Dodonaea viscosa*	Waning	**Bush medicine** Leaves; chewed (not swallowed) to treat toothache. Crushed leaves & juice; reportedly have antifungal and anti-inflammatory properties. External application used to treat stonefish & stingray wounds. Leaf infusion; externally used to reduce fever.	Widespread across Australia

Life Form	Family	Scientific name	Noongar name	Indigenous uses	Distribution
				Other uses Smoke used in ceremonies and as insect repellent.	
Shrub	Ericaceae	*Leucopogon verticillatus*	unknown	**Bush tucker** Edible berries.	South-west WA
Climber	Pittosporaceae	*Billardiera fusiformis*	Cummock, Kummuck, Gumung	**Bush tucker** Edible berries; good source of vitamin C.	South-west WA and south-east Australia
Climber	Ranunculaceae	*Clematis pubescens*	unknown	**Bush tucker** Roast tubers.	South-west WA
Herb	Apiaceae	*Daucus glochidiatus*	Kwordiny, Mongming	**Bush tucker** Edible root (i.e. carrot)	Widespread across central and southern Australia
Herb	Asteraceae	*Centipeda cunninghamii*	Unknown, but other Aboriginal name Gukwonderuk (Koori)	**Bush medicine** Decoctions; eyewash. **Other uses** Plants distributed around campsites at night to deter ants.	Widespread in central and southern Australia
Herb	Campanulaceae	*Wahlenbergia gracilenta*	unknown	**Bush tucker** Flowers; edible.	South-west WA & south-east Australia
Herb	Haemodoraceae	*Anigozanthos flavidus*	unknown	**Bush tucker** Roots; raw or roasted.	Previously endemic to south-west WA, now naturalised in NSW
Herb	Haemodoraceae	*Haemodorum spicatum*	Koolung; Meen, Mardja; Matje	**Bush medicine** Root & leaf base; treated and used to stop diarrhoea in dysentery.	South-west WA

Life Form	Family	Scientific name	Noongar name	Indigenous uses	Distribution
			(Abbott 1983; Bennett 1991)	Bulb decoctions; lung congestion relief. Bulb paste; used to treat arthritis. **Bush tucker** Bulbs; raw or roasted. **Other uses** Root; colour extracted and used as a dye.	
Herb (orchid)	Orchidaceae	*Caladenia spp.* (e.g. *C. attingens, C. harringtoniae, C. longicauda, C. nana, C. paludosa, C. radiata, C. sertina*	Kara, Kahta-ninda-yootah, Kararr, Cara	**Bush tucker** Edible roots (flavour depends on species).	Widespread, dependent on species
Herb (orchid)	Orchidaceae	*Diuris spp (e.g. Diuris longifolia)*	Cara, Djubak	**Bush tucker** Edible roots.	(*Diuris* spp - S WA, VIC, NSW, S QLD, S SA)
Herb (orchid)	Orchidaceae	*Prasophyllum fimbria*	Djubak, Tuboc	**Bush tucker** Edible roots.	Endemic to south-west WA
Herb (orchid)	Orchidaceae	*Thelymitra spp.* (e.g. *T. antennifera, T. cornicina, T. cucullate, T. flexuosa, T. fuscolutea*)	Joobuk	**Bush tucker** Edible roots (potato-like).	Widespread, dependent on species

Life Form	Family	Scientific name	Noongar name	Indigenous uses	Distribution
Herb (aquatic)	Juncaginaceae	*Cycnogeton huegelii*	Unknown	**Bush tucker** Edible tubers; raw or roasted.	South-west WA
Rush	Typhaceae	*Typha domingensis* and *Typha orientalis*	Yangeti, Yanget, Lirimbi, Yanjidi, Yunjeedie, Yunjid, Tanjil, Yandijut	**Bush tucker** Edible roots; raw or roasted.	South-west WA
Monocot	Xanthorrhoeaceae	*Xanthorrhoea preissii*	Baaluk, Balga, Baluk, Balluk (Abbott 1983)	**Bush medicine** Gum; chewed to relieve diarrhoea & constipation. Pulp; upset stomach relief. **Bush tucker** Young leaf shoots; edible. Sap; thirst quenching. Flower infusion; sweet drink. **Other uses** Resin; fire starting. Also used as a binding agent (glue/ cement). Tanning agent for kangaroo hides. Flower spikes; used as fishing spears and torches, or to carry flame to another fire. Blooming flowers; used in compass direction.	South-west WA
Monocot	Poaceae	*Microlaena stipoides*	(Grasses/generic; Gilba, Djiraly, Bobo)	**Bush tucker** Crushed seeds; used to make flour for damper.	South-west WA & eastern Australia

Life Form	Family	Scientific name	Noongar name	Indigenous uses	Distribution
Fern	Dennstaedtiaceae	*Pteridium esculentum*	Manya (denmark); Munda (perth); Moondan-gurnang (Abbot 1983)	**Bush medicine** Leaf infusion; external washes for sores and rheumatic pain. Ingested to treat worms. Leaf & stem infusions; applied externally for arthritis relief. Young stem and leaf juice; insect and ant bite relief. **Bush tucker** After extensive preparation, tips and rhizomes can be eaten.	Coastal areas in Aus
Fern	Pteridaceae	*Adiantum aethiopicum*	Karbarra	**Bush medicine** Frond infusions; chest infection treatment, taken as emetics. Crushed fronds; vapour inhaled to relieve upper respiratory tract.	South-west WA & east coast

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