Government of **Western Australia**
Department of **Water and Environmental Regulation**

Environmental and heritage values and the importance of water in the Fitzroy

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Acknowledgement of Country

The Department of Water and Environmental Regulation acknowledges the Traditional Owners and Custodians in the Fitzroy water planning area and their deep and continuing connection to the land and waters of the region.

We pay our respects to Elders past and present. We acknowledge the Traditional Owners have been Custodians of Country for countless generations and that water is integral to life.

We recognise that Aboriginal people and their culture across the Fitzroy water planning area are diverse and that continued custodianship of the land and water is fundamental to their health, spirit, culture and community.

We embrace the spirit of reconciliation, and we seek to listen, learn and build strong partnerships with genuine opportunities for Aboriginal people throughout our business.

The Fitzroy River and its tributaries is known by several names across its many nations, including the Martuwarra. To respect these differences in language we have not used dual naming in this report.

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Summary

Aboriginal people are the Kimberley's first water managers and are the Traditional Owners of their Country, as recognised in the native title determinations for the region. The Traditional Owners have been managing their Country for countless generations and continue to live according to their customs and law. They have an enduring connection to, and comprehensive knowledge of, groundwater and surface water and the ecosystems each support. We have seen this in their longstanding care and management of the Fitzroy River.

There is a growing body of work being driven by Aboriginal people on cultural science, knowledge and values across the Fitzroy River catchment. The department acknowledges the importance and uniqueness of this work which provides greater depth to our understanding of the catchment's ecological values. The cultural science and values studies, projects and records comprise knowledge held by Traditional Owners, and it is not appropriate or respectful for us to present their material in this report. Such knowledge should be considered in conjunction with this report to gain an integrated understanding of places, people and spirits that need to be protected from the impacts of water use.

This report focuses on the heritage places and ecological values that are listed for protection under legislation, policy and environmental guidance. We do not intend for it to provide a record of all the water-related values of Traditional Owners or to position the listed values at a higher level than those held by Aboriginal people.

An outline of this report

This report is one of several that will support water allocation planning in the Fitzroy planning area. It describes the environmental and heritage values, listed under legislation, policy and guidance, that depend on surface water and/or groundwater in the planning area and King Sound. It then considers available information, including newly published data, to describe water-dependent ecosystems (habitats) and important species and the current understanding of how they are supported by surface water and/or groundwater.

Environmental and heritage values

Certain environmental and heritage values in the Fitzroy planning area are the subject of various legislative instruments, guidance and policy:

- Matters of national environmental significance are listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (Cth; EPBC Act). These include places of world and national heritage including Aboriginal heritage, wetlands of international importance, listed threatened species and ecological communities, and migratory species.
- Aboriginal heritage places are listed under laws governing the protection and management of Aboriginal heritage in Western Australia on the Aboriginal Cultural Heritage Inquiry System (ACHIS).

- Areas of land and sea Country are managed by Traditional Owners through the federal Indigenous Protected Areas program.
- Sites and places of significant social or natural heritage are registered under the *Heritage Act 2018* (WA).
- Threatened species are listed under the *Biodiversity Conservation Act 2016* (WA; BC Act) – note the listing of threatened and priority ecological communities is not yet in force.
- Priority species are protected by inclusion in the Western Australian Environmentally Sensitive Areas list and recognised through policy.
- Environmental values are defined in the Western Australian Environmental Protection Authority's environmental factor guidelines. These include social surroundings, flora and vegetation, terrestrial fauna, subterranean fauna, inland waters, marine fauna, benthic communities and habitats, marine environmental quality, and coastal processes.
- Areas of high conservation significance are identified in Part B of *Environmental guidance for planning and development – Guidance statement 33* (EPA 2008).
- Conservation reserves are managed under *Conservation and Land Management Act 1984* (CALM Act; WA).
- Environmental values that are internationally and nationally significant are listed in the *Directory of important wetlands in Australia* (Environment Australia 2001) and *International Union for Conservation of Nature red list* (IUCN 2012).

Regional and local sites of ecological significance may also be identified during site-specific investigations – likely in areas where limited mapping projects or surveys have been undertaken. These may include but not be limited to:

- wetlands and waterways that persist during the dry season and provide refuges for aquatic and terrestrial fauna
- water-dependent ecosystems that are resilient to climate change
- ecosystems (or natural places) that provide a link to other water-dependent habitats and drought refuges
- springs and permanent river pools, particularly in arid areas
- wetlands and waterways that are likely to respond to management actions and plans.

Recent research

We are working with researchers active in the Fitzroy River catchment, such as:

- National Environmental Science Program (NESP) researchers, based at the University of Western Australia (UWA) and Griffith University, who are seeking to identify water requirements for key ecological assets (fish and riparian vegetation) and improve knowledge of Indigenous water relationships, values and needs.
- Murdoch University Centre for Sustainable Aquatic Ecosystems' researchers who have been studying the EPBC Act-listed Freshwater sawfish (*Pristis pristis)* in the Fitzroy River since 2002. They have also studied other fish species to define food webs and map the overall distribution of all Fitzroy species across the catchment (Morgan et al. 2004).

Researchers have been gathering important preliminary ecological and cultural data that furthers our knowledge of the region's water resources, values and dependencies.

Other investigations conducted in the Fitzroy planning area in recent years include:

- our groundwater investigations in the Fitzroy Valley (2015–18) (DWER 2023b) and La Grange (DWER 2022)
- the CSIRO's hydrogeological, hydrological, ecological and cultural programs (2016–18) which form part of its Northern Australia Water Resource Assessment (NAWRA) of the Fitzroy River catchment (Petheram et al. 2018; Pollino et al. 2018a & b; Barber & Woodward 2017).

The knowledge gained from recent investigations has informed our understanding of which components of the water regime (groundwater and/or surface water) are critical to key water-dependent habitats and species in the Fitzroy planning area. The results will help us determine ecological water requirements for the catchment and will inform future water planning.

Water-dependent habitats and species

Water-dependent habitats or ecosystems are those parts of the environment determined by the permanent or temporary presence of flowing or standing water (ARMCANZ & ANZECC 1996). These can be supported by surface water and/or groundwater. There are numerous types of water-dependent habitats across the Fitzroy planning area including:

- river pools
- off-channel and floodplain wetlands/channels
- riparian and floodplain vegetation
- springs
- aquifer and subterranean ecosystems
- estuarine and near-shore marine ecosystems.

Diverse flora and fauna rely on water-dependent habitats. In this report we describe in detail the following ecologically and culturally important water-dependent species of the Fitzroy River, its tributaries and wetlands:

- Freshwater sawfish (*Pristis pristis*)
- Barramundi (*Lates* calcarifer)
- Cherabin or freshwater prawns (*Macrobrachium spinipes*)
- Fork-tailed catfish *(Neoarius graeffei*)
- Freshwater mangrove (*Barringtonia acutangula*)
- Silver-leafed (*Melaleuca argentea*) and Green (*M. leucadendra*) paperbarks
- Coolibah (Eucalyptus *microtheca*).

The water-dependent habitats (section 8) and important species (section 9) are supported by various parts of the water regime. These are in-channel, over-bank, recessional and low-flow/groundwater input (Douglas et al. 2019). Figure 1 depicts these water regime components against a hydrograph and annual flow periods for the early wet, wet, wet/dry transition and dry seasons. The figure shows what the river level could look like during each season. The figure also summarises the way in which each part of the water regime supports specific habitats and species.

Figure 1 shows that no single part of the flow regime is more important than another. Even though water availability for most habitats and species is restricted during the long dry season, this is heavily influenced by the size of the flows in the preceding wet season. For example, large wet seasons fill river pools and off-channel wetlands and recharge the alluvial aquifer and soil moisture. Pools and wetlands act as dry season refugees for fauna. Groundwater and soil moisture not only sustains riparian and floodplain vegetation but also provides direct inputs into numerous pools and wetlands.

In-channel flows

a. connect pools, estuary and King Sound to support:
- recruitment of fish, Cherabin and Sawfish
- nutrient inputs
- flushing of 'old' water

b. connect flood-runner creeks to support movement of fauna out of main channel

c. recharge alluvial and regional groundwater and soil moisture

d. support riparian vegetation species on the riverbank.

Overbank flows

a. connect the river and floodplain to support:
- movement of fish into off-channel wetlands
- recruitment of floodplain vegetation
- off-channel wetlands
- nutrient exchange

b. occasional high-volume flows to:
- support sawfish recruitment and productivity (growth)
- scour sediment from channel and estuary
- inundate saltflats.

Recessional flows

a. low flows at the end of the wet season to support:
- migration of Cherabin upstream and onto the floodplain
- movement of Sawfish and Barramundi back into main channel
- depth and persistence of river pools during the dry season.

Groundwater

a. regional aquifers support water-dependent reaches of Fitzroy and Margaret rivers and Snake/Uralla Creek

b. alluvial aquifer supports river pools and off-channel wetlands (and dependent biota), riparian and floodplain vegetation

c. regional aquifers support springs

d. alluvial and suitable regional aquifers support stygofauna.

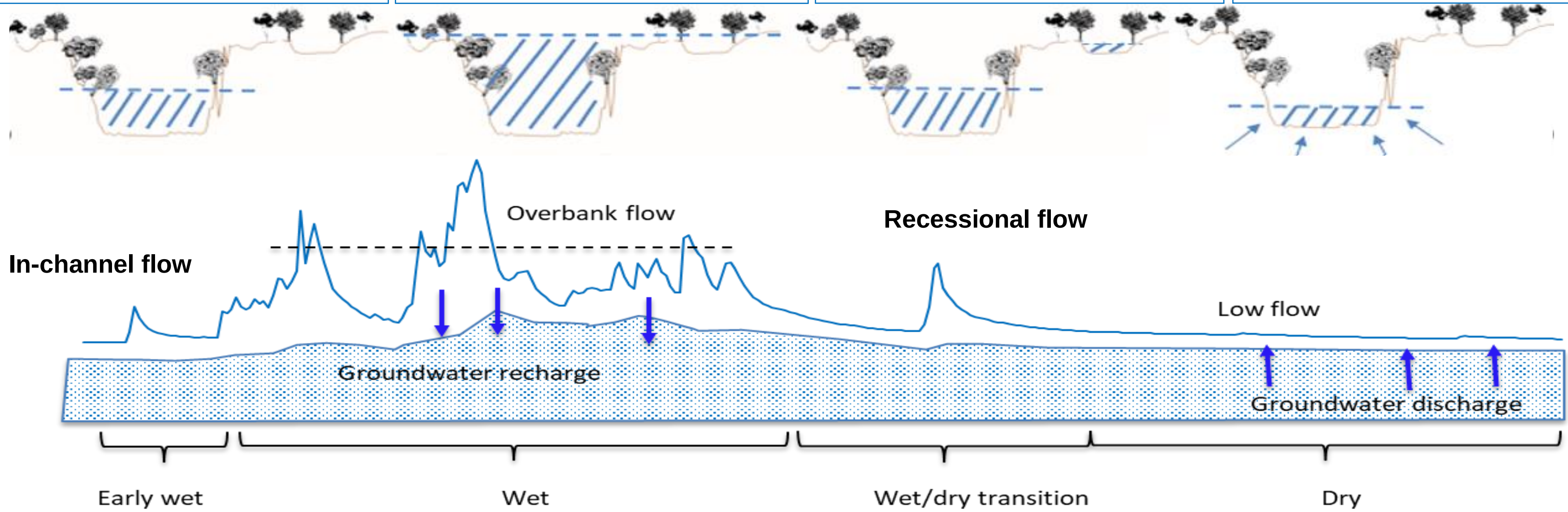


Figure 1 Summary of four main parts of the water regime and how they support habitats and important species

1 Introduction

The Government of Western Australia has been talking to people in the Fitzroy River area about opportunities for sustainable economic development while protecting the river and its catchment. Achieving this balance is the basis for the government's commitments to:

- create the Fitzroy River National Park, which will extend the Danggu Geikie Gorge National Park along the Fitzroy River to the north and along the Margaret River
- develop a management plan for the Fitzroy River to ensure the health of the river and provide a basis for sustainable economic development
- not allow the Fitzroy River or its tributaries to be dammed.

The success of any development in the catchment will rely on:

- respectful relationships between people
- strong regulatory approvals
- avoiding impact to the environment including areas with ecological, cultural, heritage and social values
- robust monitoring, management and compliance.

For Traditional Owners the river is 'living water' that provides connections to spirits, foods and medicines, cultural practices, recreation and passing on traditional knowledge to younger generations.

The river's importance to Aboriginal people is recognised under state and federal legislation, such as the *West Kimberley national heritage place* listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth: EPBC Act) and through registered Aboriginal sites of significance under laws governing the protection and management of Aboriginal heritage in Western Australia.

1.1 Purpose of this document

Water allocation planning

The Department of Water and Environmental Regulation (the department) is responsible for regulating and managing Western Australia's water resources for sustainable productive use. In areas of high demand or interest in water, such as in the Fitzroy, we develop water allocation plans. We have prepared this report to support future water planning in the Fitzroy area. It is one of several that will inform the water allocation planning process.

In this report we introduce the Fitzroy planning area and King Sound, and provide important background information. We then describe the environmental and heritage values listed under legislation, policy and guidance that depend on water (surface water and/or groundwater) (Figure 2). Finally, we consider the available information, including newly published data, to describe water-dependent ecosystems (habitats) and important species, and the current understanding of how surface water and/or groundwater support them.

There is a growing body of work on cultural science, traditional knowledge and values across the Fitzroy River catchment. We acknowledge the importance and uniqueness of this work, which provides a more complete and holistic understanding of ecological values across the catchment. However, we have focused on protected heritage places and the importance of ecological values in this report.

The cultural knowledge and values studies, projects and records comprise knowledge held by Traditional Owners, and it is not appropriate or respectful for us to publish their material in this report. Such knowledge should be considered in conjunction with this report to gain an integrated understanding of places, people and spirits that need to be protected from the impacts of water use.

The outcomes of this work will inform the development of ecological water requirements and future water planning. The ecological water requirements will be described in a separate report: *Ecological water requirements of water-dependent ecosystems in the Fitzroy water planning area (DWER 2023a)*. Figure 2 shows the overall process we have followed to identify values and issues, how they relate to water, and how this informs the ecological water requirements process.

The record flood event resulting from ex-tropical cyclone Ellie in late 2022 and early 2023 had a devastating impact on local towns and communities, with widespread flooding and significant infrastructure damage. It will take time for communities and pastoral stations to recover from this event.

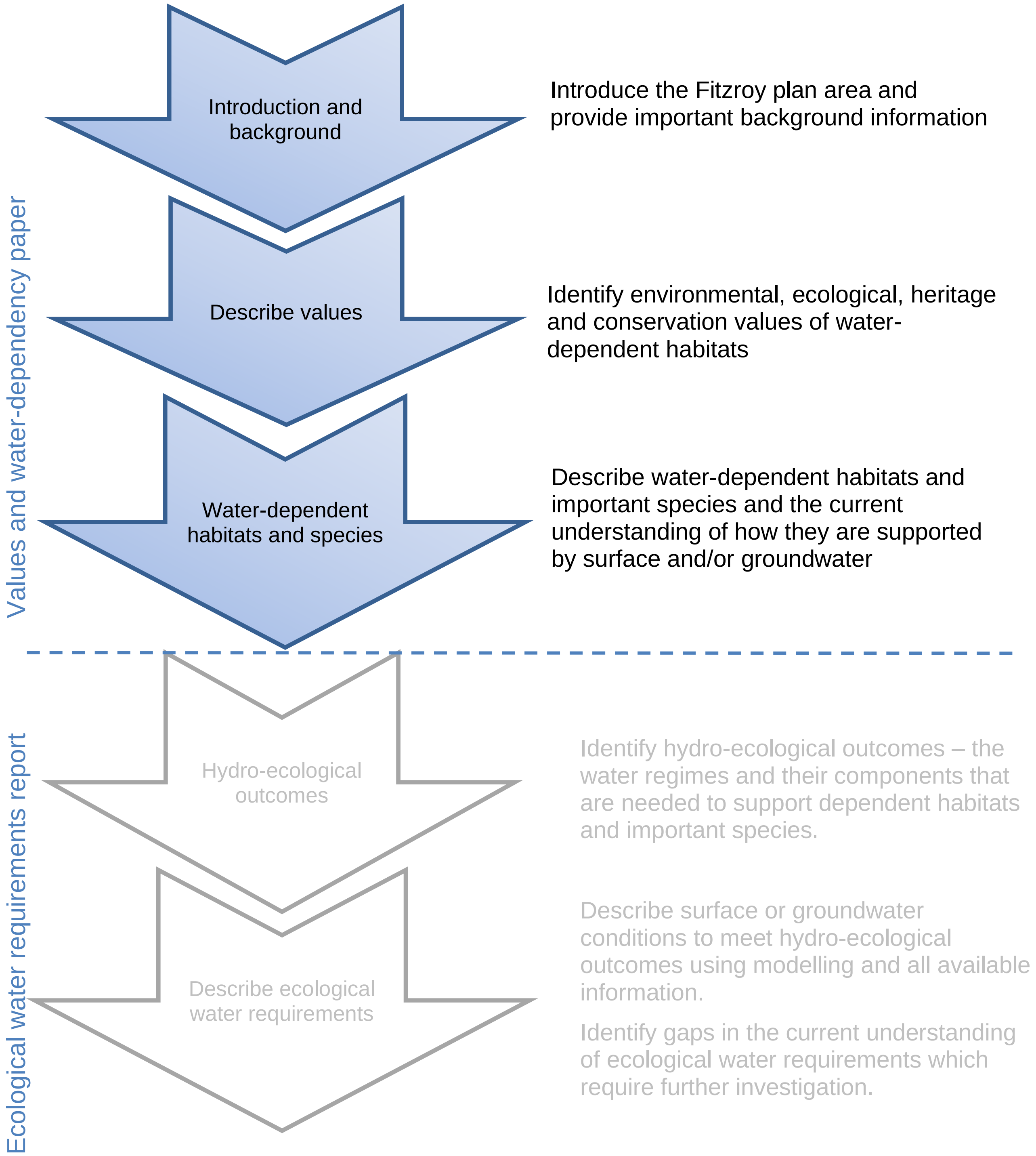


Figure 2 Values and ecological water requirements process which contributes to future water planning

2 Background

2.1 Fitzroy planning area

The Fitzroy water planning area covers 103,000 km^2, taking in most of the Fitzroy River catchment (94,000 km^2) and the Grant-Poole aquifer which extends along the Lennard Shelf to the north (Figure 3).

The Fitzroy River originates in the Durack and Wunaamin-Miliwundi (formerly King Leopold) ranges in the Central Kimberley and flows about 730 km west into King Sound near Derby.

Between King Sound and Fitzroy Crossing (300 km upstream), the Fitzroy River is characterised by a flat and wide floodplain. During the summer wet season, the river can extend 15 km over the alluvial sediments which cover more than 4,000 km^2 of the catchment. The upper catchment is characterised by bedrock, with minor localised aquifers, which constrains most smaller rivers and tributaries in the area.

2.2 Ecology

The Fitzroy River, its floodplain and tributaries provide important habitat for a diverse array of ecological communities, flora and fauna. During the wet season, flows connect river pools and recharge the alluvial aquifer before moving downstream to the estuary and King Sound. Larger flows connect the river to its floodplain, filling off-channel wetlands and creeklines. During the long dry seasons, groundwater-fed river pools and wetlands provide refugia for fish and other fauna. Groundwater also supports aquifer communities and springs.

The distribution of many species in the Fitzroy plan area is uncertain due to a lack of systematic surveys and the challenge of accessing some parts of the catchment. There may also be high levels of cryptic diversity in that species exist that are morphologically indistinguishable from each other but are genetically different and incapable of interbreeding.

Vegetation and flora

In the wet-dry tropics, the obvious green strips of riparian vegetation stand out against a sparsely vegetated savanna landscape. Floodplain vegetation also stands out but it tends to be less dense. Both riparian and floodplain species are well adapted to the flooding regimes and groundwater dynamics that occur in these areas (sections 8.3 and 9).

Groundwater-dependent vegetation includes species that require groundwater at any stage in their life cycle to maintain their condition or persist in a particular location. Riparian and floodplain vegetation communities are often groundwater-dependent but can also use surface and soil water. Other vegetation communities, such as those associated with springs, also use groundwater.

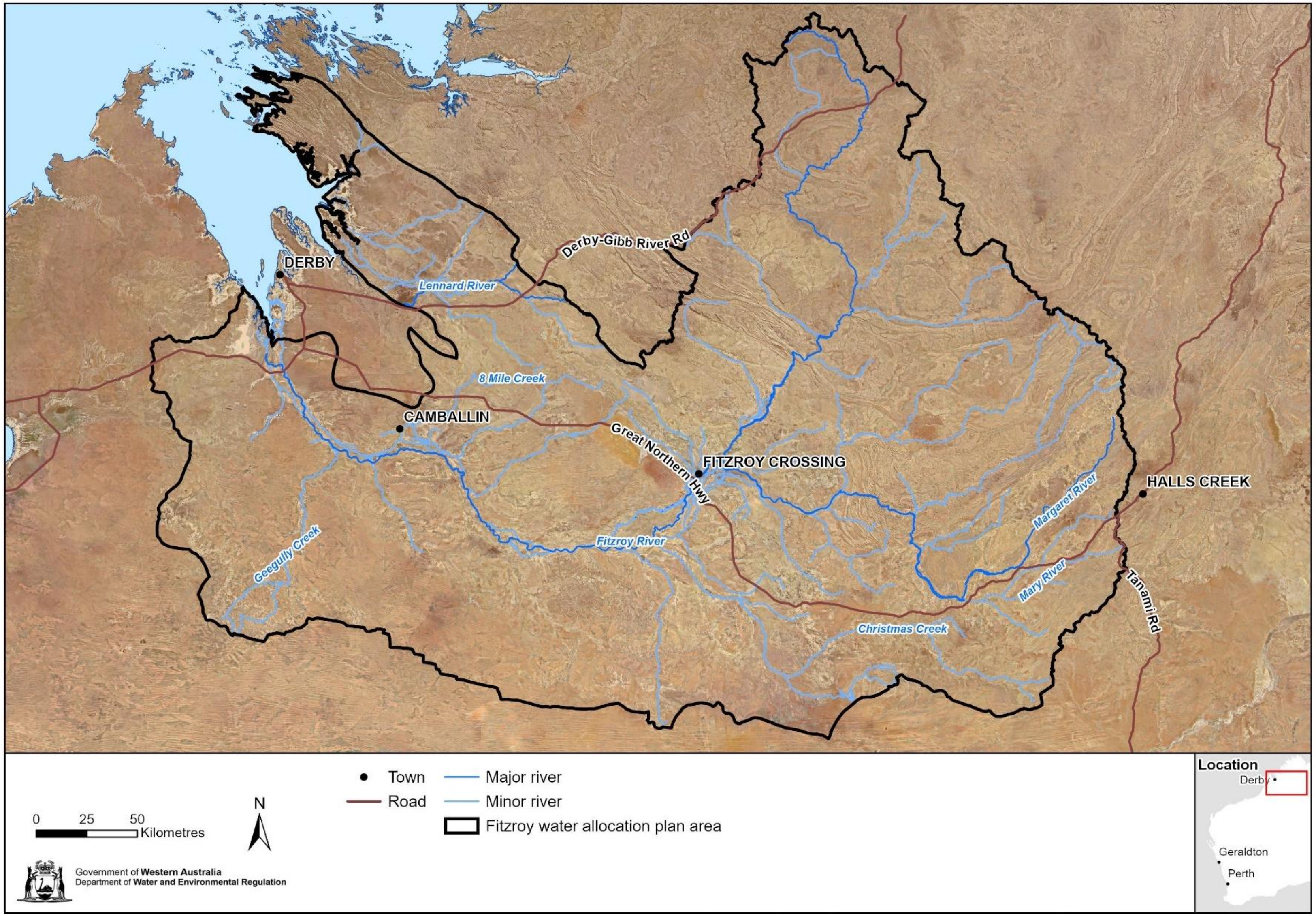


Figure 3 Fitzroy planning area

The Fitzroy plan area supports a diverse range of flora, however 137 species are threatened and/or priority listed, including aquatic plants and cryptogams (lichens, liverworts and mosses).[1] The flora of highest conservation significance is *Pandanus spiralis* var. *flammeus*, which is listed as 'endangered' under the EPBC Act and the *Biodiversity Conservation Act 2016* (WA; BC Act). The Department of Conservation, Biodiversity and Attractions (DBCA) lists the remaining species as 'priority' (Western Australian Herbarium 1998–2022 Florabase). See Section 6 and Appendix A2 for more information on listed flora.

Many of the known flora of the Fitzroy floodplain are widespread in similar habitats across northern Australia. Other flora are recognised as significant because they are restricted to a small area of habitat, or have cultural significance (e.g. Freshwater mangrove) or ecological significance (e.g. silver and green leafed melaleucas; Pandanus). In many cases the distribution of significant tree species define a landscape or habitat visually, if not ecologically (e.g. Coolibah, River red gum).

Fauna

The Fitzroy River, its tributaries and wetlands support 40 native fish species. Of these, 25 are freshwater species and 15 are estuarine or marine but may spend part of their lives in freshwater environments (Shelley, Morgan et al. 2018). This is higher than the number of freshwater species found in the Pilbara (12) and south-west (10), but similar to other large northern Australian rivers, possibly due to catchment size (Morgan et al. 2004).

The distribution of species varies between the lower (27), middle (22) and upper (17) reaches of the Fitzroy River and is different again across the tributaries. This is likely due to the diversity of habitat types (Morgan et al. 2004).

The estuarine and marine species include the high-conservation-value freshwater sawfish (*Pristis pristis*), Dwarf sawfish (*Pristis clavata*), the Northern river shark (*Glyphis garricki*) and the commercially valuable and recreationally and culturally important Barramundi (*Lates calcarifer*) (sections 6 and 8).

Mammals, both native and introduced, also rely directly on the river for water and for the riparian habitat it supports. Native species include the Northern quoll (*Dasyurus hallucatus*), Ghost bat (*Macroderma gigas*) and Water rat (*Hydromys chrysogaster*). Cattle are the most prominent introduced species but pigs, camels, donkeys, horses, cats, foxes and wild dogs are also common.

The river and its floodplain provide habitat for many birds, including more than 30 migratory species such as the Curlew sandpiper (*Calidris ferruginea*) and Greater sand plover (*Charadrius leschenaultia)*. The Camballin floodplain is particularly important to these species. Riparian habitat supports species such as the purple-crowned fairy wren (*Malurus coronatus coronatus*) and Peregrine falcon (*Falco peregrinus*).

[1] P1 – 57, P2 – 21, P3 – 52, P4 – 5; WA Herbarium

The iconic Saltwater crocodile (*Crocodylus porosus*) and Freshwater crocodile (*Crocodylus johnstoni)* rely on river pools and permanent wetlands during the dry season, along with other reptiles such as the Long-necked turtle (*Chelodina rugosa*). Appendix A has a full list of conservation-listed fauna.

Threatened and priority ecological communities

The following threatened and priority ecological communities occur across the Fitzroy planning area:

- Endangered
  - Big Springs: assemblages of Big Springs organic mound springs
- Vulnerable
  - North Kimberley Mounds: organic mound springs sedgeland community of the North Kimberley bioregion

  Priority 3
  - Gogo land system
  - Boab-dominated assemblages (MVT limestone ranges)
  - Leopold land system
  - Gladstone land system
  - Kimberley vegetation association 67
  - Kimberley vegetation association 759
  - Kimberley vegetation association 807
  - Kimberley vegetation association 834

  Priority 2
  - Invertebrate community of Tunnel Creek

  Priority 1
  - Monsoon vine thickets and camaenid land snails of limestone ranges (Napier Range)
  - Kimberley vegetation association 33
  - Kimberley vegetation association 71
  - Kimberley vegetation association 718
  - Kimberley vegetation association 719
  - Kimberley vegetation association 760
  - Kimberley vegetation association 767
  - Kimberley vegetation association 872
  - Kimberley vegetation association 1271
  - Invertebrate community of Napier Range Cave
  - Invertebrate assemblages of the cliff foot spring around Devonian reef system.

2.3 Climate

Climate of the Fitzroy River catchment and recent trends

The Fitzroy River experiences a semi-arid to arid monsoonal climate with large seasonal and year-to-year rainfall variations. Most rain falls in the wet season from November to April. High evaporation and dry conditions are prevalent from May to October. These patterns are reflected in streamflow data with river flows high in the wet season and little to no flow over the dry season.

Long-term records show that since the 1960s annual rainfall has generally increased. Yet low rainfall years still occur – as seen in the very dry 2018–19 wet season (Figure 4). Soil moisture, runoff and temperature have also increased in recent years (Bureau of Meteorology 2022).

Climate change is being experienced now and must be a fundamental part of water planning and associated decision-making.

Traditional Owners have told us that the seasons are changing, plants and animals are behaving differently, and sacred water places are under threat. Traditional knowledge needs to be part of the water planning process, both to understand what is happening on Country, and to develop solutions to the problems that climate change presents.

Climate change and its potential effect on ecosystems and values

Much work is being done to understand how the climate might change into the future and the implications for water resources in Western Australia. In 2015 the Bureau of Meteorology (BoM) and the CSIRO[2] released national climate projections for Australia.

These climate projections draw on global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Specific information for Western Australia was summarised in *Western Australian climate projections: summary* (DWER 2021).

BoM then developed a suite of national climate change projections, providing water resource managers with local-scale data to use in water resource investigations (Srikanthan et al. 2022a). Climate change information for the Fitzroy planning area, which is in the Monsoonal North natural resource management (NRM) region of Western Australia, is reported in *Monsoonal North – national hydrological projections assessment report* (Srikanthan et al. 2022b) and summarised below.

[2] Commonwealth Scientific and Industrial Research Organisation

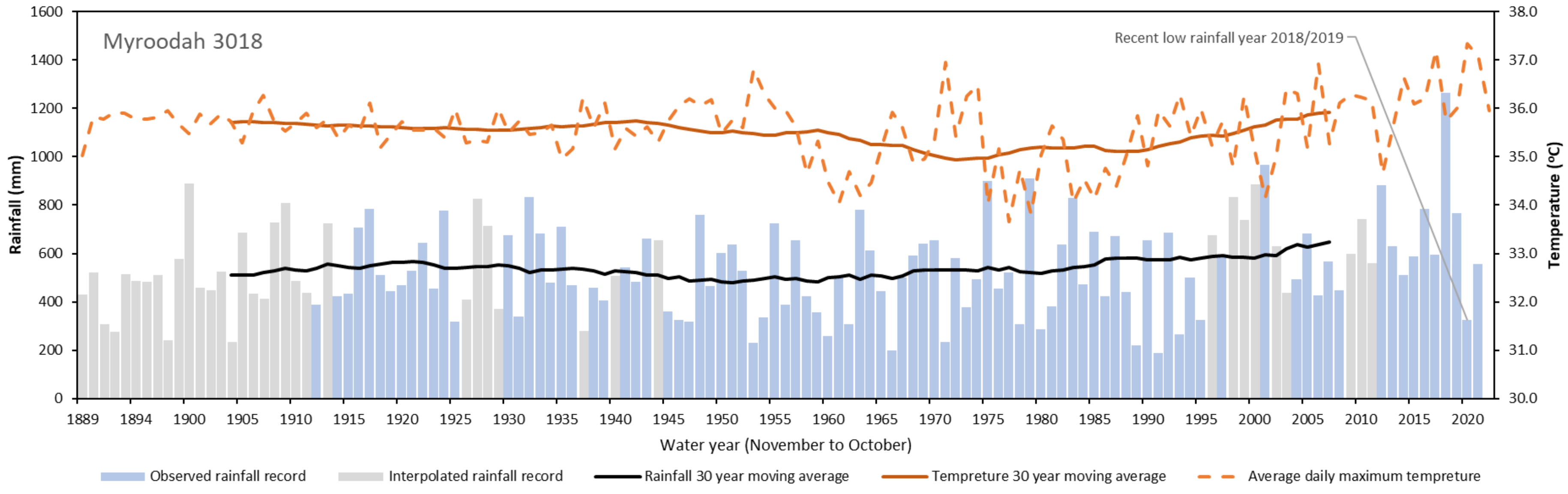


Figure 4 Long-term rainfall recorded at Myroodah (BoM site 3018)

Projections for the Monsoonal North region in Western Australia show:

- low confidence in projected changes in rainfall, which means that it may increase, or it may decrease
- high confidence that when rain falls, the intensity of heavy rainfall events will increase, and tropical cyclones – although projected to be fewer – will be more intense
- a projected increase in temperature and evaporation with more days of extreme heat temperatures over 35°C
- high confidence that sea levels will rise and more frequent sea-level extremes will occur.

These changes may affect the intensity of fire and influence the timing of the flowering and fruiting of plants, and animal migration. Sea-level rise may impact on freshwater ecosystems that exist along the coastline of the King Sound. These changes may also influence crop water demands, as well as inflow, recharge and evaporation from open waterbodies, including permanent river pools and shallow groundwater.

2.4 Hydrogeology and surface water

Hydrogeology

The Fitzroy planning area comprises the sedimentary aquifers in the Fitzroy Trough and Lennard Shelf of the Canning Basin in the west and the fractured rock aquifers of the King Leopold and Halls Creek orogens in the east (Figure 5).

The aquifers in the study area comprise (from youngest to oldest) the:

- Alluvial aquifer (regional aquifer)
- Liveringa Group aquifer (regional aquifer, but can also be an aquitard)
- Noonkanbah Formation (aquitard with localised low yielding, variable quality aquifers)
- Grant-Poole aquifer (regional aquifer)
- Wallal Sandstone aquifer (regional aquifer, found mainly in the south-west of the planning area)
- Devonian Reef aquifer (regional aquifer)
- Fractured Rock aquifers (regional aquifer).

Alluvial aquifer

The Alluvial aquifer refers to all mapped alluvial deposits within the Canning Basin extent of the Fitzroy planning area. It is a shallow watertable aquifer that underlies and borders the lower Fitzroy River, Lennard River and some major tributaries.

The alluvium around the Fitzroy River is an extensive unconfined aquifer covering around 3,200 km^2 and can be up to 30 m thick (Lindsay & Commander 2005).

Groundwater recharge is from a combination of rainfall, floodwater from the Fitzroy and Margaret rivers and throughflow from regional aquifers such as the Poole Sandstone or Grant Group. Depth to groundwater varies but is generally shallow. Monitoring from recent investigations recorded water levels between 3 and 7 m below ground level (mbgl) around Camballin and 9 to 16 mbgl around Fitzroy Crossing (DWER 2023b).

The Alluvial aquifer is likely to be highly connected with the overlying rivers and other surface water bodies and will be supporting ecosystems, particularly during the dry season. It can also be connected to or facilitate discharge from underlying aquifers. Recent groundwater investigations support previous findings (Lindsay & Commander 2005) of strong inter-connectivity between the alluvial aquifer and the Fitzroy and Margaret rivers. This connectivity can be seasonably variable, with the river system acting either as a gaining or losing stream depending on local surface water levels.

Canning-Broome aquifer

The Canning-Broome Sandstone aquifer is a minor unconfined aquifer system in the Fitzroy planning area that comprises minor isolated outcrops. It may support groundwater-dependent ecosystems where it is shallow, but it is not in hydraulic connection with the Fitzroy River (DWER 2023b).

Canning-Wallal aquifer

The Wallal Sandstone aquifer is a high-yielding regional aquifer found mainly in the south-west and north-west areas of the Fitzroy planning area.

Recharge is likely to be via infiltration from rainfall during the wet season. In the area south of Camballin, there is evidence that the Canning-Wallal is in hydraulic connection with and is contributing flow to the Fitzroy River (DWER 2023b).

Canning-Erskine aquifer

The Canning-Erskine aquifer is an unconfined aquifer present as a small deposit on Myroodah Station. It is hydraulically separated from underlying aquifers by the Blina Shale. While only one deposit is mapped, it may also exist in other areas where the Blina Shale is currently mapped. Recharge is likely by direct infiltration from rainfall.

It may support groundwater-dependent ecosystems where it is shallow, but it is not in hydraulic connection with the Fitzroy River (DWER 2023b).

Liveringa Group

The Liveringa Group is present at shallow depths throughout the sedimentary basin. While it is a significant regional aquifer, it has variable quality and in some areas functions as an aquitard. Where the Liveringa Group is an aquifer, it is typically low yielding with marginal to brackish groundwater quality (DWER 2023b), although this is based on limited information as relatively few bores are drilled into the aquifer (Taylor et al. 2018).

Recharge is from either direct infiltration of rainfall in the wet season, leakage from the overlying Fitzroy Alluvial aquifer or, in some areas, directly from the Fitzroy River (i.e. through Le Lievre Swamp near Camballin). In an area downstream from Fitzroy Crossing, the Liveringa Aquifer likely discharges into the Fitzroy River. This is caused by groundwater flow from the aquifer meeting the lower-permeability mudstones of the Noonkanbah Formation and being forced upwards towards the river (Harrington & Harrington 2015).

Noonkanbah Formation

The Noonkanbah Formation is generally a regional aquitard, although there are a few low yielding, brackish to saline bores in the unit (Lindsay & Commander 2005). It is present across much of the Fitzroy plan area, although not in the north-east and south-west.

Recent work shows the Noonkanbah Formation is shallower in some areas of the Fitzroy plan area than was thought in previous conceptualisations, with several shallow bores intersecting the unit where it was not expected to be present (DWER 2023b). Little is known about the hydraulic properties of this aquifer. Existing information suggests it generally has very low hydraulic conductivity and will effectively separate aquifers unless conduits such as faults are evident (DWER 2023b).

Grant Group and Poole Sandstone aquifers

The Grant Group and Poole Sandstone are hydraulically connected and managed as a single aquifer for groundwater licensing purposes. This is a regionally extensive, major aquifer that is confined at depth and unconfined where it outcrops along the length of the Lennard Shelf, as well as in major anticlinal structural features in the Fitzroy Trough around Camballin and Noonkanbah (Figure 5).

Where the Grant-Poole aquifer is deeper or confined, faults can act as pathways for groundwater to flow, either to the surface or to the shallow alluvial aquifer, as noted in the area between Fitzroy Crossing and Noonkanbah (Harrington et al. 2011; DWER 2023b).

Groundwater recharge to the Grant-Poole aquifer is from direct infiltration of rainfall, leakage from overlying aquifers and regional aquifer throughflow. Groundwater flow is from east to west, potentially with some flow towards the Fitzroy River between Fitzroy Crossing and Noonkanbah (Taylor et al 2018).

Devonian Reef aquifer

The Devonian Reef is a limestone aquifer which can be up to 2,000 m thick (DWER 2023b). It contains fresh groundwater, is regionally extensive and outcrops in the eastern part of the Fitzroy plan area, with notable outcrops at Geikie Gorge, Windjana Gorge, Tunnel Creek and the Mimbi Caves (DWER 2023b) (Figure 5). Groundwater recharge is mainly through direct infiltration of rainfall but as the aquifer has karstic features, this is likely to be highly variable (DWER 2023b).

Groundwater flows from the Devonian Reef aquifer appear to be strongly connected to both the Fitzroy and Margaret rivers, as well as the Poole Sandstone and Grant Group and alluvial aquifers.

Fractured rock aquifers

Fractured rock aquifers that sit within basement rock formations (Haig 2009) cover much of the north-eastern part of the Fitzroy planning area.

Groundwater recharge is rainfall dependent and will only occur directly where fractured, jointed and weathered zones are exposed to rainfall (Haig 2009). The rocks contain very little groundwater outside of these zones.

Groundwater interaction with the Fitzroy River

The lower Fitzroy River has possible interaction with groundwater across much of its extent. There is evidence of interaction between the Fitzroy River and its floodplain with the Devonian Reef and Grant-Poole aquifers on Bunuba and Gooniyandi Country near Fitzroy Crossing; the Liveringa aquifer on Yi-Martuwarra Ngurrara and Gooniyandi Country; the Grant-Poole aquifer near Noonkanbah; and the Canning-Wallal near Camballin on Nyikina Mangala Country (DWER 2023b).

During the wet season, flooding is likely to recharge the alluvial aquifer and the underlying regional aquifers where they are connected to the alluvial aquifer. During the dry season it is possible that permanent river pools and wetlands are sustained by groundwater from the underlying regional aquifers.

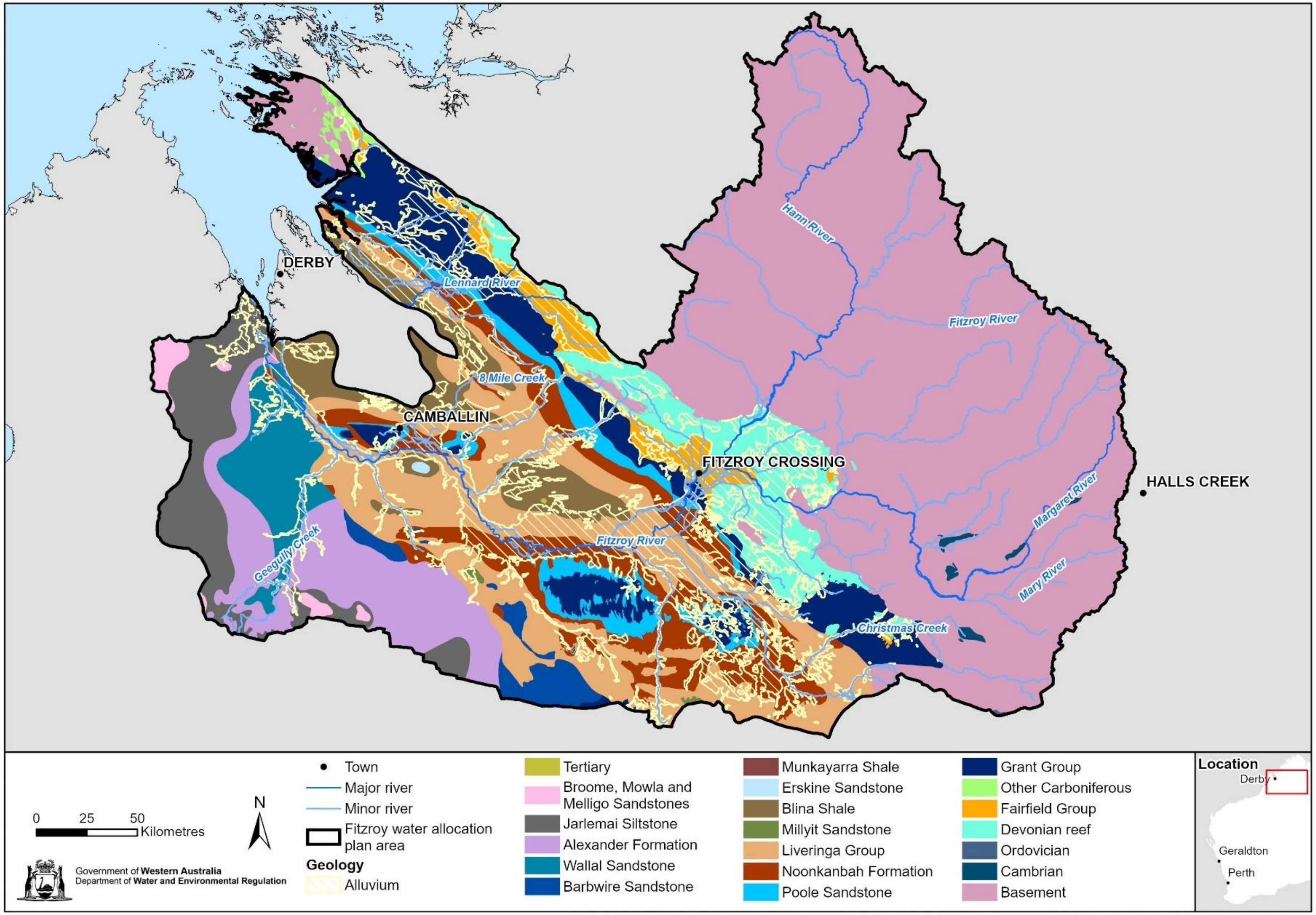


Figure 5 Surface geology of the Fitzroy groundwater area

Surface water

Flow in the Fitzroy River is highly variable, both between years and throughout the year. The wet season occurs from November to April with more than 90 per cent of streamflow occurring in the three months from January to March in an average year. Streamflow in the headwater catchments ceases relatively soon after the end of the wet season. On the floodplain, high flows during the wet season can contribute to the recharge of the sandy floodplain soil which subsequently discharges to the river during the dry season (DWER 2023c).

The river has an average annual flow of about 9,120 GL (1999–2020) measured at Fitzroy Barrage (station 802003). However, flows modelled by CSIRO over a 125-year period (1890–2015) show a lower average of 6,500 GL (Hughes et al. 2017). These volumes are the largest of any river in Western Australia, and at least 10 times larger than any river in the south-west. Total measured annual flow has ranged from 676 GL in 2019 to 27,646 GL in 2011 (DWER 2023c).

At present we have 13 gauging stations operating along the river and its tributaries, which provides good spatial coverage of streamflow across the catchment (Figure 6).

In late 2022 and early 2023 an unprecedented flooding event hit the Fitzroy River catchment. The long-term implications of this for people, communities and the environment are significant and will become apparent over time. The flood caused significant erosion and sedimentation of river channels and floodplain areas. The extent of changes to the river, such as the position and depth of river pools, will become clear as the dry season progresses.

Camballin/Fitzroy Barrage

The Camballin Barrage (commonly called Fitzroy Barrage) is the largest built structure on the Fitzroy River that impedes the flow of water (Figure 6). It was constructed across the main channel at Camballin in the 1950s as part of a now-abandoned irrigation scheme.

The barrage has changed the annual flooding pattern of the river (AECOM Australia Pty Ltd; Morgan et al. 2009), exacerbating downstream erosion and channelisation (Toussaint et al. 2001). It also acts as a barrier to migratory species, including Cherabin, Freshwater sawfish and Barramundi (Morgan et al. 2016).

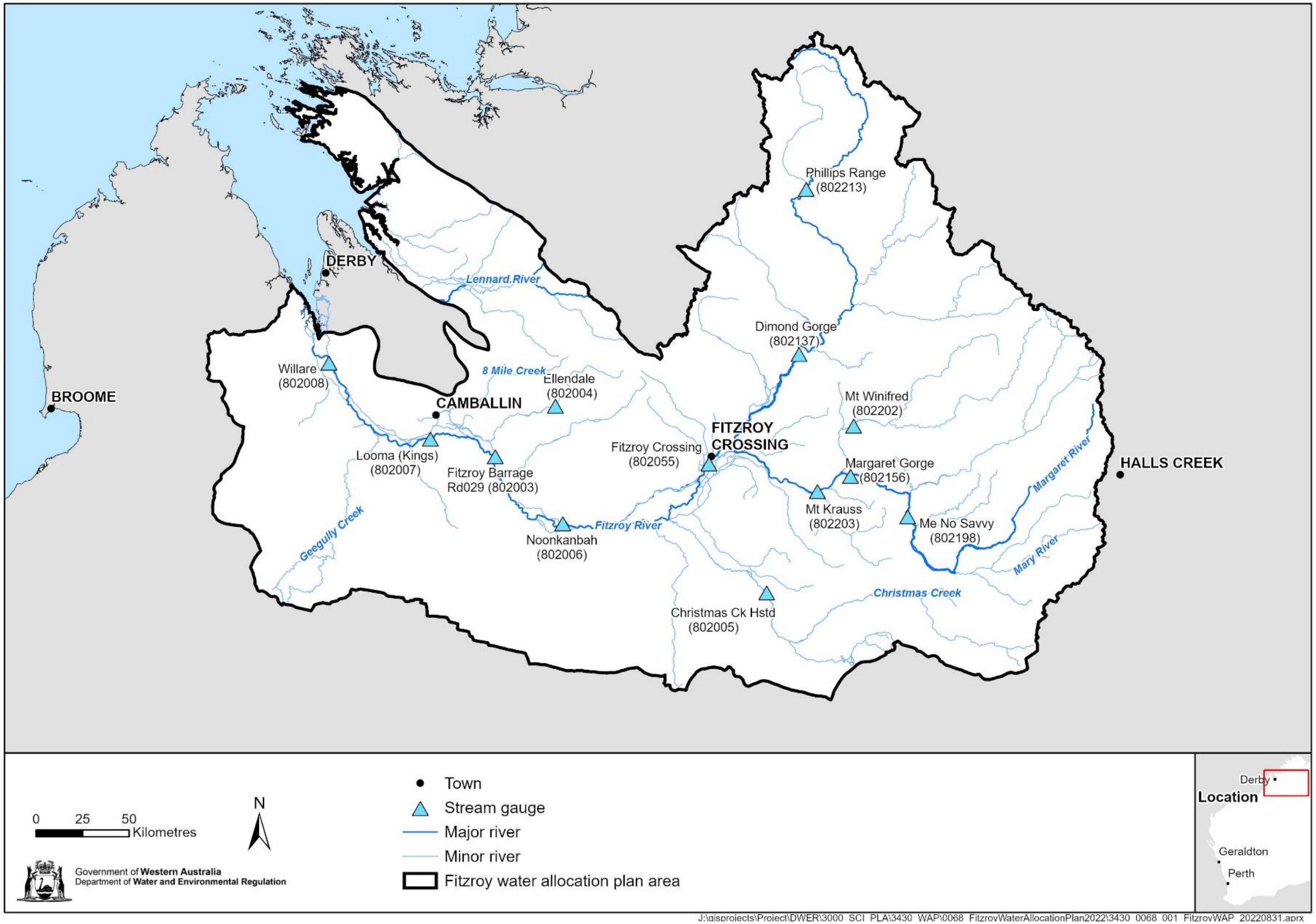


Figure 6 Location of the department's river gauging stations

3 Traditional Owner cultural values

Traditional Owners have lived with the Fitzroy River for countless generations. Water and water places are integral to their systems of knowledge and society. It is partly the recognition of this cultural significance that led to listing of the Fitzroy River, and many other areas of the catchment, as heritage sites on the ACHIS and as a national heritage site under the EPBC Act (Cth).

Regarded as the essence of life, water in the Fitzroy River catchment underpins cultural practices and social structures including kinship relationships with fish and other beings (Douglas et al. 2019). ‘Freshwater places’ (river pools, wetlands, springs) are linked with conception spirits and cosmological forces important to the existence and health of aquatic ecosystems (Douglas et al. 2019).

Traditional Owners have rich cultural beliefs about the creation of the Fitzroy River and its tributaries. The creation of the river is associated with the activities of mythical beings or serpents during the ‘Dreamtime’ – *Pukarrikarra* (Mangala), *Bukarrarra* (Nyikina) and *Ngarranggani* (Ngarinyin) (Jackson & O’Leary 2006).

In the narratives of the Nyikina and Mangala people, the river was created by a snake/serpent that was speared by Woonyoomboo. The serpent reared up with Woonyoomboo’s spear in his head and the track of his tail became the river and the mouth of the river (Jackson & O’Leary 2006).

There is a growing body of work being driven by Aboriginal people on cultural science, knowledge and values across the Fitzroy planning area. We acknowledge the importance and uniqueness of this work which provides greater depth to our understanding of the catchment’s cultural, ecological and social values. However, we have focused on protected heritage places and ecological values in this report.

The cultural science and values studies, projects and records comprise knowledge held by Traditional Owners, and it is not appropriate or respectful for us to present their material in this report. Such knowledge should be considered in conjunction with this report to gain an integrated understanding of places, people and spirits that need to be protected from the impacts of water use. However, in the Section 9.1 we briefly describe some animal and plant species of specific importance to people of the Fitzroy River in the context of their water dependence.

We recognise that there are many language groups in the Fitzroy with different traditional names for plants, animals and places. We have only used traditional names sparingly and where they are specifically published in other work.

3.1 Traditional Owners of the Fitzroy

Traditional Owners have significant custodial responsibilities for land and waters in the Kimberley region and many people have legally recognised native title rights and land holdings. They form several language groups, including Bunuba, Kija, Walmajarri, Wankatjunka, Gooniyandi, Nyikina, Western Jaru, Mangala, Worrowa, Andajin and Ngaranyin.

About 8,200 people live in the Fitzroy River catchment (including Derby) – 64 per cent of whom are Aboriginal (DPIRD 2020). Most people live in the towns of Derby and Fitzroy Crossing. About 65 smaller Aboriginal communities are located across the Fitzroy planning area – see map below (Figure 7). The map labels all communities in the Fitzroy planning are with permanent residents of more than 50 people (Department of Aboriginal Affairs 2013).

Native title is determined, or is under claim, across large parts of the Fitzroy planning area with numerous native title parties having multiple determinations (Figure 7). Table 1 shows finalised determinations, by Native Title party, and the prescribed bodies corporate that represent them, as of December 2022.

Table 1 Native title parties with a determination in the Fitzroy planning area (December 2022)

Native title party	Registered native title body corporate (RNTBC)
Boorroola Moorrool Moorrool	Walalakoo Aboriginal Corporation
Bunuba (multiple)	Bunuba Dawangarri Aboriginal Corporation
Dambimangari	Wanjina-Wunggurr (Native title) Aboriginal Corporation
Giniyjawarrni Yoowaniya Riwi	Giniyjawarrni Yoowaniya Riwi Aboriginal Corporation
Gooniyandi (multiple)	Gooniyandi Aboriginal Corporation
Jaru	Jaru Aboriginal Corporation
Karajarri People (Area A)	Karajarri Traditional Lands Association (Aboriginal Corporation)
Kurungal	Tiyatiya Aboriginal Corporation
Malarngowem	Malarngowem Aboriginal Corporation
Mayala People	Mayala Inninalang Aboriginal Corporation
Ngarrawanji	Indigenous Land and Sea Council
Ngurrara Part A	Yanunijarra Aboriginal Corporation
Noonkanbah	Yungngora Aboriginal Corporation
Nyikina Mangala (multiple)	Walalakoo Aboriginal Corporation
Rubibi Community	Yawuru Native Title Holders Aboriginal Corporation
Wanjuna-Wunggurr Willinggin	Wanjina-Wunggurr (Native Title) Aboriginal Corporation
Warlangurru	Warlangurru Aboriginal Corporation
Warrwa and Warrwa Mawadjala Gadjidgar	Warrwa Peoples Aboriginal Corporation
Yi-Martuwarra Ngurrara	Yanunijarra Aboriginal Corporation
Yurriyangem Taam	Yurriyangem Taam Aboriginal Corporation

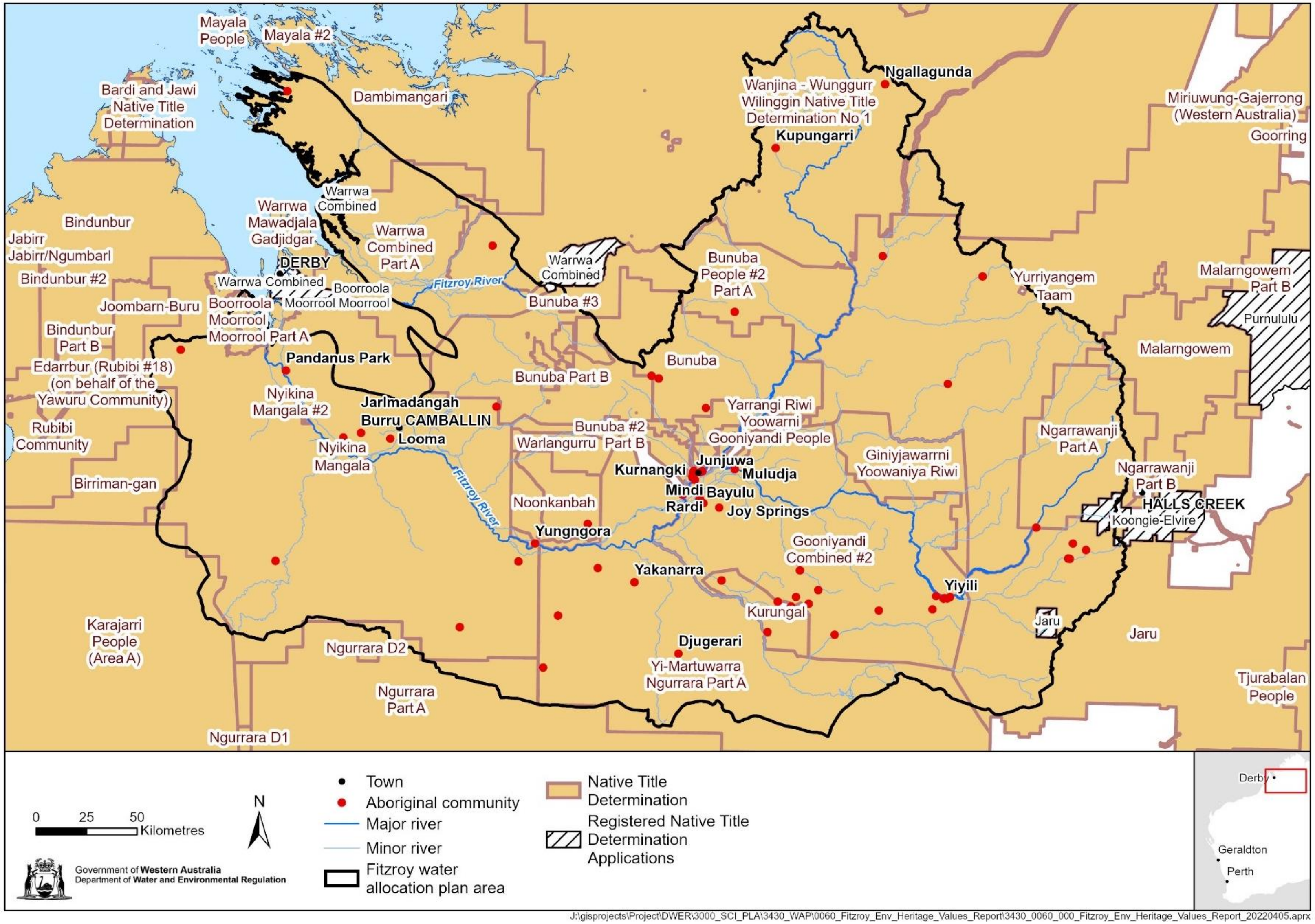


Figure 7 Native title areas and Aboriginal communities of the Fitzroy planning area (those labelled > 50 people)

4 Legislation to protect environmental and heritage values

4.1 Broad categories of environmental and heritage values in the Fitzroy planning area

Certain environmental and heritage values in the Fitzroy planning area are the subject of various legislative instruments, guidance and policy:

- Matters of national environmental significance are listed under the EPBC Act (Cth). These include places of world and national heritage including Aboriginal heritage, wetlands of international importance, listed threatened species and ecological communities, and migratory species.
- Aboriginal heritage places are listed under laws governing the protection and management of Aboriginal heritage in Western Australia.
- Areas of land and sea Country are managed by Traditional Owners through the federal Indigenous Protected Areas (IPA) program.
- Sites and places of significant social or natural heritage are registered under the *Heritage Act 2018* (WA).
- Threatened species are listed under the BC Act (WA) – note the listing of threatened and priority ecological communities is not yet in force.
- Priority species are protected by inclusion in the Western Australian Environmentally Sensitive Areas list and recognised through policy.
- Environmental values are defined in the environmental factor guidelines of Western Australia's EPA. These include social surroundings, flora and vegetation, terrestrial fauna, subterranean fauna, inland waters, marine fauna, benthic communities and habitats, marine environmental quality, and coastal processes.
- Areas of high conservation significance are identified in Part B of *Environmental guidance for planning and development – Guidance statement 33* (EPA 2008).
- Conservation reserves are managed under the *Conservation and Land Management Act 1984* (WA; CALM Act).
- Environmental values that are internationally and nationally significant are listed in the *Directory of important wetlands in Australia* (Environment Australia 2001) and *International Union for Conservation of Nature red list* (IUCN 2012).

Regional and local sites of ecological significance may also be identified during site-specific investigations – likely in areas where limited mapping projects or surveys have been undertaken. These may include but not be limited to:

- wetlands and waterways that persist during the dry season and provide refuges for aquatic and terrestrial fauna
- water-dependent ecosystems that are resilient to climate change

- ecosystems (or natural places) that provide a link to other water-dependent habitats and drought refuges
- springs and permanent river pools, particularly in arid areas
- wetlands and waterways that are likely to respond to management actions and plans.

4.2 Legislation and international listings

In this section, environmental and heritage values are those considered in legislation, policies and guidance that protect environmental and heritage places, including Aboriginal heritage.

Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act is the Australian Government's central piece of environmental legislation. The Act provides a legal framework for the protection and management of nationally and internationally important species, ecological communities and heritage places. These are defined in the Act as matters of national environmental significance and include:

- national heritage places
- listed threatened flora and fauna
- threatened ecological communities
- Ramsar-listed wetlands
- migratory bird species protected under international agreements (CAMBA, JAMBA, ROKAMBA, Bonn Convention).[3]

EPBC Act listing of species, ecological communities or heritage places is not necessarily more important than listings under Western Australian legislation (see below). Instead, the EPBC Act establishes assessment and approval requirements that are to be considered in addition to existing approvals required under state law. This means that an action still needs to be approved under all applicable state laws as well as under the EPBC Act.

Laws governing the protection and management of Aboriginal heritage in Western Australia

Aboriginal heritage holds significant value to Aboriginal people for their social, spiritual, historical, scientific, or aesthetic importance within Aboriginal traditions. Laws are in place in Western Australia to protect and manage Aboriginal heritage.

[3] Agreements between the government of Australia and the governments of Japan (JAMBA), China (CAMBA) and The Republic of Korea (ROKAMBA), and the Bonn Convention, relate to the protection of migratory birds.

All Aboriginal heritage sites in Western Australia are protected by law, regardless of whether they are a registered site. Under Aboriginal heritage laws proponents are required to seek consent for any activity that will knowingly damage an Aboriginal heritage site.

Aboriginal heritage places can be listed in the Aboriginal Cultural Heritage Inquiry System (ACHIS) under the *Aboriginal Heritage Act 1972* (WA).

Heritage Act 2018

The *Heritage Act 2018* (WA) promotes the understanding and appreciation of Western Australia's social and historical heritage sites. It provides for the identification and documentation of places of heritage significance and for their conservation, use, development and adaptation.

International Union for Conservation of Nature Red List

The IUCN Red List, founded in 1964, is the world's most comprehensive inventory of the conservation status of fauna and flora. It evaluates the extinction risk to species using set criteria. As of 2021, more than 40,000 threatened species were classified as vulnerable, critical or endangered (Watts 2018).

The EPBC Act (Cth) and BC Act (WA) have adopted the IUCN conservation categories, but have applied separate listings. This can lead to species being included in all three lists with three different conservation codes. Although the IUCN list is important to consider, it has no legislative powers.

Environmental Protection Act 1986

The *Environmental Protection Act 1986* (WA; EP Act) established the EPA and makes provisions for it to undertake environmental impact assessments of significant proposals. Assessments must consider key environmental factors such as sea, land, inland waters, air and people.

Significant ecosystems covered under the inland water environmental factor guideline and relevant to the Fitzroy planning area include:

- wetlands listed in the *Directory of important wetlands in Australia* (DIWA) (Environment Australia 2001)
- wild rivers identified by the Australian Heritage Commission and the Department of Water and Environmental Regulation (DoW 2009)
- springs and pools
- ecosystems which support significant flora, vegetation and fauna species or communities, including migratory waterbirds
- ecosystems which support significant amenity, recreation and cultural values
- saline lakes, estuaries and near-shore ecosystems reliant on groundwater or surface water inputs.

Part V of the EP Act and the Environmental Protection (Clearing of Native Vegetation) Regulations 2004 regulate the clearing of native vegetation. Under the EP Act, clearing is generally not permitted where native vegetation supports biodiversity values, land conservation and water resource protection. This includes native vegetation that is significant habitat for threatened species and communities or is associated with a wetland or watercourse.

In May 2022 we released the *Native vegetation policy for Western Australia* (DWER 2022)[4]. This policy provides a whole-of-government approach to achieving better outcomes for native vegetation and improved clarity and certainty for stakeholders.

Biodiversity Conservation Act 2016

The BC Act (WA) provides for listing protected species and threatened ecological communities, including key threatening processes (such as land degradation) and critical habitats.

The BC Act also establishes recovery plans and other modern features of biodiversity conservation and management. Like the EPBC Act, the BC Act has adopted the IUCN conservation categories but has applied separate listings.

The EPBC Act and BC Act provide for a statutory process whereby the Minister for Environment can identify and list threatened ecological communities (TEC). No formal statutory TEC list has yet been made under the BC Act. However, decision-makers continue to use the non-statutory TEC list endorsed by the Western Australian Minister for Environment for guidance.

Although priority ecological communities (PEC) are not listed in the BC Act, they are maintained under DBCA's conservation codes. PEC are possible threatened ecological communities that do not meet survey criteria or that are not adequately defined.

Conservation and Land Management Act 1984

The CALM Act (WA) provides for the protection of public lands and water which includes national parks, nature reserves, marine reserves and conservation parks. These reserves mostly consist of areas of crown land set aside for the protection and conservation of biodiversity and/or natural or cultural heritage values.

[4] www.wa.gov.au/government/publications/native-vegetation-policy-western-australia

5 Listed heritage values

In this section we discuss the listed heritage values identified across the Fitzroy planning area, including King Sound.

National heritage list under the *Environmental Protection and Biodiversity Conservation Act 1999*

The national heritage list is established under the EPBC Act (Cth). It includes natural, Indigenous and historic places of outstanding value to the nation.

The Commonwealth heritage list is also established under the EPBC Act. This includes natural, Indigenous and historic places on Commonwealth lands and waters or under Australian Government control, which are identified as having Commonwealth heritage values by the federal Minister for the Environment.

In 2011 the Minister for Sustainability, Environment, Water, Population and Communities announced the West Kimberley's inclusion in the national heritage list, and the area is now protected under the Act (Commonwealth of Australia 2011).

This listing recognises the outstanding heritage values of 19 million ha of the West Kimberley, including Aboriginal, historic, aesthetic, cultural and natural heritage values. It also recognises and celebrates the region's pastoral history.

> The Fitzroy River and a number of its tributaries together with their floodplains and jila sites (waterholes) of Kurrpurrngu, Mangunampi, Paliyarra and Kurungal, demonstrate four distinct but complementary expressions of the Rainbow Serpent (Yoongoorrookoo) tradition associated with indigenous interpretations of the different ways in which water flows within the catchment and are of outstanding heritage value to the nation under criterion (d) for their exceptional ability to convey the connectivity of the Rainbow Serpent tradition within a single freshwater hydrological system – Commonwealth of Australia 2011.

The lower Fitzroy River and its floodplain are covered in the listing along with major tributaries including the Nerrima, Geegully, Kalyeeda and Christmas creeks. Geikie (Danggu) and Windjana (Bandilngan) gorges are also named in the national heritage list (Figure 8).

The 568,000 ha Yampi defence area, 75 km northeast of Derby, is listed as a natural site. Criterion for the listing include the site's location at the confluence of three biogeographic regions; the diversity of its geology, landforms and soils: and presence of endemic plant species and priority fauna (Department of Agriculture, Water and the Environment 2004).

Aboriginal heritage places listed on the Aboriginal Cultural Heritage Inquiry System (ACHIS)

There are close to 1,000 registered sites listed on the ACHIS in the Fitzroy planning area. Many of these Aboriginal heritage places were a key component of the national heritage listing. Site types include artefacts/scatter, painting, engraving, camp, mythological, ceremonial, rock shelter, repository/cache, quarry, water source and grinding patches (Figure 9).

Further registered sites are listed in King Sound (see Section 4.2).

We recognise that only a fraction of Aboriginal heritage is listed, particularly secret or sacred sites such as men's or women's law sites. For this reason, Aboriginal people must always be consulted about their heritage in their area.

Indigenous Protected Areas

IPA are conservation reserves within Australia's national reserve system. IPA are areas of land and/or sea declared as protected areas by Traditional Owners and recognised by the federal or state governments. They are managed for cultural and natural values according to customary law and practices. Although managed in line with the IUCN, IPA are voluntary agreements and independent of legislation.

The IPA program is administered by the National Indigenous Australians Agency. There are three indigenous groups with IPA that fall within the Fitzroy planning area and also extend well beyond the planning area (Figure 10):

- Wilinggin – on and around Gibb River Station, including areas around the Hann River in the north-east of the planning area
- Dambimangari – northern side of Cone Bay in the north-west corner of the planning area
- Karajarri – south of Dampier Downs Station in the south-west corner of the planning area.

Nyikina Mangala people are in the consultation phase of establishing an IPA on their lands in the Fitzroy River catchment.

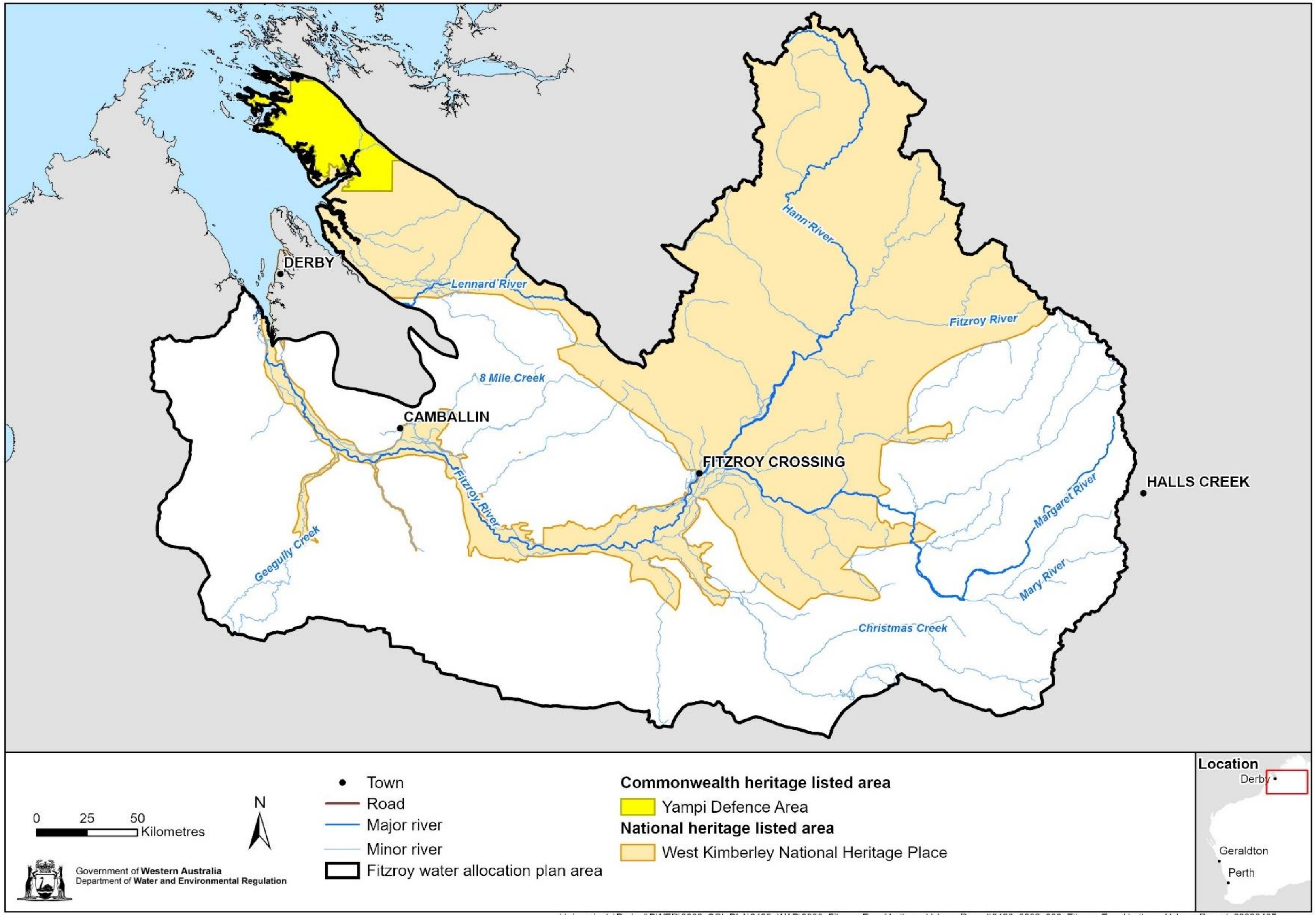


Figure 8 National and Commonwealth heritage places in the Fitzroy planning area, EPBC Act (Cth)

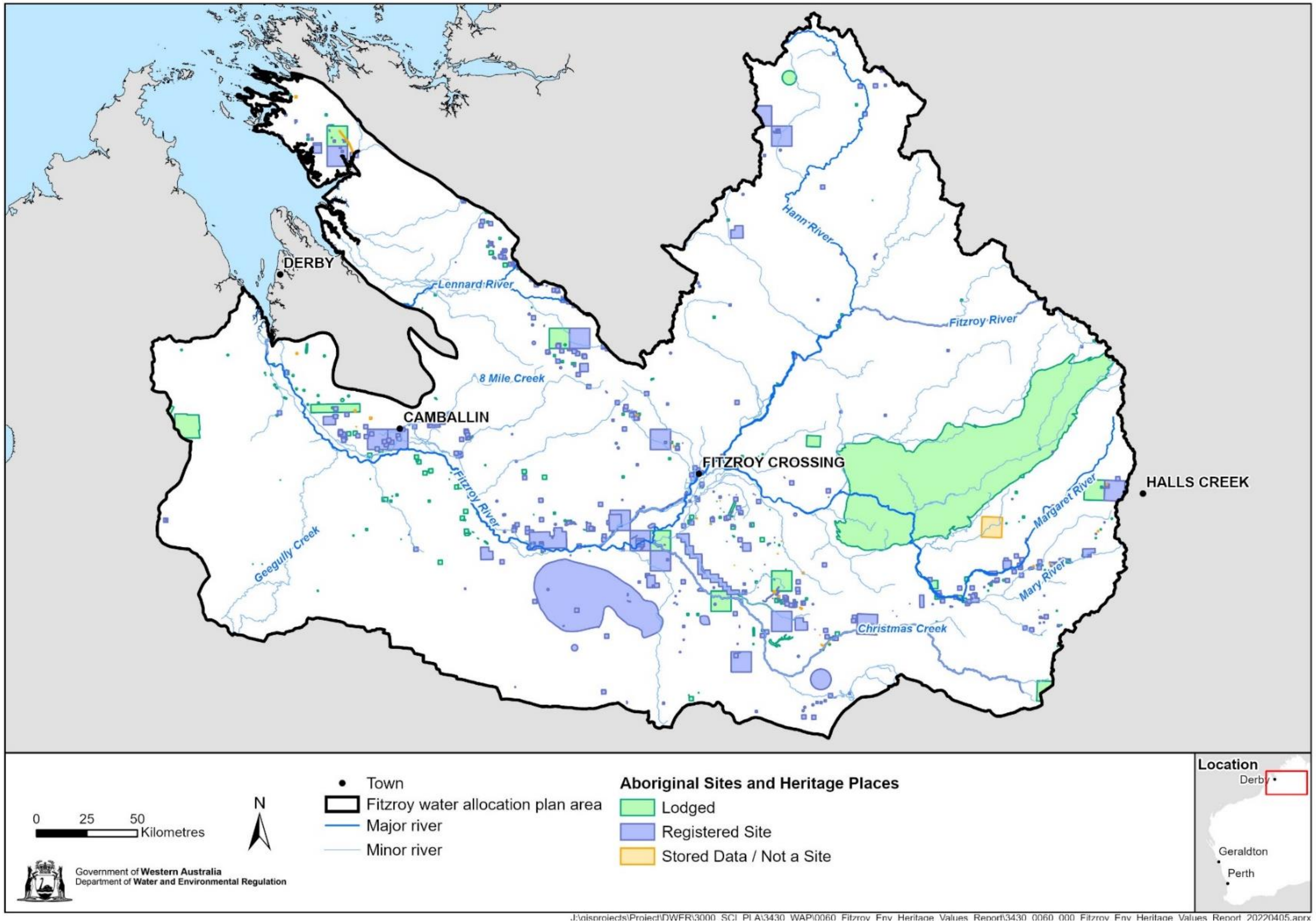


Figure 9 Aboriginal heritage places listed in the ACHIS in the Fitzroy planning area (as of October 2019)

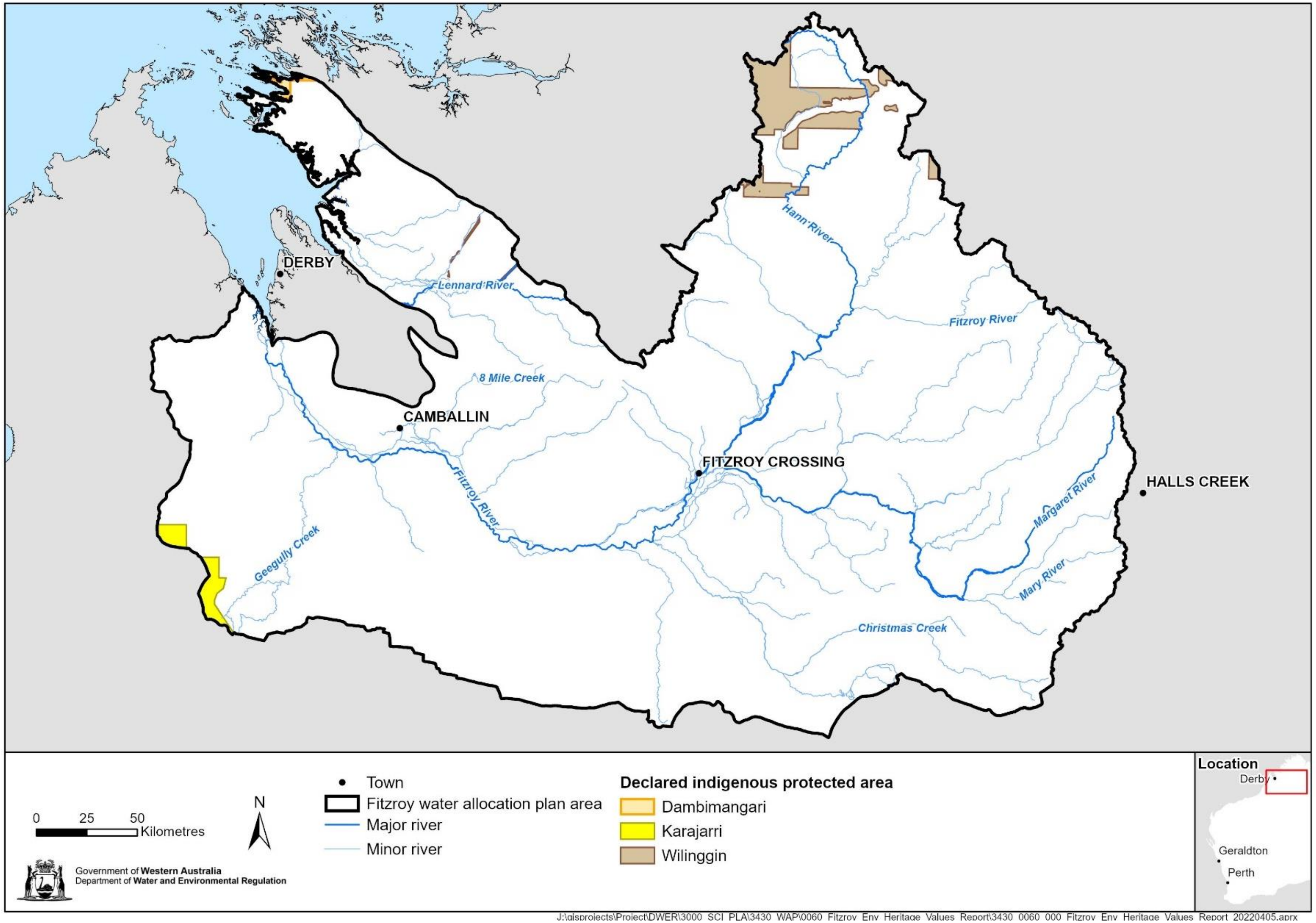


Figure 10 Indigenous Protected Areas in the Fitzroy planning area (as of August 2013)

Historical heritage places listed under the *Heritage Act 2018*

Nine European heritage sites are listed under the *Heritage Act 2018* (WA) in the Fitzroy planning area (Figure 11). Of these, six are associated with station homesteads:

- Glenroy, Fossil Downs and Old Cherabun stations
- the Gogo and Liveringa homestead groups
- Lillimilura ruins and grotto.

The remaining sites are:

- an abattoir and aerodrome also on Glenroy Station
- the low-level crossing at Fitzroy Crossing
- a stock route reserve (reserve 23226) which runs from Fitzroy Crossing to Nobbys Well south of Derby, loosely following the Fitzroy River.

Conservation estate listed under the *Conservation and Land Management Act 1986*

Conservation estate listed under the CALM Act (WA) includes national parks, nature reserves, marine reserves and conservation parks. This land is managed by DBCA, which often makes co-management arrangements with Traditional Owners.

In the Fitzroy planning area, 3,329 km^2 is reserved as conservation estate (Figure 12). This includes reserves that protect parts of the Fitzroy River and major tributaries:

- Bandilngan (Windjana) National Park
- Dimalurru (Tunnel Creek) National Park
- Balili (Devonian Reef) National and Conservation parks
- Danggu (Geike Gorge) National and Conservation parks
- Jungai-wa/Guwinyia (Brooking Gorge) Conservation Park
- Miluwindi (King Leopold Ranges) Conservation Park.

Under DBCA's *Plan for our parks* government has recently established several national and marine parks that are co-managed with Traditional Owners in the Kimberley. This includes the newly announced Bunuba National Park extending from Danggu National Park to Dimond Gorge along the Fitzroy River and then north into Bunuba Country. The Warlibirri National Park was created in 2022, covering areas of the Margaret River upstream of Fitzroy Crossing on Gooniyandi Country (Figure 12). The plan also includes the Buccaneer Archipelago marine parks situated in Mayala, Dambimangari, Bardi and Jawi Sea Country.

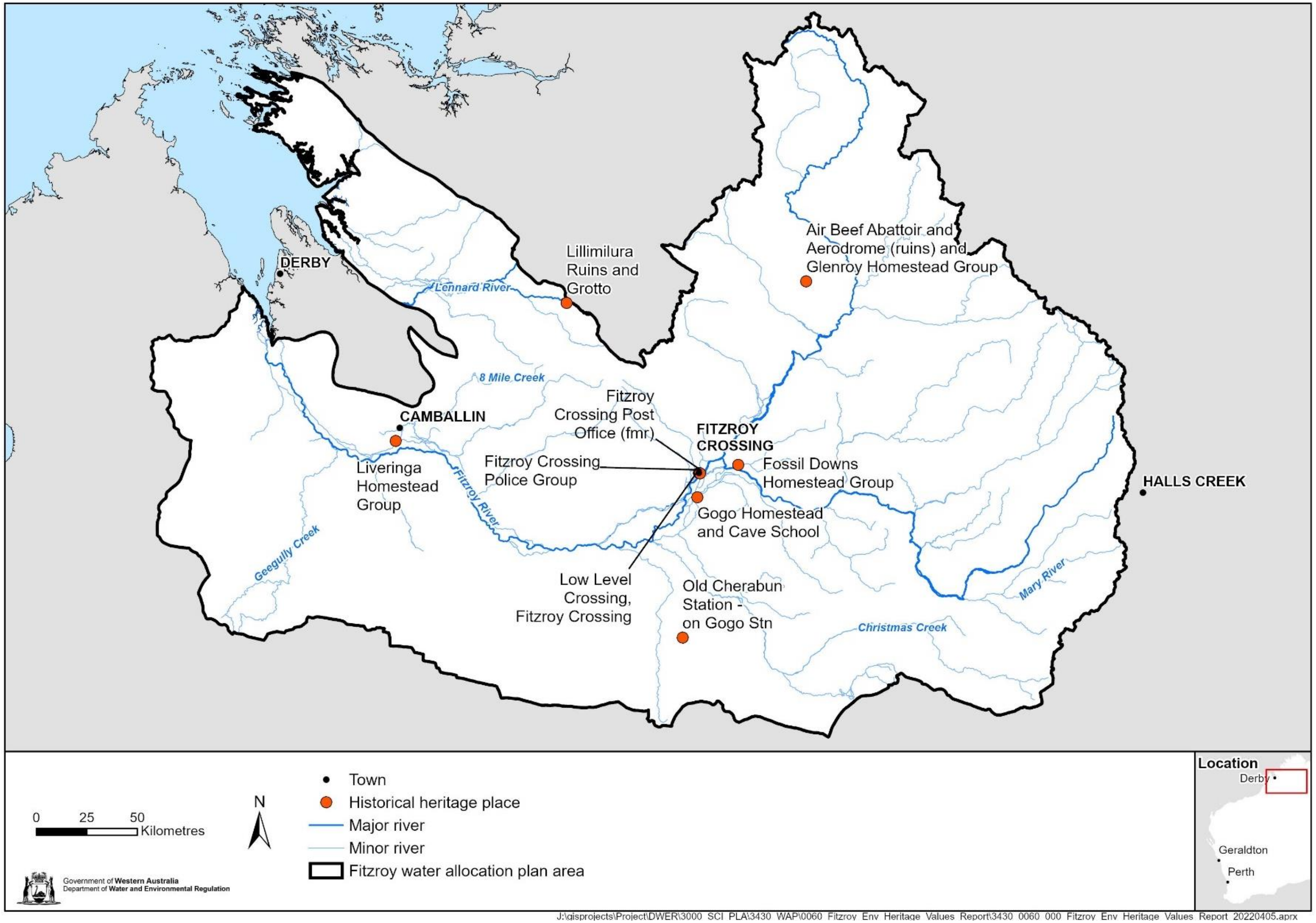


Figure 11 Historical heritage places, Heritage Act 2018 (November 2020)

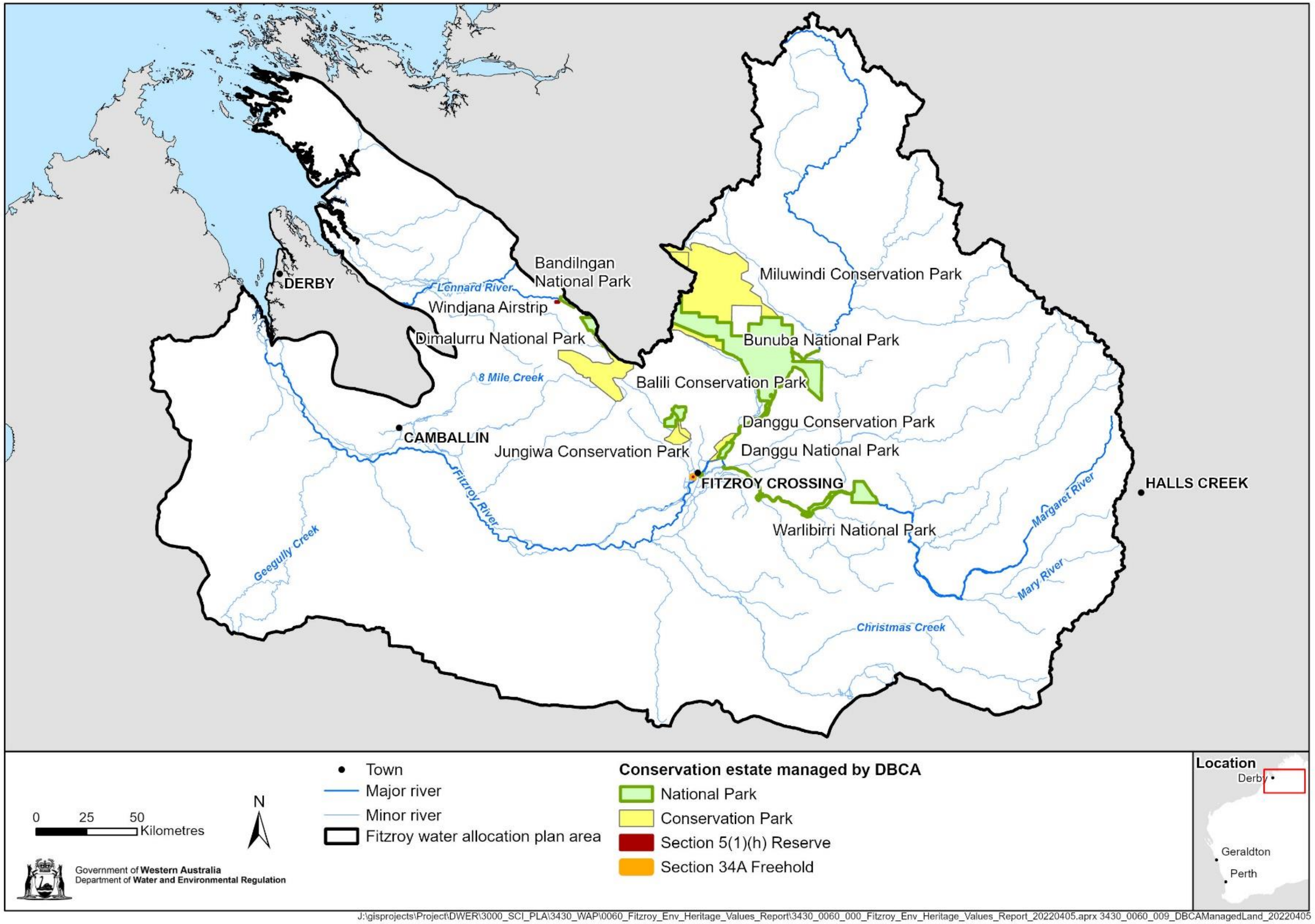


Figure 12 Conservation estate managed by Department of Biodiversity, Conservation and Attractions (as of August 2023)

6 Listed environmental values

In this section we identify and discuss the listed environmental values across the Fitzroy planning area, including King Sound. Values are described by water-dependent ecosystem type (e.g. wetlands, riparian vegetation). We briefly address the Aboriginal cultural values and flora and fauna these ecosystems support.

Values associated with wetlands and waterways

Directory of important wetlands of Australia (DIWA)

A wetland may be considered nationally important if it meets one or more of the following criteria:

1 It is a good example of a wetland type occurring within a biogeographic region in Australia.

2 It is a wetland which plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex.

3 It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles or provides a refuge when adverse conditions such as drought prevail.

4 The wetland supports one per cent or more of the national populations of any native plant or animal taxa.

5 The wetland supports native plant or animal taxa or communities which are considered endangered or vulnerable at the national level.

6 The wetland is of outstanding historical or cultural significance (Environment Australia 2001).

Camballin floodplain (Le Lievre Swamp system – Iljamalkarda) is a seasonally inundated wetland on the Fitzroy River's Camballin floodplain located between Mount Wynne Creek and Liveringa Station homestead (Environmental Australia 2001) (Figure 13). It is a listed DIWA wetland as it meets criteria 1, 2, 3, 4 and 6 above. The floodplain was identified as a high-value ecological asset in the Northern Australian Sustainable Yields project by McJannet et al. (2009).

Distinct wetlands on the floodplain are Le Lievre Swamp (1,300 ha), Moulamen Swamp (300 ha), 17 Mile Dam (700 ha, 13 km long, 100–1,000 m wide, including Lake Josceline), several unnamed swamps and Uralla/Snake Creek (10 km long, 50–100 m wide) (Department of Environment 2000) (Figure 13).

Geikie Gorge (Danggu) is located on the Fitzroy River upstream of Fitzroy Crossing in the Danggu Geikie Gorge National Park. It is listed as a 'permanent river' (criteria 1), which plays an important ecological or hydrological role in the natural functioning of the broader Fitzroy River (criteria 2) and has outstanding historical and cultural significance (criteria 6) (Environmental Australia 2001). All national parks are protected by the CALM Act (WA).

Windjana Gorge (Bandilngan) is on the Lennard River (criteria 1) within the Lennard River National Park. Three permanent pools in the gorge and fringing riparian vegetation provide a significant refuge for fauna (criteria 3) (Department of Environment 2000). The gorge is also of considerable significance to Aboriginal people with 10 listed Aboriginal heritage places in the gorge area (criteria 6). Sites are mostly listed because they contain paintings, artefacts, carvings and burial sites but Lillimilura Grotto is listed as a water source.

The Yampi Sound training area covers 560,000 km^2 and contains sections of coastline, tidal flats and floodplains (criteria 1) (Department of Environment 2000). Robinson River occurs in the south of the area. It supports EPBC Act-listed fauna including the Nabarlek (*Petrogale concinna monastria*), Northern quoll (*Dasyurus hallucatus*), Red goshawk (*Erythrotriorchis radiata*) and Gouldian finch (*Erythrura gouldiae*) (criteria 5).

Gladstone Lake is a permanent 25 ha wetland (criteria 1) 500 m west of the Hann River (Department of Environment 2000). It is an important bird habitat, supporting waterbirds, waders and woodland species (criteria 3). The lake is of European cultural value as a survey mark with the initials ‘FH XV1’ (Frank Hann) is cut into the trunk of large boab tree nearby (criteria 6).

Wild rivers

Stewart River, in the north-west of the Fitzroy planning area, is a listed wild river, due to its near-pristine nature and very high environmental value (DoW 2009). Other wild rivers occur just beyond the planning boundary (Figure 13). These are Jinunga Creek, Charnley River, Chamberlain River and Sturt Creek.

Threatened and priority flora and fauna

The Freshwater sawfish (*Pristis pristis*) and Dwarf sawfish (*Pristis clavata*) are found in the lower Fitzroy River and tributaries (Figure 13). Both are listed as vulnerable under the EPBC Act. In the IUCN red list the Freshwater sawfish is categorised as critically endangered (CR) and the dwarf sawfish as endangered (EN).

All sawfish species in Australia are also listed by the Convention on International Trade in Endangered Species (CITES). The Freshwater whipray (*Himantura chaophraya*) is an IUCN-listed species. Sawfish and whiprays rely on permanent, deep river pools for habitat and shallow ‘runs’ for hunting (Whitty et al. 2017).

Crocodiles – both Saltwater (*Crocodylus porosus*) and Freshwater (*Crocodylus johnstoni*) – are listed under CITES and as specially protected species in the BC ACT (WA). The Saltwater crocodile is also a listed migratory species under the EPBC Act. They both rely on permanent river pools or wetlands during the dry season (Department of Environment 2015).

The priority fish species, Prince Regent hardyhead (*Craterocephalus lentiginosus*) and Greenway’s grunter (*Hannia greenwayi*), are listed under DBCA’s conservation codes. They are highly dependent on permanent sections of rivers and creeks in the Fitzroy planning area. The Barnett River gudgeon (*Hypseleotris kimberlensis*) is listed as endangered under the IUCN red list. It is endemic to the upper Fitzroy River catchment and found in gorges of Manning Creek and Barnett River (Morgan & Moore 2019).

The Camballin floodplain is an important waterbird habitat with 20 of the 67 recorded species listed under the Japan–Australia and/or China–Australia migratory bird agreements (JAMBA/CAMBA) (Storey et al. 2001). For this reason, the listing of the floodplain as a wetland of international importance (Ramsar) has been proposed (Jaensch & Watkins 1999; Storey et al. 2001; DEC 2009). Beyond Camballin, the wetlands of Mallalah and Sandhill Swamp floodplains are, when flooded, also considered important waterbird habitats.

The water lilies *Nymphoides beaglensis* (priority 3), *Nymphaea kimberleyensis* (P1), *Nymphaea carpentariae* (P1) and *Utricularia muelleri* (P3; a floating herb) are aquatic species listed by DBCA (Western Australian Herbarium 1998–2022). These species are found in off-channel wetlands (Department of Parks and Wildlife 2015). The aquatic moss *Warnstorfia fluitans* (P2) and sedges *Fimbristylis sieberiana* (P3) and *Schoenus punctatus* (P3) are also likely to require permanent fresh water away from the main channel.

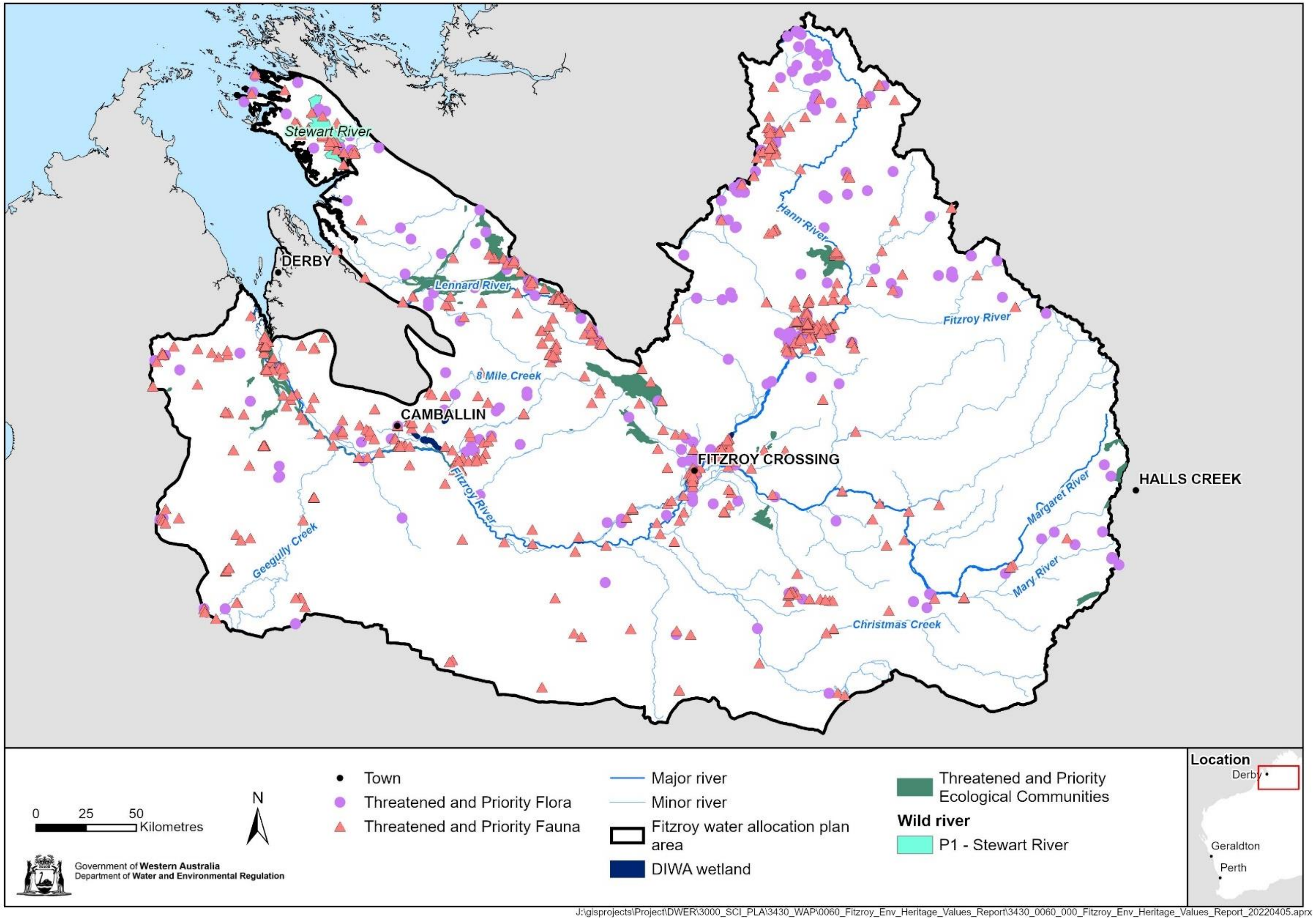


Figure 13 Listed species, ecological communities and wetlands

Values associated with riparian and floodplain vegetation

Threatened and priority fauna and flora

Numerous fauna species listed under the EPBC Act (Cth) and/or BC Act (WA) are likely to rely on riparian vegetation. The habitat requirements of the following five birds include permanent fresh water and/or fringing woodlands along watercourses and *Melaleuca* swamps (Skroblin & Legge 2012; Department of Environment 2015; Pusey & Kath 2015):

- Red goshawk (*Erythrotriorchis radiatus*; vulnerable)
- Gouldian finch (*Erythrura gouldiae*; endangered)
- Australian painted snipe (*Rostratula australis*; endangered)
- Purple-crowned fairy wren (*Malurus coronatus coronatus*; endangered)
- Northern masked owl (*Tyto novaehollandiae kimberli;* IUCN vulnerable).

Conservation advice for the Purple-crowned fairy wren describes its preferred habitat as:

> … a well-developed mid-storey under a dense canopy of emergent *Eucalyptus* and *Melaleuca* species (Garnett et al., 2011). In the Kimberley region, it usually occurs where the mid-storey is dominated by *Pandanus aquaticus*…or *Barringtonia acutangula*, a freshwater mangrove…, accompanied by a variety of shrubs…" (Threatened Species Scientific Committee 2015).

Certain other bird species found in the Fitzroy area are covered by international agreements (Appendix A). The majority of these, except for the Rainbow bee-eater, may depend on wetlands or riparian vegetation in the Fitzroy planning area (Department of Environment 2015).

The Northern quoll (*Dasyurus hallucatus*; endangered) may also be locally dependent on these habitats, as in parts of Queensland it is more likely to be present near permanent water sources (Department of Environment 2015; Shaw et al. 2022).

There are 137 listed threatened and priority flora in the catchment (see Appendix A). *Cayratia cardiophylla* (P2), a deciduous climber, is found in seepage areas amongst rocks. In the Fitzroy it is found around Geike Gorge. The annual herb *Gomphrena cucullata* (P3) is known from the Fitzroy floodplain, where it potentially germinates in response to floods.

Cullen candidum (P1), a tall shrub, is associated with clayey sands and may be associated with creeklines. *Corchorus fitzroyensis* (P3), a small shrub, was recorded at numerous locations in alluvial soils or cracking clays associated with the Fitzroy River and Cunningham Anabranch.

One priority flora species, previously unrecorded in the Fitzroy River catchment, was identified by UWA/NESP researchers in 2018. *Thespidium basiflorum* (P1) was found on the floodplain and at an off-channel wetland. It is possible that this species has a wider distribution in the catchment as the UWA/NESP research work was not designed as a targeted flora survey.

Priority ecological communities

There are numerous DBCA-listed priority ecological communities (PEC) in the Fitzroy planning area. However only the following vegetation associations and land systems may be associated with groundwater or surface water systems (Figure 13):

- Vegetation association 67 (P3), multiple occurrences
- Vegetation association 759 (P3), multiple occurrences
- Vegetation association 1271 (P1), multiple occurrences
- Leopold Land system (P3), multiple occurrences
- Gogo land system (P3), multiple occurrences.

The three vegetation associations occur in the lower Fitzroy River area downstream of Camballin and likely depend on river flow. The Leopold and Gogo land system PEC may also be associated with river flows.

Values associated with springs

In arid and semi-arid environments, springs are critically important sources of water supporting terrestrial fauna, and aquatic and riparian habitat. Springs are often significant Aboriginal cultural places and crucial sources of water for pastoralists. A review of spatial datasets found more than 400 springs mapped in the Fitzroy planning area (Figure 14).

There are two spring complexes in the Fitzroy planning area on the list of threatened ecological communities (TEC) endorsed by the Western Australian Minister for the Environment: Big Springs and the North Kimberly organic mound springs (Figure 14).

Big Springs is a non-tidal freshwater forested wetland located 18 km north-east of the mouth of the May River (Environment Australia 2001). The springs comprise a main seepage and a complex of springs, 22 of which are included in the listed TEC. The main seepage covers an area of around 40 ha with the smaller seepages in the surrounds, ranging from a few square metres to around 3 ha (Environment Australia 2001). The total spring area is about 80 ha. Big Springs is listed as ‘vulnerable’.

The main seepage at Big Springs is dominated by forests of *Terminalia macrocarpa* with *Melaleuca leucadendra, Pandanus spiralis*, *Nauclea orientalis*, *Sesbania formosa* and *Timonius timon.* Internal moats support the Mangrove fern *Acrostichum speciosum*. Patches of *Typha domingensis,* Duckweed (*Lemna aequinoctialis*) and, less commonly, Hornwort (*Ceratophyllum demersum*) occur. One population of climbing swamp fern (*Stenochlaena palustris*) was recorded (Environment Australia 2001).

Big Springs hosts several invertebrates that are rare, undescribed or restricted to springs of the Kimberley. These include one mite species (*Arrenurus* sp. WA 30) known only at this site and a copepod (*Phyllognathopus volcanicus*) not previously recorded in Australia (DBCA 2020). However, these species are not yet assessed as priority species.

It has been reported that Big Springs is an artificially enhanced wetland, with its size and water output being boosted by rusted-out, flowing artesian bores. Yet a totally artificial origin seems highly improbable, given its physical and floristic complexity (Environment Australia 2001).

A group of organic mound springs occur in the Fitzroy planning area's north: on and adjacent to the upper Hann River on Mt Elizabeth and Gibb River stations (Figure 14). Nine of these are the 'organic mound springs sedgeland community of the north Kimberley bioregion' TEC listed as vulnerable.

The mound springs are distinguished by the invertebrates they support and the sedgelands and grasslands found at the centre of their seepage zones (Barrett & English 2017). Rarely collected aquatic invertebrate species have been recorded in the community: a unique and undescribed *Arrenurus* sp., the darwinulid ostracod *Alicenula serricaudata* and the atyid shrimp *Caridina spelunca*, which is restricted to groundwater-associated habitats in the central Kimberley (Bennelongia 2017).

A total of 122 plant species have been recorded across the mound springs and their associated assemblages (Barrett & English 2017). Seven species that could be considered indicators of mound springs (or their margins) have been collected – *Cyperus unioloides, Eleocharis ochrostachys, Eriocaulon inapertum, Lobelia leucotos, Rhynchospora gracillima, Spiranthes* aff. *sinensis* and *Utricularia circumvolute*. Larger species such as *Melaleuca* sp., *Pandanus spiralis* and *Banksia dentata* also fringe the springs (DBCA 2020). These springs are floristically distinct from near-coastal springs such as Big Springs.

Threatened flora and fauna

The only known populations of the Edgar Range pandanus (*Pandanus spiralis* var. *flammeus*) – listed as endangered under both EPBC Act (Cth) and BC Act (WA) – are found at Logues Spring in the Edgar Ranges (Department of Environment and Conservation 2011). A priority 1 charopid land snail (Noonkanbah) (*Pilsbrycharopa tumida*) was recorded at Pandanus Spring south on Millijidee Station.

Values associated with subterranean and aquifer ecosystems

Subterranean ecosystems in northern Western Australia, including alluvial aquifer systems, support a diversity of stygofauna (groundwater dwelling) and troglofauna (living above the groundwater table). However, few surveys have been conducted in the Kimberley and no species are conservation listed to date.

There are, however, three PEC in the Fitzroy planning area that are likely to be associated with either aquifers or caves:

- invertebrate assemblages of the cliff foot springs around Devonian reef system (P1)
- the invertebrate community of Napier Range Cave (P1)
- the invertebrate community of Tunnel Creek (P2).

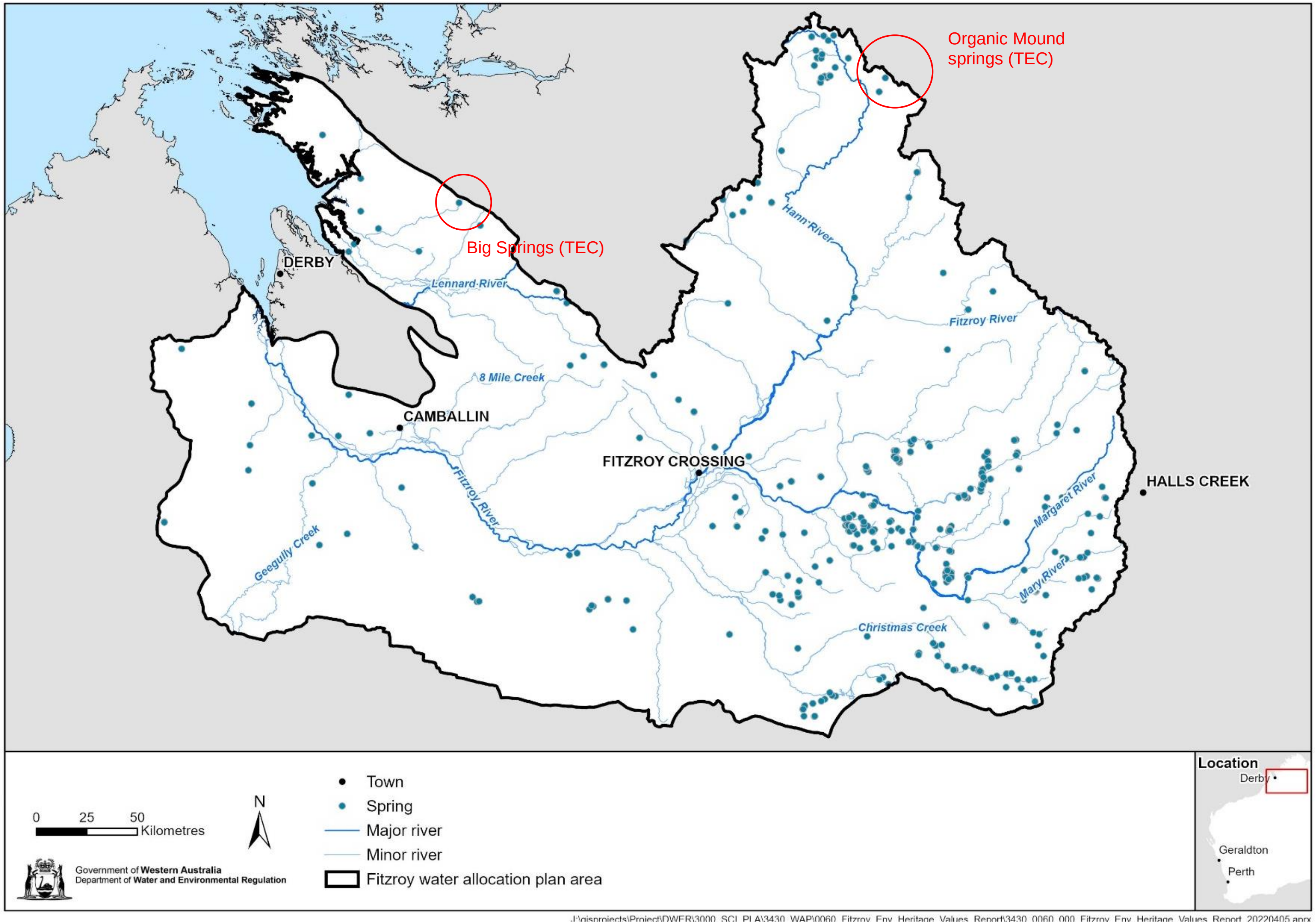


Figure 14 Listed TEC and other springs of the Fitzroy planning area

Values associated with estuarine and near-shore marine habitats

The Fitzroy, May, Meda and Robinson rivers flow into King Sound, providing fresh water and nutrients for seagrass, mangrove and saltflat communities (Pollino et al. 2018b) (Figure 15). King Sound supports listed flora and fauna species and TEC. The sound's outer area is an EPA redbook reserve, much of which will be captured in the proposed marine parks for the Buccaneer Archipelago and surrounds.

At present seagrass meadows are only mapped in the sound's northern extent. Seagrasses provide significant ecosystem services in coastal waters, including primary productivity, habitat, carbon storage and sediment stabilisation (McMahon et al. 2017). They are also an important food source for EPBC Act-listed species such as the Dugong (*Dugong dugon*) and Green turtle (*Chelonia mydas*).

The EPBC Act-listed Northern river shark (*Glyphis garricki*) is also known from King Sound and the estuary. Large individuals are found in the sound's highly turbid estuarine areas, with newborns and small juveniles more likely to occur closer to river mouths where salinity levels are low (Whitty 2011). The IUCN-listed Dwarf sawfish (*Pristis clavata*), Green sawfish (*Prisits zijsron*) and Narrow sawfish (*Anoxypristis cuspidata*) have also been reported from King Sound (Morgan et al. 2021).

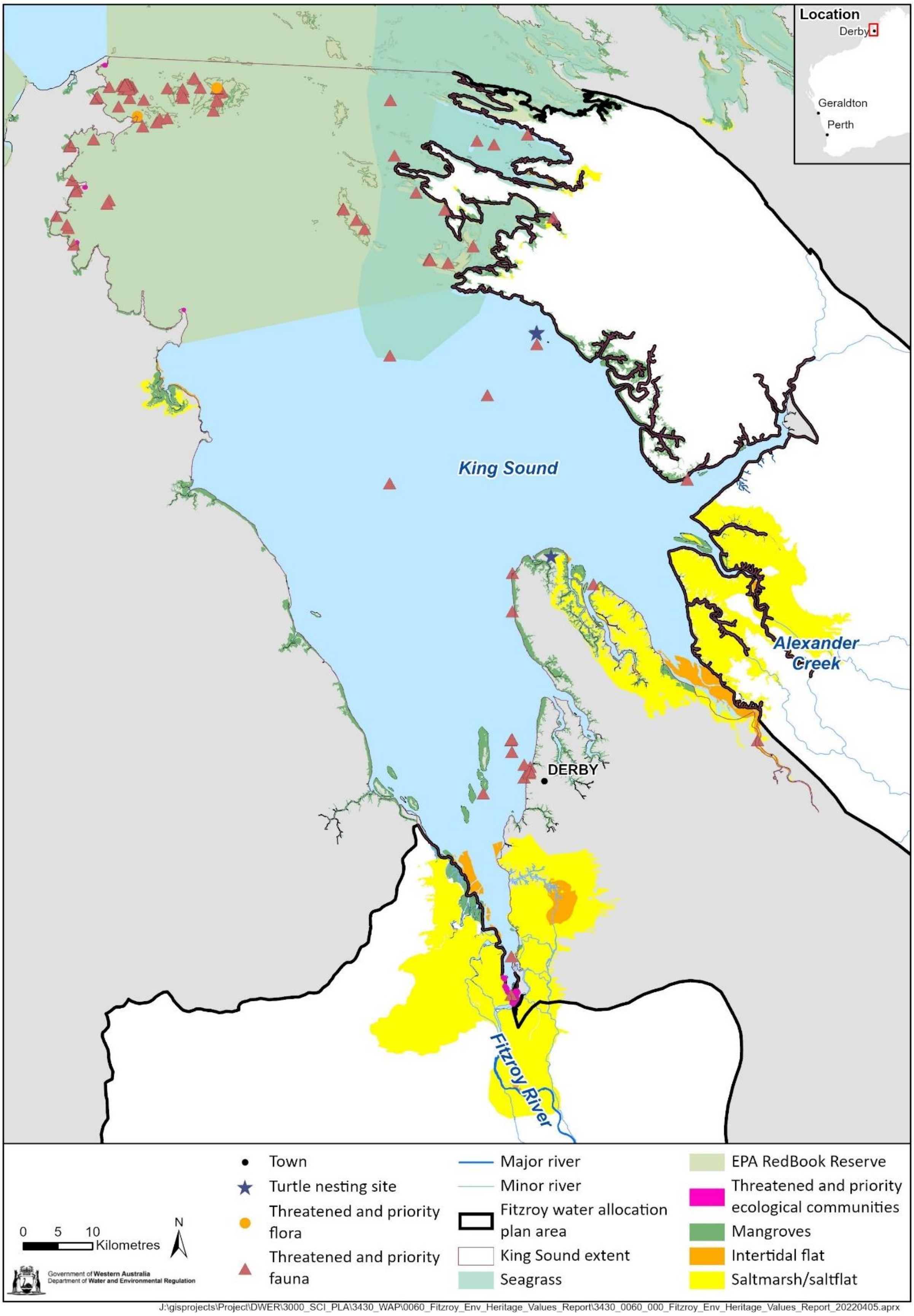
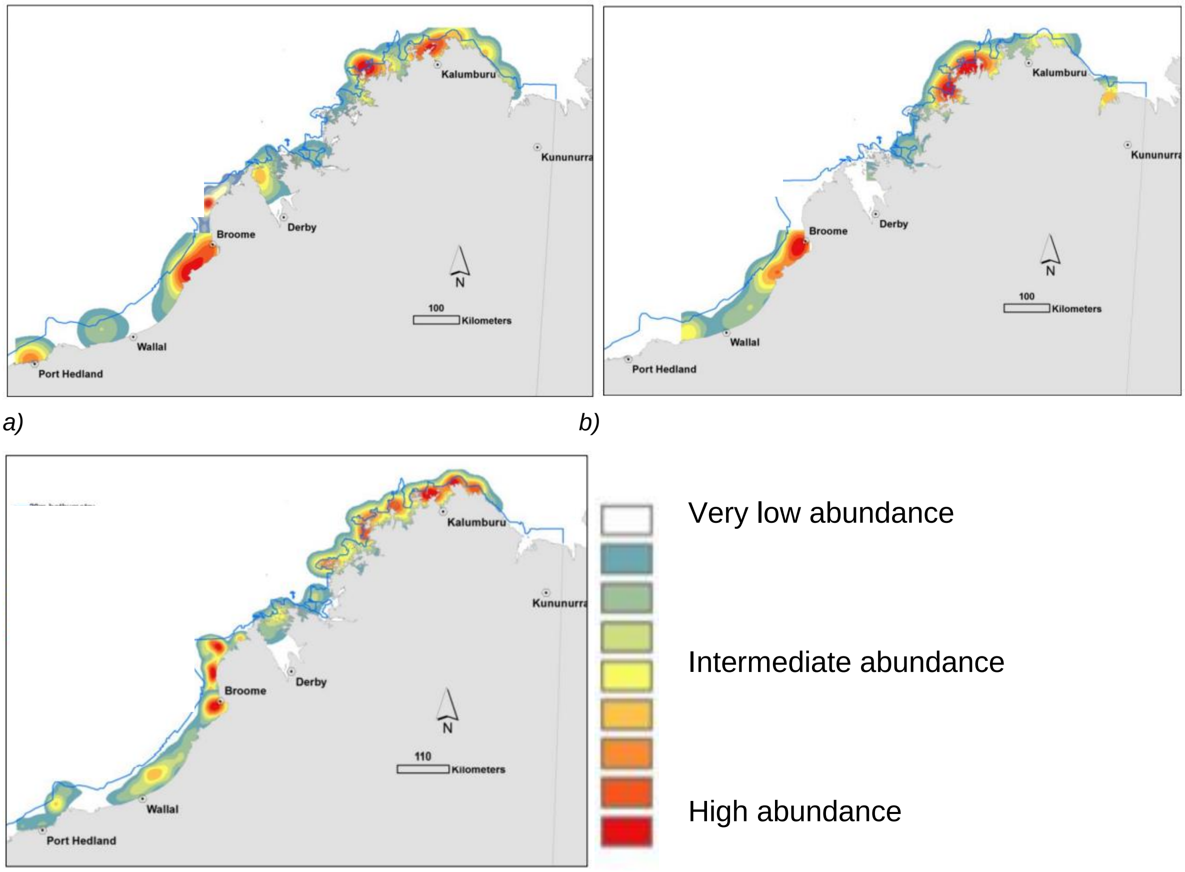


Figure 15 Ecosystems and listed species of King Sound and the Fitzroy estuary

The Snubfin dolphin (*Orcaella heinsohni*) is a listed migratory species under the EPBC Act. It is also IUCN listed and considered vulnerable under the *Nature Conservation Act 1992* (Qld). ‘Snubbies’ are an obligate inshore species and have been recorded in the estuary and King Sound near Derby and Doctors Creek (Pollino et al. 2018a). They are thought to have small ranges and hence the estuary’s condition may be critical for their survival.

In 2017 observational data from various aerial surveys was combined with Aboriginal knowledge to produce ‘hotspot’ maps of dugong, snubbies and various sea turtle occurrences across the Kimberley (Bayliss & Hutton 2017). Dugong and turtles were recorded in intermediate to low abundances in the mid to outer areas of King Sound (Figure 16).



a) *b)* *c)*

Figure 16 Abundance ‘hotspots’ of a) dugong, b) snubfin dolphin and c) sea turtles (from Bayliss & Hutton 2017)

Thirty-six listed migratory bird species have been recorded in and around King Sound. These include the critically endangered Eastern curlew (*Numenius madagascariensis*), Curlew sandpiper (*Calidris ferruginea*) and Bar-tailed godwit (*Limosa lapponica*). When they visit northern Australia all three species seek out intertidal mudflats, mangroves and lagoons.

7 Recent research

The department is working with researchers active in the Fitzroy River catchment, such as those from the:

- National Environmental Science Program (NESP), based at the University of Western Australia (UWA) and Griffith University
- Centre for Sustainable Aquatic Ecosystems at Murdoch University.

Researchers have been gathering important preliminary ecological and cultural data that furthers our knowledge of the region's water resources, values and dependencies.

Other investigations conducted in the Fitzroy planning area in recent years include:

- our groundwater investigations in the Fitzroy Valley (2015–18) (DWER 2023b) and La Grange (DWER 2022)
- the CSIRO's hydrogeological, hydrological, ecological and cultural programs (2016–18) which form part of its Northern Australia Water Resource Assessment (NAWRA) of the Fitzroy River catchment (Petheram et al. 2018; Pollino et al. 2018a & b; Barber & Woodward 2017).

The results have informed the development of ecological water requirements (EWR) for the catchment, which will inform future water planning.

National Environmental Science Program (2016-2021) - Northern Hub at UWA and Griffith University

In 2015, the Water for Food project and the department commissioned preliminary reviews of the current understanding of the Fitzroy River's Aboriginal and environmental values (Jackson 2015; Pusey & Kath 2015). The Pusey and Kath (2015) review identified significant gaps in the information needed to form and implement management strategies to maintain existing values.

The Pusey and Kath (2015) review listed 22 potential environmental research projects, several of which were developed by the Northern Hub at UWA and Griffith University (supported and funded by the Australian Government's NESP). The projects included those that sought to identify water requirements for key ecological assets (fish and riparian vegetation) and improve knowledge of Indigenous water relationships, values and needs.

Northern Hub researchers (UWA/NESP) engaged with Traditional Owners, prescribed bodies corporate (PBC), and Indigenous rangers and ranger co-ordinators throughout the program. They discussed the aims of the work and potential environmental study sites before any research began. They also engaged rangers and/or Traditional Owners throughout the field component of the research. This often involved camping on-Country with the project team. Before any results were published, the researchers presented the outcomes to Traditional Owners, registered native title bodies corporate (RNTBC) and ranger groups for review and approval.

We worked closely with the research team throughout the program, providing field support, water data, model outputs and co-authoring journal papers. In turn, the research team provided us with ecological data, publications, mapping and other information as it became available. Some of the data and information collected was not shared, as it remains culturally sensitive and did not have Traditional Owner support for release.

In the project's early stages the Northern Hub developed a conceptual model that described the potential impacts of water resource development on ecological and socio-cultural relationships with water regimes (Douglas et al. 2019). The conceptual model was based on knowledge about the Fitzroy River, learnings from other northern tropical rivers, and local/regional information from other similar river systems. Using the hydro-socio-ecological model, the research derived a set of 10 principles and considerations for water planning (Douglas et al. 2019).

Principles 1–5 and associated key considerations focus on the water allocation process. Principles 1–3 recognise Indigenous rights, interests, knowledge and responsibilities and principle 4 explains that multiple world views and relationships will interact in the water planning process. Principle 5 recognises that our understanding of the impacts of water resource development may be incomplete or contested (Douglas et al. 2019). Principles 6–10 focus on the importance of ecological and Indigenous relationships to key flow components. Principles 5–10 will play an important part in describing ecological water requirements for the Fitzroy plan area.

The principles derived by Douglas et al. (2019) are:

1 Indigenous water rights, values, knowledge and governance principles have been overlooked in Australian water policy and planning practice. There should be joint planning and management with Indigenous people.

2 A multi-scale approach to participatory planning and evaluation is needed.

3 Indigenous people have the right to use water for their economic, social and cultural development.

4 Planning occurs in a setting where there are multiple world views and many different ways of relating to water.

5 Knowledge of impacts from water source development can be incomplete and/or contested.

6 Within-bank flows promote longitudinal connectivity and are important for the ecology of the river and its estuary.

7 Overbank flows (flood) allow lateral connectivity that maintains the health of habitats distinct from the main channel.

8 Recessional flows are important for maintaining key habitats, particularly during the dry season.

9 Groundwater aquifers are important in maintaining subterranean, off-channel, riparian and spring habitats and can provide dry season flows to the river.

10 Antecedent hydrological conditions have an important influence over the ecology of the system.

The NESP/UWA project on the environmental water needs of the Fitzroy River involved several on-ground ecological studies. The new information gained from these has been published in scientific journals and reports, including:

- vegetation distribution and composition in relation to flood inundation (Freestone et al. 2020; Brauhart 2021; Canham et al. 2021a; Freestone et al. 2022) and potential groundwater sources (Canham et al. 2021b)
- functional traits of plants that affect how they tolerate different degrees of water availability (Canham et al. 2022)
- functioning of riverine food webs (Beesely et al. 2020; Burrows et al. 2020)
- habitat use and distribution of Cherabin (*Macrobrachium spinipes*) (Beesley et al. 2022) and Fork-tailed catfish (*Neoarius graeffei*) (Beesley et al. 2021a)
- critical pool depth thresholds to protect fish species' occurrence and richness in river pools and floodplain wetlands (Gwinn et al. in prep)
- Indigenous understandings of river flows and their dependencies (Douglas et al. 2019; Milgin et al. 2020; Laborde & Jackson 2021; Laborde & Jackson 2022).

In the project's final phase, the researchers refined their conceptual model based on new scientific evidence gathered from the targeted ecological studies of the Fitzroy River (Beesley et al. 2021b). The results from these studies are discussed throughout this report and will inform our ecological water requirements, specifically for fish, foodwebs and riparian and floodplain vegetation.

Centre for Sustainable Aquatic Ecosystems at Murdoch University

Researchers at the Centre for Sustainable Aquatic Ecosystems at Murdoch University have been studying the EPBC Act-listed Freshwater sawfish (*Pristis pristis)* in the Fitzroy River since 2002. They have also studied other fish species to define food webs and map the overall distribution of all Fitzroy fish species at 70 sites across the catchment (Morgan et al. 2004). This work has provided much published information, including:

- fishes of the Fitzroy River catchment (Morgan et al. 2004) and broader Kimberley region (Morgan et al. 2011)
- food webs of fishes of the Fitzroy River (Thorburn et al. 2014)
- ecology of Freshwater sawfish and Dwarf sawfish (Thorburn et al. 2007)
- population genetics of Freshwater sawfish (Phillips et al. 2009; 2017)
- predation of Freshwater sawfish (Morgan et al. 2017) and sawfish parasites in the Fitzroy River (Morgan et al. 2010)
- metabolic rates of Bull sharks and Freshwater sawfish (Lear et al. 2020)
- population structure of Northern river sharks (Feutry et al. 2020) and the importance of the Fitzroy River (Morgan et al. 2011).

Working with Nyikina-Mangala rangers each dry season from 2008 to 2019, the Murdoch team fitted up to 32 individual sawfish – from two permanent pools on the main channel – with acoustic tags, and monitored their movements continuously for several months (Whitty et al. 2017). This study's objective was to understand the habitat preferences of different-aged sawfish across the dry season.

The team conducted a similar study of the movement patterns of the EPBC Act-listed Dwarf sawfish (*Pristis clavata*) in the Fitzroy estuary and King Sound in 2015–16 (Morgan et al. 2021). Results from this work and data from historical catches between 2002 and 2016 were collated to describe the population dynamics of this species.

The team has also monitored Freshwater sawfish in Uralla/Snake Creek since 2008 and assessed the impacts of barriers to sawfish migration in the Fitzroy, Ord and Ashburton rivers (Morgan et al. 2016).

While undertaking sawfish surveys, the Murdoch team collected data on a broad range of other species including Barramundi, smaller fish, sharks and Cherabin, as well as information on water quality. We directed funds to the team to analyse and report on some of this previously unpublished additional data to help inform our ecological water requirements for the Fitzroy plan area.

The recent work has provided important published information specific to the Fitzroy, including:

- daily and seasonal movement of Freshwater and Dwarf sawfish between different habitats (Whitty et al. 2009; Whitty et al. 2017; Morgan et al. 2021)
- sawfish recruitment requirements (Lear et al. 2019; Morgan et al. 2021)
- variability in fish ecology in dry season pools (Lear et al. 2020; Lear et al. 2022)
- effects of hydrology and climate on Barramundi recruitment and growth (Morrongeiollo et al. 2020; Roberts et al. 2021)
- factors affecting the loss of body condition in Freshwater sawfish over the dry season (Lear et al. 2021)
- relationship between flood magnitude and water quality in dry season pools (Gleiss et al. 2021).

Department of Water and Environmental Regulation

Fitzroy Valley

The department investigated groundwater in the Fitzroy Valley through the state-funded Water for Food program, the federally funded NAWRA program (CSIRO) and our own State Groundwater Investigation Program (SGIP) from 2015–2018 (DWER 2023b).

Under the Water for Food program we installed groundwater monitoring, exploration and production bores north of the river across Mt Anderson, Brooking Springs and Kimberley Downs pastoral stations to determine the prospectivity of the Poole Sandstone and Grant Group aquifers in this region. We also installed bores within the

Darlngunaya and Bungardi Aboriginal communities on Bunuba Country. These bores are all located west of Fitzroy Crossing in the lower Fitzroy River catchment area.

Through the SGIP we sampled existing bores (Figure 17) and river pools in the Fitzroy Valley and installed groundwater monitoring bores closer to the river (DWER 2023b). In addition, Geoscience Australia conducted airborne electro-magnetic (AEM) surveys. This work was part of a comprehensive water resource investigation to map the extent and salinity of alluvial aquifers and provide greater knowledge of deeper geological structures.

The SGIP project has built on our existing research along the river between Willare and Fitzroy Crossing and consolidated our knowledge of groundwater resources and their links to water-dependent ecological, social and cultural values of the river.

La Grange

Also part of the SGIP are ongoing groundwater investigations in the La Grange area immediately south-west of the Fitzroy River catchment. An important part of this work is to identify and describe groundwater-dependent ecosystems, including near-shore seagrass communities (Antao et al. 2020).

This work will use geochemical tracers, specifically radon isotopes (Rn^{22}), to identify hot spots of groundwater discharge. Short-lived radon isotopes are not present in marine seawater in significant concentrations, so its presence in near-shore waters indicates groundwater input (Antao et al. 2020).

The results of this work will increase our knowledge of groundwater inputs into the near-shore marine environment in the La Grange area. We expect to be able to apply what we learn to the marine and estuarine ecosystems of King Sound.

Figure 17 DWER hydrogeologist (Steve Clohessy) sampling a groundwater bore

Northern Australia Water Resource Assessment project

In recognition of some of the challenges and opportunities facing northern communities and primary producers, the Australian Government engaged the CSIRO to assess the opportunities for water and agricultural development in northern Australia. As part of this, the NAWRA project assessed water resources in the Fitzroy River catchment, one of three priority regions identified across northern Australia.

Major outputs from the assessment were surface and groundwater models for understanding water availability across the catchment. The surface water model focused on the lower Fitzroy River and the groundwater model on the Grant and Poole sandstone aquifers.

The NAWRA environmental activities were desk based. The ecology team identified and prioritised key ecological assets (species, functional groups and habitats) (Pollino et al. 2018a) before collating existing information and developing conceptual models (Pollino et al. 2018b). The models focused on biophysical drivers of change including flow-ecology relationships.

The ecology team used Landsat imagery to identify and map persistent waterholes (river pools), wetlands and persistent vegetation in the Fitzroy Valley. Records from other sources were accessed to map known locations of important fauna and key habitats, including marine and estuarine assets.

The surface water hydrology modelling identified potential risks to ecological assets from water resource development. The model assessed the potential impacts of various abstraction scenarios against the flow-ecology response relationships, or hydrometrics, described for each asset (Petherman et al. 2018).

The Indigenous water values activity involved direct consultation with Traditional Owners to discuss values, rights, interests and aspirations with respect to water and irrigated agricultural development in the Fitzroy River catchment (Barber & Woodward 2017).

The final assessment (Petherman et al. 2018) did not recommend one development over another, nor assume any development pathway. It provided a range of possibilities and the information required to interpret them.

8 Water-dependent habitats

Water dependent habitats or ecosystems are those parts of the environment where the species composition and natural ecological processes are determined by the permanent or temporary presence of flowing or standing water (ARMCANZ & ANZECC 1996). These can be supported by surface water and/or groundwater. There are numerous types of water-dependent habitats across the Fitzroy planning area (Figure 18) including:

- river pools
- off-channel and floodplain wetlands/channels
- riparian and floodplain vegetation
- springs
- aquifer and subterranean ecosystems
- estuarine and near-shore marine ecosystems.

In this section we provide background on each type of water-dependent habitat (above). Using the four main parts of the water regime as previously described by UWA/NESP (Douglas et al. 2019) (Figure 19), we then identify which components (surface water or groundwater) are critical to each habitat and how, in turn, these support dependent fauna and flora. Finally, we describe threats to each habitat which are both water and development related. Where available, we focus on the results of recent investigations specific to ecosystems of the Fitzroy River catchment.

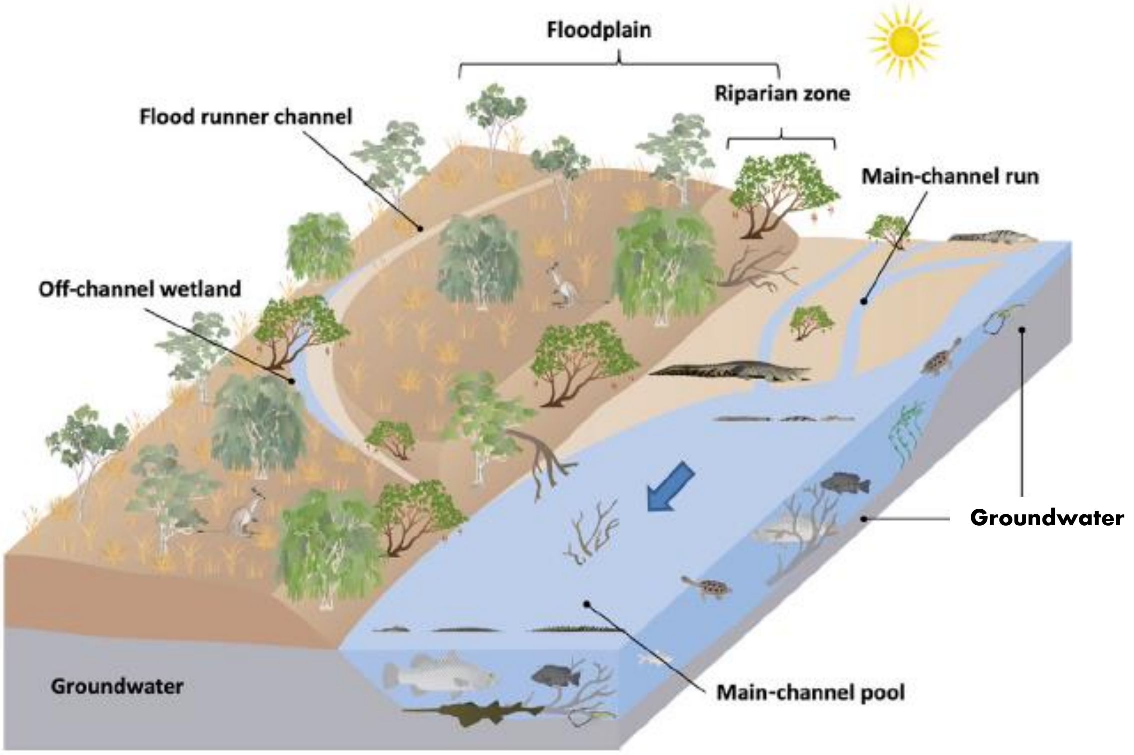


Figure 18 Water-dependent habitats of the Fitzroy (Douglas et al. 2019)

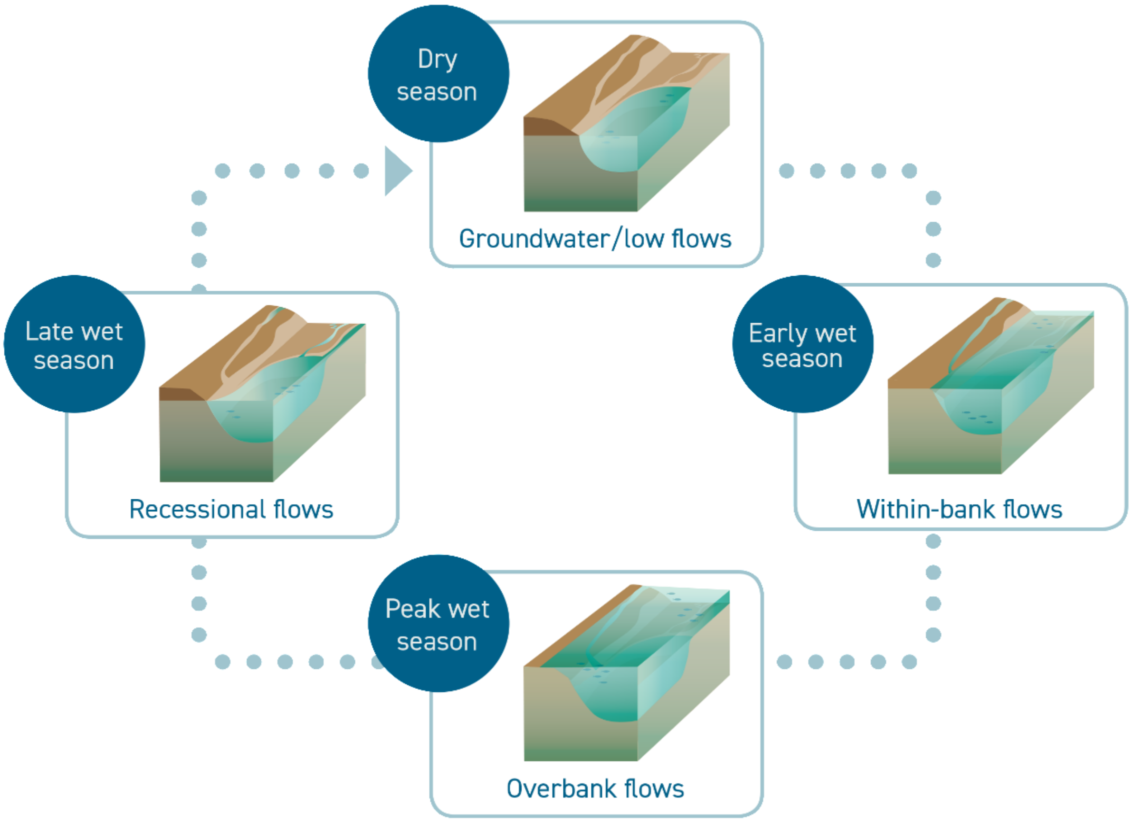


Figure 19 Important components of the Fitzroy River's water regime (Douglas et al. 2019)

8.1 River pools

Persistent pools are found along the Fitzroy River, major tributaries and other smaller rivers in the catchment (Figure 20; Figure 21). The pools support freshwater and marine fish species, invertebrates, waterbirds, frogs, reptiles and aquatic flora.

During the dry season the lower Fitzroy River supports a sequence of pool, glide, run and riffle habitats[5] connected by longitudinal baseflow (groundwater). Riffles are very shallow areas found between these habitats that become impassable during the late dry season (Whitty et al. 2017).

Pools are especially important during the dry season – they provide refuge habitat and sustain populations of fish and other fauna including the culturally significant Freshwater sawfish (*Pristis pristis*), Barramundi (*Lates calcarifer)*, Fork-tailed catfish (*Neoarius graeffei*) and Cherabin (*Macrobrachium spinipes*). It is important that large, deep pools are protected as they will persist after a limited wet season and provide critical habitat over the following protracted dry season.

Flows of varying size that connect the river to King Sound are important for spawning and recruitment of fish and other fauna with estuarine life phases; for example,

[5] Whitty et al. (2017) describe glides as shallow areas immediately downstream of pools, runs as areas connecting pools, and riffles as varying in depth depending on which they are closer to (i.e. deep near pools, shallow near glides).

sawfish, Cherabin and Barramundi (Lear et al. 2109; Roberts et al. 2021), as well as for flushing nutrients and chlorophyll *a* into the estuary and King Sound.

First flush, or freshing flows during the early wet season, reconnect the pools with one another and flush ‘old water’ downstream (Burford et al. 2021). Overbank flows (Figure 22) connect the river to floodplain (off-channel) wetlands and fish can move out of the main channel away from large predators. High-volume flows are thought to scour sediment from pools and the estuary (Beesley et al. 2021b) and have been found to promote Freshwater sawfish recruitment (Lear et al. 2019).

The river pools are connected to and interact with the underlying alluvial aquifer and, in some areas, deeper regional aquifers (DWER 2023b; Harrington & Harrington 2016). During flow events, shallow alluvial or unconfined groundwater is recharged, and the watertable rises. When there is no flow in the river, groundwater discharges into the pools (Figure 22).

As alluvial aquifer or unconfined groundwater levels decline, connection between the river channel and aquifer is reduced, with only deep pools or low (elevation) sections of the river intersecting the watertable (Figure 22). Aquatic habitat is reduced as surface water recedes and then groundwater levels progressively decline. As groundwater continues to naturally decline, aquatic fauna become isolated into a series of disconnected pools.

Figure 20 A persistent river pool on the lower Fitzroy River

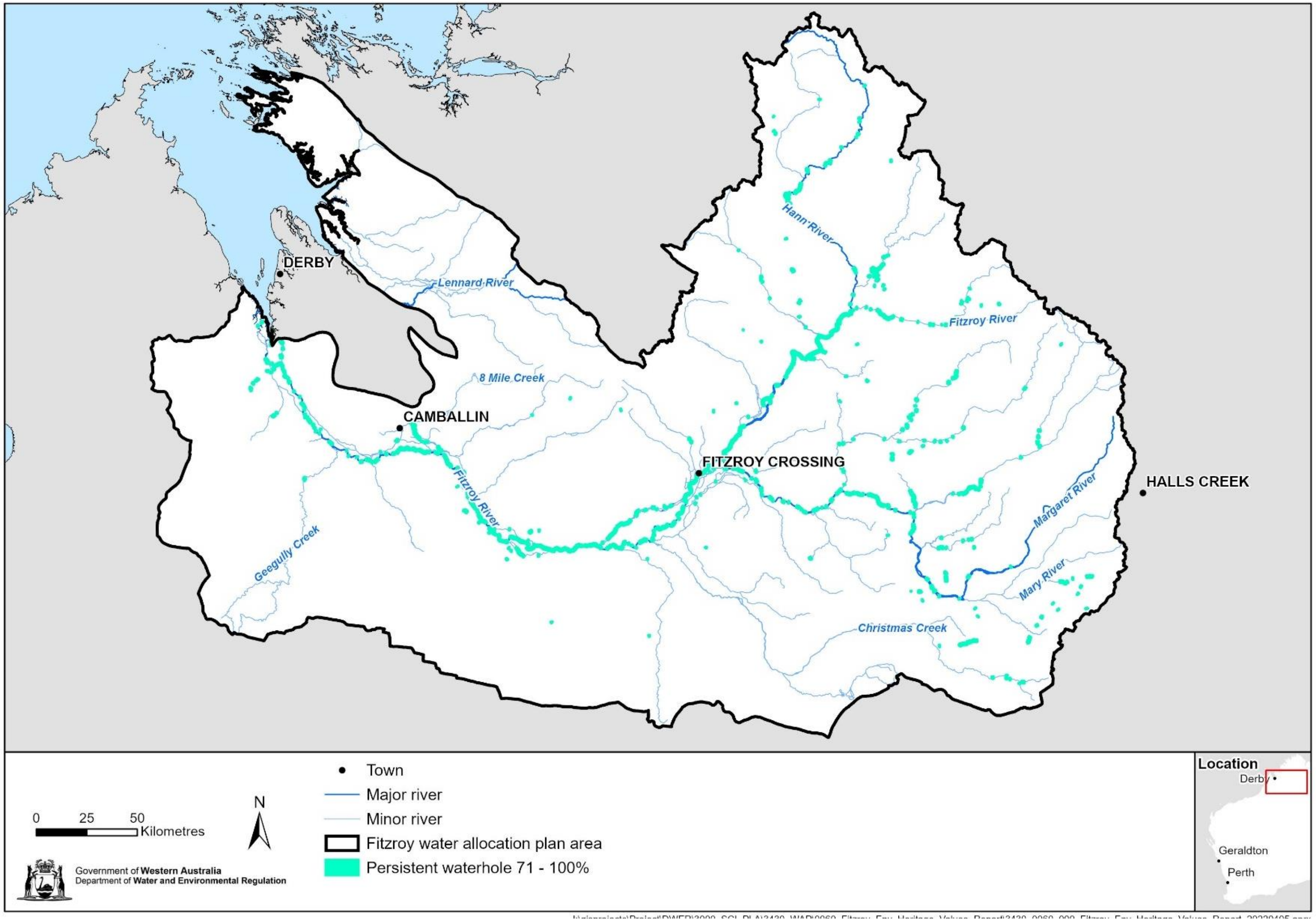


Figure 21 River pools/waterholes of the Fitzroy planning area (>70 per cent persistence)

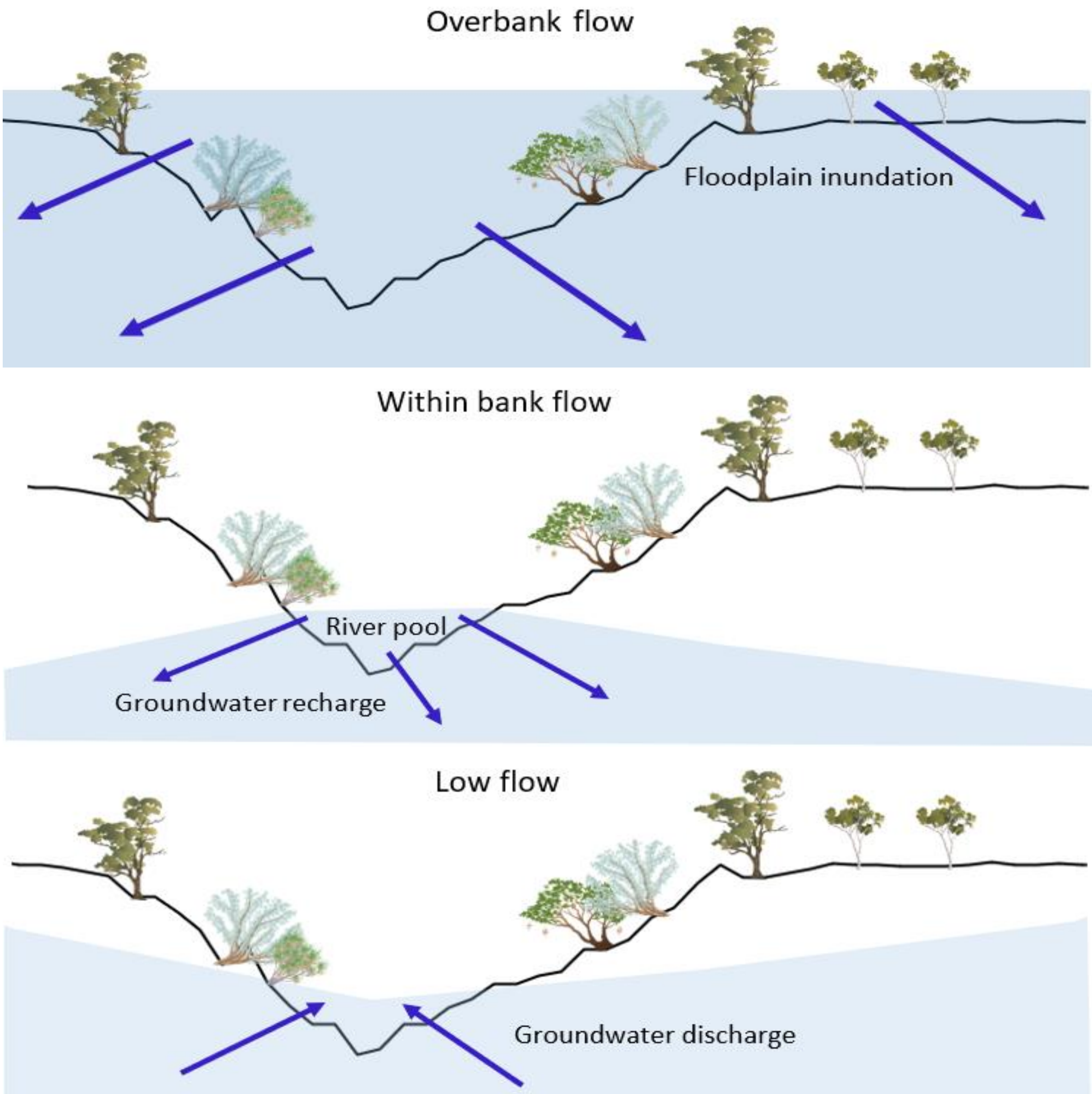


Figure 22 River's response to changes in flow and groundwater levels

Sources of groundwater

Many of the pools on the Fitzroy River and some of the larger tributaries are supported by groundwater inputs for at least part of the year. Inputs can be from the Fitzroy alluvial aquifer and/or regional aquifers (Grant-Poole, Devonian reef, Liveringa and Wallal aquifers). Groundwater throughflow to the King Sound is also likely to be important for the seagrass, mangrove and saltflat ecosystems.

Through the SGIP we sampled surface water and groundwater between 2015 and 2018 to identify potential interactions between water in the Fitzroy River and groundwater in the alluvial or regional aquifers. Interpretations of those possible interactions are presented in the report *Fitzroy Valley groundwater investigations 2015–2018* (DWER 2023b) .

Fauna

Fish and other fauna (e.g. frogs and reptiles) have strategies for surviving seasonal variations in river pool depth, velocity and connectivity (WRM 2008). Twenty-three freshwater fish species (those that breed in fresh water) are known from the Fitzroy River (Table 2) (Morgan et al. 2004). Some large-bodied fish, including the Freshwater sawfish, Freshwater whipray and Barramundi, have marine and freshwater life phases (Cook et al. 2016; Lear et al. 2019).

These species spend their early life in the estuary, moving upstream early in the wet season when river pools are connected (within-bank flows). Some individuals move out onto the floodplain when flows overtop the riverbanks (overbank flows) and connect to off-channel wetlands.

Late wet-season flows (recessional flows) allow some individuals to move back into pools in the main channel for the dry season. Other species, such as the Long-necked turtle (*Chelodina rugosa*), lay eggs under water or in moist soil and develop and hatch during the dry season (Jackson et al. 2011; Pusey & Kath 2015).

Table 2 Freshwater fishes of the Fitzroy River

Common name	Scientific name	Common name	Scientific name
North-west glassfish	*Ambassi sp. 1*	Barnett River gudgeon	*Hypseleotris kimberleyensis*
Fitzroy River glassfish	*Ambassi sp. 1*	Spangled perch	*Leiopotherapon unicolor*
Barred grunter	*Amniataba percoides*	Western rainbowfish	*Melanotaaenia australis*
Indonesian shortfin eel	*Anguilla bicolor*	Kimberley mogurnda	*Mogurnda oligolepis*
Toothless catfish	*Anodontiglanis dahli*	Bony bream	*Nematalosa erebi*
Freckled/Prince Regent hardyhead	*Craterocephalus lentiginosus*	Blue/lesser salmon catfish	*Neoarius graeffei*
Mouth almighty	*Glossamia aprion*	Black catfish	*Neosilurus ater*
Tank goby	*Glossogobius giuris*	Hyrtl's catfish	*Neosilurus hyrtlii*
Kimberley archerfish	*Toxotes kimberleyensis*	Falsespine catfish	*Neosilurus pseudospinosus*
Greenway's grunter	*Hannia greenwayi*	Blackbanded gudgeon	*Oxyeleotris selheimi*
Western sooty grunter	*Hephaestus jenkinsi*	Rendahl's catfish	*Porochilus rendahli*
		Freshwater longtom	*Strongylura krefftii*

Persistent pools are particularly important for sustaining fauna as they provide habitat in all seasons. Seasonal changes in river pool levels, driven by changes in flow in the main channel, provide variation in pool depth and size. This provides a diversity of aquatic habitat that enables fauna to complete their lifecycle. Flows in run and riffle habitats that adjoin pools in the dry season are likely to sustain spawning habitat for some fish species (e.g. catfish, grunters).

Non-permanent habitats that adjoin pools in the dry season are likely to sustain spawning habitat for some fish species (e.g. catfish, grunters). Non-permanent habitats (e.g. non-permanent pools, glides, runs and riffles) when flowing, provide aquatic habitat that allows increased productivity and exchange of biota between refuges.

Many macroinvertebrate species complete life cycles and enter diapause (or dormancy) based on the timing of intermittent surface flows and the persistence of residual pools (WRM 2008). Seasonal drought is therefore well tolerated. However, the unpredictable nature of longer-term drought (inter-annual) is more difficult for fauna to deal with (Pinder & Leung 2009).

Inter-annual drought generally has a negative impact on macroinvertebrate density (WRM 2008). However, the effect on an individual pool depends on whether it dries completely and/or crosses other critical ecological thresholds (e.g. water quality, temperature). At the river scale, the proportion of pools that retain water during protracted dry periods is important because persistent pools provide refuge for fauna and act as sources of colonisers once the drought ends (Pinder & Leung 2009).

In Chapter 9 we discuss recent studies of fish and other aquatic fauna by researchers from UWA and Griffith University (NESP's Northern Hub) and the Centre for Sustainable Aquatic Ecosystems (Harry Butler Institute) at Murdoch University.

River pool water quality

Water quality – especially turbidity, dissolved oxygen and temperature – are important drivers of aquatic ecosystem health, particularly in dry season refugial pools (Pusey & Kath 2015).

Stratification of the water column can be an issue in dry season pools. In such pools, the surface layer of water is warmed by the sun and becomes less dense than the water below it. The lower layer becomes progressively cooler and heavier, making it difficult for the layers to mix (by wind). Due to lack of mixing, dissolved oxygen in the lower layer is not replenished and is quickly used up by aquatic fauna, which can lead to fish kills (Gleiss et al. 2021).

Nutrient inputs into the Fitzroy River and its tributaries are driven by heavy rains and floodwater and can be exacerbated by the presence of cattle in the catchment. In some years, early heavy rains wash material into the river and cause anoxia (algae grow rapidly using up the nutrients and then when the nutrients are depleted, the algae die and decompose, using up the available oxygen in the water column) (Gleiss et al. 2021). Fish deaths can occur under these conditions (Beesley et al. 2022). This is not uncommon in the Fitzroy River catchment.

To date, the water quality information available for the lower Fitzroy River has been limited. However, recent studies by the teams at Murdoch University (Gleiss et al. 2021) and the UWA/NESP (Beesley et al. 2018) have provided information on the physicochemical conditions specific to river pools of the Fitzroy River.

UWA/NESP researchers undertook a preliminary assessment of water quality at six sites: three permanent pools and three shallow ‘runs’ on the main river channel upstream of Willare in October 2017 (Beesley et al. 2018).

Murdoch University researchers sampled water quality in two river pools 2–3 km long downstream of Myroodah Crossing and upstream of Camballin Barrage – over three dry seasons between July 2017 and November 2019 (Gleiss et al. 2021).

The wet season flows preceding each dry were quite varied wherein 2017–18 had some of the largest flows on record, 2019–20 had some of the lowest, and 2018–19 was considered intermediate (Gleiss et al. 2021). This allowed water quality in the dry season to be considered in relation to the preceding wet season flows.

Although the research teams sampled different pools at different times using varying methods, a similar suite of water quality parameters were measured. The parameters were temperature, pH, conductivity (a measure of salinity), dissolved oxygen, turbidity and chlorophyll *a*.

The results showed that dissolved oxygen generally remained stable and close to saturation (80–120 per cent) across the three dry seasons; however, it became hypoxic (low; <20 per cent) in deeper areas (>3 m) of both pools after the large wet season of 2017 (Gleiss et al. 2021). Pool water temperature generally increased across each dry season (~20^{o}C in mid-August to >30^{o}C in mid-October) (Gleiss et al 2021).

Dissolved oxygen and temperature decreased with pool depth (Beesley et al. 2018) and while there were clear diurnal changes in both parameters at the surface, these became muted at depth (Gleiss et al. 2021). Temperature and dissolved oxygen were generally higher in runs (~37^{o}C at midday) than pools, except in areas where groundwater was upwelling through the sand (29-32 ^{o}C) (Beesley et al. 2018).

Although electrical conductivity (EC) or salinity increased slightly with pool depth (0.2–0.5 mS/cm) it was constantly low and uniform across years, but slightly higher in the early dry (Gleiss et al. 2021).

Chlorophyll *a* and turbidity increased at pool depths greater than 1.5 m and were similar in pools and runs (Beesley et al. 2018) Yet both were consistently low with no obvious seasonal pattern (Gleiss et al. 2021).

Of note is that only minor changes in most water quality parameters were detected between years, despite drastic differences in flow of the preceding wet seasons. The exception was dissolved oxygen, which was low and close to hypoxic following the high flow year of 2017. This was believed to be a result of water depth rather than nutrient input as the water column in the deeper areas of pools did not mix as well as shallower water, leading to thermal stratification and depleted oxygen (from biological use) at depth >3 m (Gleiss et al. 2021).

Although these preliminary findings describe initial water quality conditions in some parts of the river, more data – both spatial and temporal – is needed to identify potential seasonal and inter-annual ranges in key water quality parameters and to establish baseline conditions.

Food webs

Murdoch University researchers determined food webs for several fish species, including key predators such as Freshwater sawfish (*Pristis pristis*) and Bullsharks (*Carcharhinus leucas)* in the Fitzroy River (Thorburn et al. 2014).

The researchers examined stomach contents to describe seasonal and long-term changes in the diets and feeding habits of the most abundant teleost (bony fish) and elasmobranch (sharks and sawfish) species. They also used the isotope ratios $\delta^{13}C$ and $\delta^{15}N$ to determine which food resources were the most important sources of energy to each species.

The study suggested that aquatic insects and, to a lesser extent, filamentous algae were important food sources for many of the species. However, as energy sources, they did not appear to be as important as prey types available throughout the year (e.g. fish, molluscs and Cherabin) (Thorburn et al. 2004).

The study also found that diet overlap between species was highest during the wet season, when prey availability was likely to be high, decreased in the early dry season as fish became more specialised in their feeding, and increased again in the late dry when food became very limited (Thorburn et al. 2004).

UWA/NESP researchers investigated the links between wet-season floodplain production (carbon and nutrients) and the biomass of fish in main-channel refuge pools (Beesley et al. 2020). They collected leaves, algae, macroinvertebrates and fish in the lower Fitzroy during a late dry season and then algae and fish in creeks and wetlands on the floodplain in the following wet season (Beesley et al. 2020). Analysis of $\delta^{13}C$ and $\delta^{15}N$ isotope ratios showed:

- that algal biofilm growing on rocks, logs and plants is an important source of energy for fish living in floodplain pools during the wet season
- fish and prawns in dry season pools in the main channel are using energy from tree leaves or microscopic algae (phytoplankton) living in the water.

Research on benthic algae (Burrows et al. 2020) found that the amount of algal biofilm on river substrates (sand, rocks, logs) was influenced by flow, being lower at high-velocity flows and higher at low-velocity flows. This suggests that changes to longitudinal flow and velocity may influence the amount of benthic algae produced and impact on food webs (Beesley et al. 2021).

During low flows in the dry season, hyporheic upwelling can occur where groundwater is shallow and discharging into the river or at the base of the riverbed in deeper, slow-flowing or stagnant river pools. The biomass of benthic algal biofilms was greatest in areas of hyporheic upwelling, indicating the importance of low flows and groundwater inputs in sustaining food sources in river pools and floodplain wetlands (Burrows et al. 2020). Reductions in groundwater inputs are likely to impact biofilm productivity (Beesley et al. 2021).

Threats to river pool habitat

Numerous threats to pools on the Fitzroy River and its tributaries are associated with water resource development and pastoral activities, as well as broader phenomena such as climate change and invasive species.

Surface water abstraction or diversion from the main river channels may reduce the size, depth and persistence of pools during the dry season. This would reduce available habitat for fauna and flora and potentially impact on water quality. Water taken during the dry season and low-flow periods would likely reduce connectivity between pools, restricting the movement of fish and other fauna up and down the river.

Groundwater abstraction could mean less groundwater flow into river pools, reducing available habitat during the dry season. Declining inputs of nutrient-rich groundwater may impact biofilm productivity and disrupt food webs.

Dams, other structures (e.g. Camballin Barrage) and road crossings on the main channel could inhibit the movement of fish and other instream fauna. These barriers may noticeably hold back flow during years with smaller wet season flows, reducing water exchange between the main channel and floodplain wetlands, and limiting pool scouring.

Changes in land use, including the intensification of irrigated agriculture, may lead to degradation and loss of riparian vegetation and increased nutrient and/or pesticide runoff into the river. Cattle having direct contact with the river causes bank erosion and the spread of weeds following disturbance. Vegetation clearing may also increase sediment loads delivered to the river and contribute to increased turbidity and pool infilling.

Climate change may result in greater variation in rainfall and higher temperatures, causing pools to dry earlier in the dry season. Sea-level rise may affect estuarine ecosystems in the mouths of the Fitzroy and other rivers in the King Sound by shifting the estuarine shoreline, altering the tidal range and inundating lowland coastal areas, potentially salinising river pools and wetlands that were previously freshwater-dominated.

Cane toads (*Rhinella marina)* are an invasive species linked to the decline of native predator species in northern Australia, including the Kimberley (Shine & Doody 2011). Cane toads are toxic at all stages of their life cycle (eggs, tadpoles, toadlets and adults) and their ingestion can kill native predators including birds, other frogs, reptiles and mammals. The red claw crayfish (*Cherax quadricarinatus*) has not been recorded in the Fitzroy to date but if established, it is likely to have substantial impacts, particularly on endemic invertebrates and aquatic plants (A. Pinder pers. comm. Dec 2022).

Threats may also interact or compound. For example, water resource development may exacerbate drying of river pools, which may increase the penetration of fires into these ecosystems and/or the frequency and intensity of fires, which would likely have substantial implications for wetland biota. This may include invasion of weedy grasses and plant disease.

Summary

The parts of the water regime most important to river pools are:

- groundwater inputs during the dry season to support dependent ecosystems and species (Burrows et al. 2020)
- annual wet season flows
  - first-flush, in-channel and recessional flows to support various spawning and recruitment requirements for fish, Cherabin and other fauna with estuarine life phases (Lear et al. 2019; Morrongeillo et al. 2020; Lear et al. 2021; Morgan et al. 2021)
  - freshwater flows in-channel to connect the river and estuary and support the movement of fauna and nutrients (Lear et al. 2019)
  - overbank flows to connect the river and floodplain (Beesley et al. 2020)
- occasional high-volume wet season flows
  - scour sediment from the river channel and estuary (Beesley et al. 2021b)
  - promote freshwater sawfish recruitment (Lear et al. 2019)
  - support nutrient and carbon inputs into King Sound (Hipsey et al. 2017).

8.2 Off-channel and floodplain wetlands

The Fitzroy River floodplain supports permanent and ephemeral off-channel wetlands (Figure 23). These wetlands include those on low-lying areas of the floodplain and flood-runner channels (creeks) to braided channels that carry wet-season flows out onto the floodplain and then drain excess water back into the river (Figure 24) (Beesley et al. 2020).

Connectivity to main channel

Hydrological connectivity between off-channel wetlands and the main channel is complex and variable (Pollino et al. 2018a). It drives fluxes of nutrients, biota and energy and supports the habitat and ecological diversity of floodplain ecosystems (Bunn et al. 2006; Burford et al. 2021).

The Fitzroy River flows seasonally in its headwaters and is perennial in the lower reaches. Overbank flows large enough to connect the river and the floodplain only occur briefly each wet season, which is typically less than three weeks (Jardine et al. 2012). However, smaller in-channel flows, often in the early wet season, can also move up distributary or flood-runner creeks close to the main channel.

UWA/NESP’s Fitzroy foodweb study (Beesley et al. 2020) found that algal biofilm produced in floodplain wetlands was the main source of energy supporting fish in those habitats. This suggests that changes to the movement of water across the floodplain could alter food webs and reduce fish productivity (Beesley et al. 2021).

UWA/NESP researchers have also found that floodplain wetlands are sites of high zooplankton abundance, compared with the main channel. As zooplankton are an important food source for larval fish and small fish, this may contribute to the higher rates of fish growth in this habitat type (L. Beesley pers. comm. April 2022).

Other new work by UWA/NESP suggests that off-channel and floodplain wetlands provide habitat for cherabin, mostly adult individuals (Beesley et al. 2022) and sustain bait fish for Aboriginal people (as discussed in Section 9.1).

Recent studies by Murdoch University described the movement of Freshwater sawfish (*Pristis pristis)* (Lear et al. 2021) and Barramundi (*Lates calcarifer)* in and out of the main channel and off-channel creeklines. Both species recruit in marine waters and move upstream where they may spend several years, before generally returning to the marine environment as adults.

In years where the main river and floodplain are well connected, both species move out into creeklines and wetlands where food is abundant and there is less pressure from large predators (e.g. Saltwater crocodiles and Bullsharks). Recessional flows at the end of the wet season signal sawfish and barramundi to move into deep, permanent off-channel wetlands or back into the main channel.

Murdoch researchers also described the inter-annual and annual differences in fish abundance and community structure between off-channel creeks and the main river channel (Lear et al. 2020). This work looked at large- and small-bodied species. Inter-annual differences were driven by wet season flow volumes (Lear et al. 2020).

In general, species richness, abundance and diversity of dry season fish assemblages were greater in creek habitats than in the main channel, and in the late dry season and in low-volume wet seasons (Lear et al. 2020).

This is likely due to the fish having greater access to the still, shallow habitats that most dry season spawners rely on for reproduction in low-volume wet seasons (Lear et al. 2020). Conversely, greater access to the floodplain and flowing habitats in high-volume wet seasons may be more suitable for wet-season spawners.

In the Daly River in the Northern Territory, intermittent creeks are also important habitats for spawning and recruitment of many fish species (Pusey et al. 2020). Off-channel recruitment is thought to help maintain diversity across the entire catchment and highlights the importance of connectivity between off-channel creeks and wetlands and the Fitzroy’s main channel.

Floodplain wetlands of the Northern Territory also provide feeding and breeding habitat for wetland birds, frogs, turtles and other semi-aquatic species (Finlayson et al. 2006). Recent observations by UWA/NESP researchers in the Fitzroy also suggest wetlands are important for frog recruitment and invertebrates, especially at locations that have not been connected to the river (or connected very briefly) and support very few fish (L. Beesley, pers. comm. April 2022).

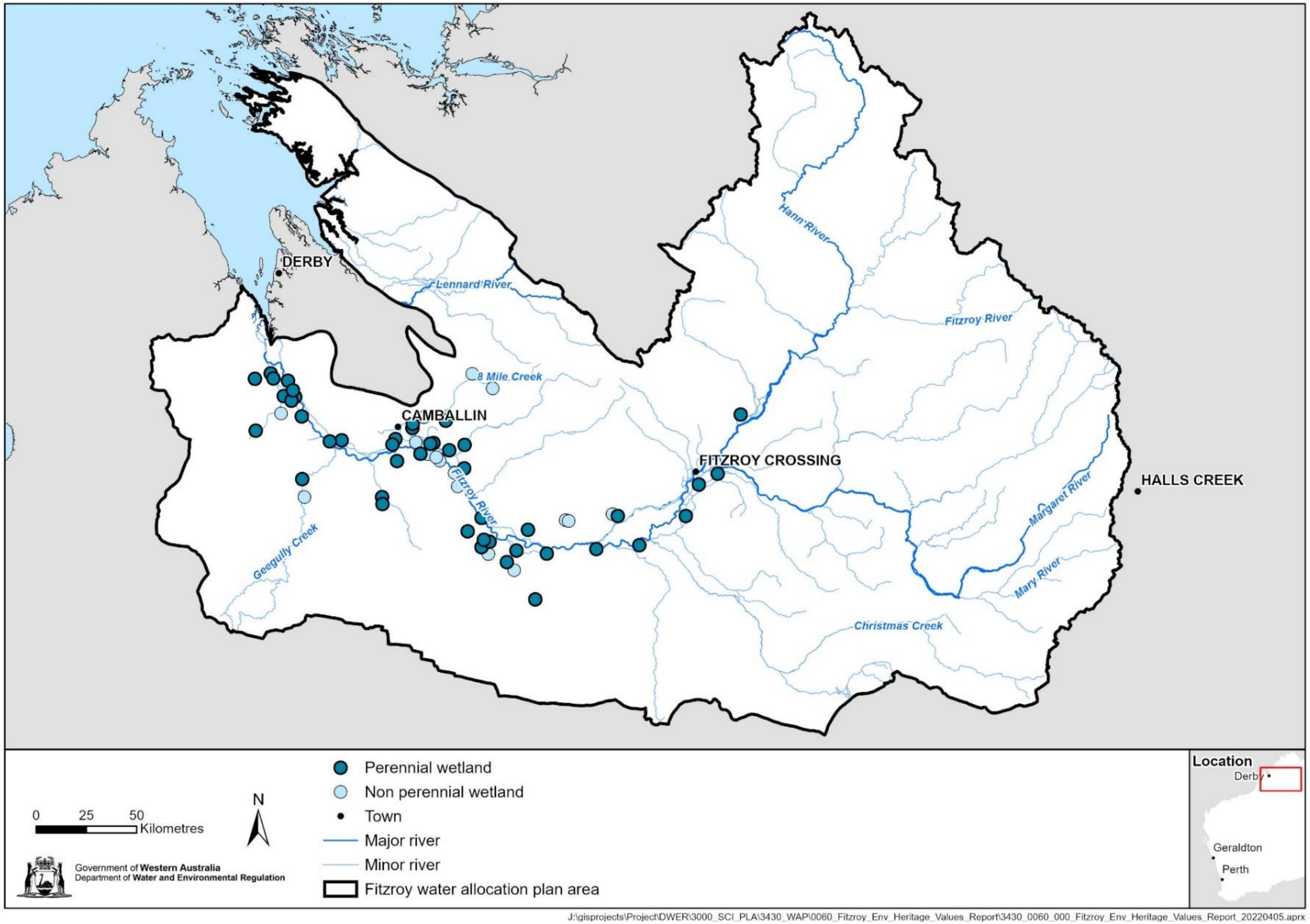


Figure 23 Persistent (perennial and non-perennial) wetlands of the lower Fitzroy floodplain

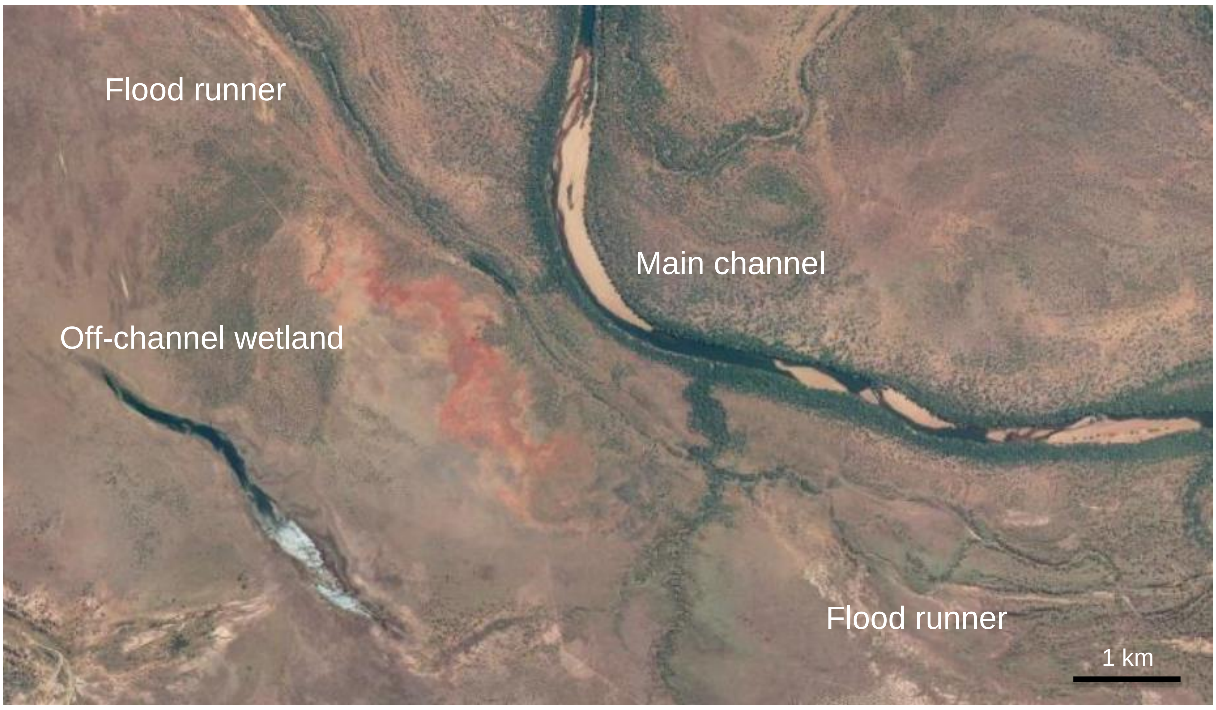


Figure 24 Fitzroy main channel, 'flood runners' and off-channel wetland

Groundwater inputs

Some floodplain wetlands, especially those that are highly persistent, are supported by groundwater inputs during the dry season (DWER 2023b). Most wetlands in the Fitzroy planning area are on the floodplain, therefore the Alluvial aquifer is likely to be the main source of groundwater – although regional aquifers may also play a role.

Threats to wetlands

Numerous threats to off-channel and floodplain wetlands are associated with water resource development and pastoral activities, as well as broader phenomena such as climate change and invasive species.

Surface water diversion could reduce connectivity between wetlands and the main channel, disrupting the recruitment and migration of fauna, reducing available habitat (e.g. wetland size, depth and persistence) and altering food webs. Groundwater abstraction could also reduce wetland depth and persistence and disrupt food webs. Dams or other irrigation structures, road crossings and raised roadways could affect flows across the floodplain – thus prolonging dry season conditions and inhibiting the movement of fish and other fauna.

Changes in land use, including intensification of irrigated agriculture, could lead to degradation and loss of vegetation, increased nutrient and/or pesticide runoff into the wetlands and weed invasion. Cattle often use wetlands as drinking locations and their pugging destroys the benthic substrate, destroying macrophytes and increasing water turbidity.

Climate change may result in greater variation in rainfall and higher temperatures, causing wetlands to dry earlier in the dry season. Sea-level rise may affect estuarine ecosystems in the mouths of the Fitzroy and other rivers in the King Sound by shifting the estuarine shoreline, altering the tidal range and inundating lowland coastal areas, potentially salinising wetlands and river reaches that were previously freshwater-dominated.

Cane toads (*Rhinella marina)* are toxic at all stages of their life cycle (eggs, tadpoles, toadlets and adults) and their ingestion can kill native predators including birds, other frogs, reptiles and mammals.

Threats may also interact or compound. For example, water resource development may exacerbate drying of wetlands, which may increase fire penetration into these ecosystems and/or the frequency and intensity of fires, which would likely have substantial implications for wetland biota. This may include invasion of weedy grasses and plant disease.

Summary

Parts of the water regime important to off-channel and floodplain wetlands are:

- groundwater inputs during the dry season to support Cherabin and bait fish (Beesley et al. 2021b; Beesley et al. 2020)
- annual wet season flows:
  - early season flows connect flood-runner creeks and support the movement of fish in and out of main channel (Beesley et al. in prep)
  - early season and overbank flows support the recruitment of fish (Lear et al 2020; Pusey et al. 2020)
  - overbank flows support river and floodplain wetland connectivity and promote system-wide primary productivity (Jardine et al. 2012; Beesley et al. 2020)
  - overbank flows provide habitat for small-bodied fish (Gwinn et al. in prep), Cherabin (Beesley et al. 2022), waterbirds, frogs and turtles (Finlayson et al. 2006)
  - recessional flows at the end of the wet season allow large-bodied fish to move back in the main channel (Lear et al. 2020).

8.3 Riparian and floodplain vegetation

The shallow alluvial and unconfined aquifers of the Fitzroy and major tributaries are likely to support phreatophytic (groundwater-dependent) vegetation for at least part of the year. Riparian and floodplain species composition, distribution and physical structure are largely driven by proximity to the river, depth to groundwater and the area inundated – creating broad vegetation zones (Deane et al. 2017; Jansson et al. 2019; Freestone et al. 2020).

We mapped persistently green vegetation across the Fitzroy planning area using satellite imagery to derive normalised distribution vegetation index (NDVI) values (Figure 25). Persistent greenness at the end of the dry season indicates that vegetation is well hydrated. In the Fitzroy, this suggests vegetation has access to a water source in addition to rainfall.

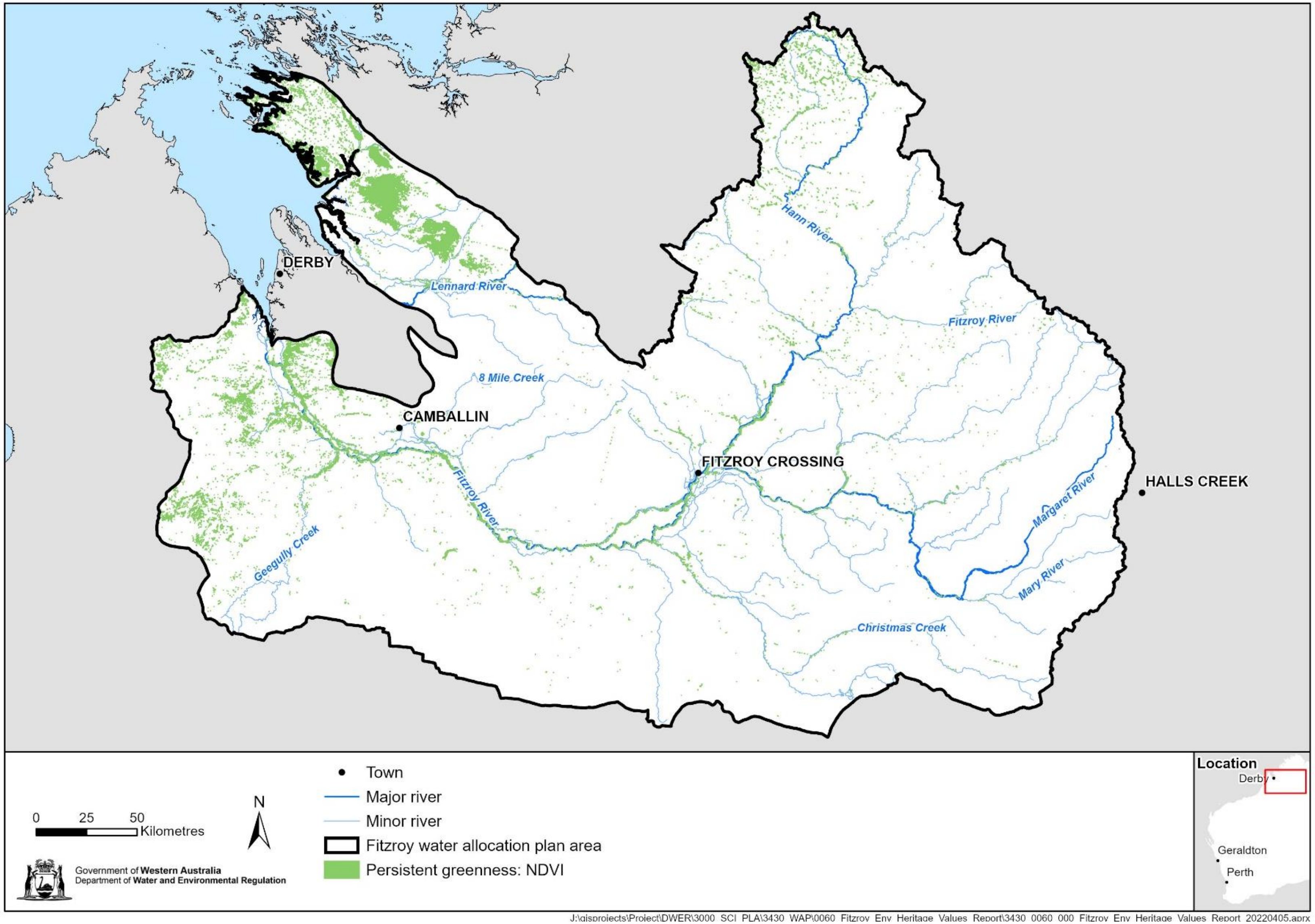


Figure 25 Distribution of persistent vegetation across the Fitzroy planning area

The mapping showed persistent green vegetation along the riparian zone of the main channel of the middle and lower reaches of the Fitzroy River and major tributaries. This persistence indicates that riparian vegetation is potentially accessing groundwater from the Fitzroy alluvial aquifer during the dry season (Figure 25).

Fox et al. (2001) mapped vegetation units associated with riparian and floodplain areas at a scale of 1:1,000,000. Detailed vegetation types cannot be shown at this scale of mapping; however, the displayed vegetation units are likely to need permanent access to either surface or groundwater and occasional inundation (Figure 26). They include:

- C7: *Eucalyptus camaldulensis* (River red gum) and/or *Eucalyptus microtheca* (Coolibah) or *Eucalyptus coolabah* (Coolibah) or *Eucalyptus gymnoteles (*Coolibah) woodland on channels and levees.
- C10: *E. microtheca* (coolibah) or *Eucalyptus gymnoteles* (Coolibah) and/or *Eucalyptus* spp. +/- *Excoecaria parvifolia* (Gutta percha) grassy low woodland.
- C18: *Dichanthium fecundum* (curly bluegrass) and *Chrysopogon fallax* (golden beard grass) tussock grassland sparsely wooded with low trees.
- C20: Swamps, lakes and lagoons, frequently ephemeral, +/- fringing woodlands, shrublands, herblands and sedgelands

Researchers from UWA/NESP surveyed vegetation at 58 sites made up of up to 15 replicates of four different hydro-ecological habitats – riverbank, top of riverbank, floodplain and off-channel (Canham et al. 2021a). They identified 26 woody riparian plant species and 71 understorey species (Freestone et al. 2020).

The overall aim of this work was to develop a predictive joint species distribution model (JDSM) to show the relationship between hydrological habitats and riparian and floodplain species. The model identified that the duration of inundation was the key driver of woody plant species occurrence in the Fitzroy River catchment, predicting distribution better than rainfall, temperature, fire history or soil clay content (Canham et al. 2021a). The model was used to determine the probability of occurrence and the expected spatial distribution of the 26 woody species.

This work also characterised the species composition and structure of riparian and floodplain vegetation (Freestone et al 2022). It showed that riverbank (riparian) and floodplain habitats were the most dissimilar across the four habitat types.

A UWA/NESP A soil seedbank study investigated the link between water availability and the occurrence of herbaceous species across the Fitzroy (Brauhart 2021). Samples from 15 floodplain wetlands were germinated in a glasshouse under different inundation treatments. The study found floodplain wetlands support a diverse mix of herbaceous ephemeral species, and that composition is generally unique to each wetland (Brauhart 2021). The region likely has hundreds of unique wetland soil seedbanks.

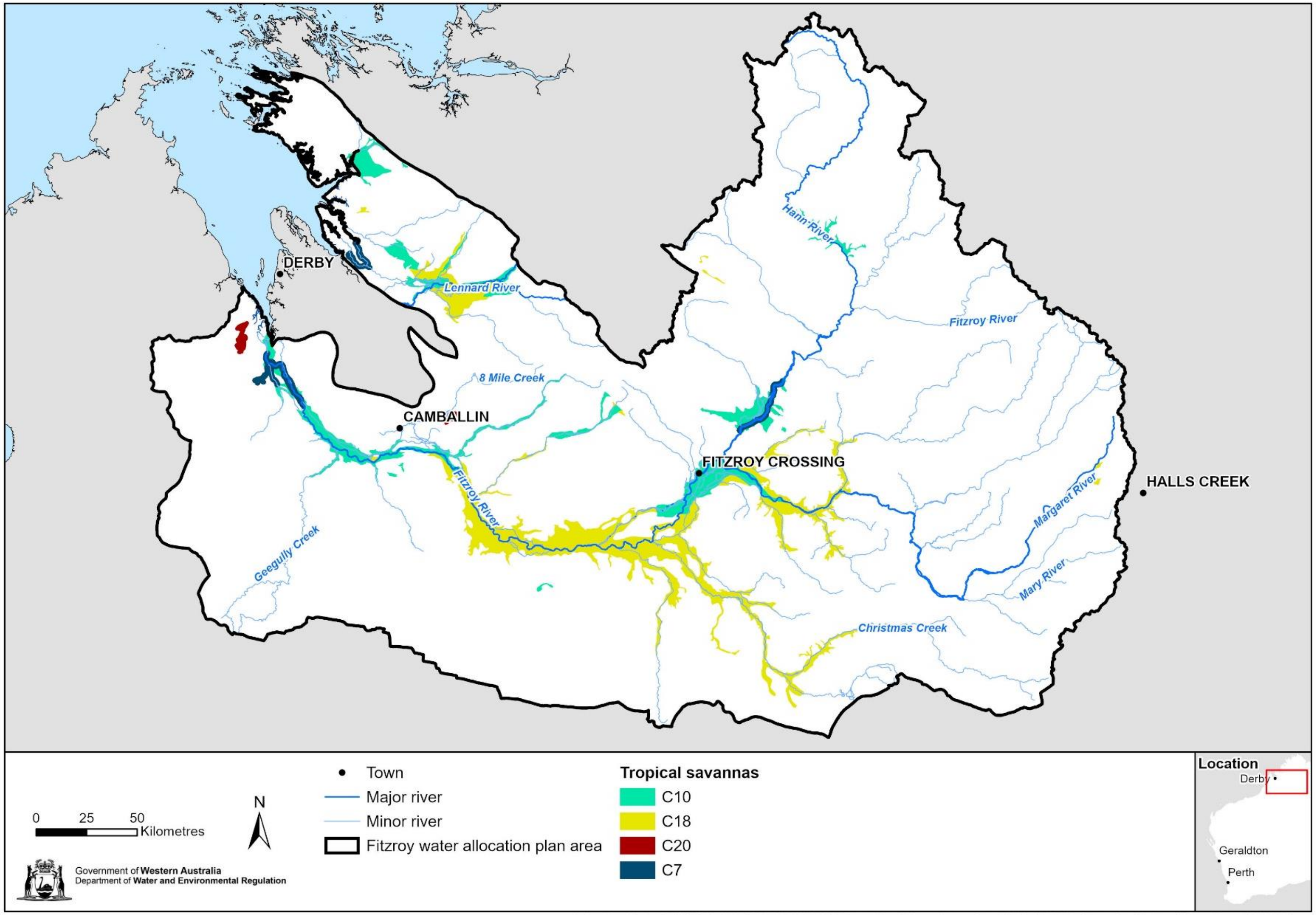


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Figure 26 Potential groundwater-dependent vegetation units

The UWA/NESP functional traits study (Canham et al. 2022) assessed key aspects of the physiology of plants and their relationship with the water regime of the Fitzroy River catchment. Pre-dawn shoot water potential, leaf mass, leaf carbon content and xylem vessel diameter were among the aspects examined.

Most species closest to the river had trait values that reflected a high degree of water availability and high levels of flooding disturbance (Canham et al. 2022). In contrast, species that occurred on higher ground and further from the river had trait values reflective of fewer flooding impacts and much drier conditions.

This study shows that individual tree species are physiologically adapted to a given water regime (Canham et al. 2022). Changes in surface water or groundwater availability may negatively affect those species closest to the river, while benefiting those further up-gradient.

Riparian vegetation

Riparian vegetation fringes the Fitzroy River's main channel and larger tributaries. Healthy riparian vegetation is important to river health and provides relatively productive ecosystems in an arid environment (Douglas et al. 2005). Riparian ecosystems in arid environments also provide important habitat for terrestrial fauna (van Dam et al. 2005).

The narrow riparian zones of the lower Fitzroy are formed by riverbank and top of bank habitats (Freestone et al. 2020). While riverbanks are steep, the top of bank habitats are relatively flat. Four tree species generally dominate these habitats, specifically *Melaleuca argentea* (Silver-leafed Melaleuca), *Barringtonia acutangula* (Freshwater mangrove), *Melaleuca leucadendra* (Green-leafed Melaleuca) and *Eucalyptus camaldulensis* (River red gum).

Recruitment and growth

The reproduction, dispersal of propagules and age structure of riparian vegetation depends on the natural flow regime (Pettit et al. 2001). Seed fall needs to coincide with suitable flow conditions; for example, as floodwaters are receding and exposing fresh moist soils.

In the Kimberley, many eucalypt species have short reproductive cycles – flowering at the end of the dry season and releasing seed at the end of the wet (Pollino et al. 2018a). Overbank flows are important for the distribution of seed and to replenish localised soil moisture content and the broader alluvial aquifers.

Seedling establishment and continued growth may depend on floodwater or rainfall stored in the soils or shallow groundwater, whichever source is easiest for vegetation to access (Bunn et al. 2006; Canham et al. 2021a).

The UWA/NESP vegetation species distribution study (Freestone et al. 2020; Canham et al. 2021a) found few seedlings and a high proportion of bare ground on the riverbanks of the lower Fitzroy, suggesting high flows may be too frequent, deep and fast to allow seedling establishment there.

The impact of frequent high-velocity flows is seen in the fact that some of the largest trees on the lower Fitzroy occur in riverbank habitats. These trees have deep roots and very large trunks (which allow them to withstand high-velocity flows), with the average area of woody trunk (stand area) more than 2.5 times greater than other habitats (Freestone et al. 2020). Trees in the riverbank habitat were also slightly healthier than those in other habitat types and provided greater canopy cover.

Top-of-bank habitats had a larger proportion of large seedlings and saplings, indicating this habitat is important for the recruitment of tree species (Freestone et al. 2020). Although the trees in these habitats were much taller than on the riverbanks, their basal areas were up to five times smaller.

Species distribution

UWA's species distribution research found that *Barringtonia acutangula* (Freshwater mangrove), *Melaleuca argentea* (Silver-leafed melaleuca) and *M. leucadendra* (Green-leafed melaleuca) were strongly associated with riverbank sites (Freestone et al. 2020; Canham et al. 2021a) (Figure 27). On the Fitzroy's main channel all three species can potentially be inundated to a depth of 3.5 m for up to 1.5 months of the year and are physiologically adapted to long periods of inundation and high-velocity flows (Freestone et al. 2020).

Tree species richness was greatest in top-of-bank sites (20 species). The most common was *Atalaya hemiglauca* (Whitewood) with *Eucalyptus camaldulensis* (River red gum) dominating canopy cover and stand area (Freestone et al. 2020; Canham et al. 2021a) (Figure 27).

These species are adapted to less inundation disturbance than riverbank species – up to 1 m for one month of the year – and probably rely on groundwater at the end of the dry season. Top-of-bank sites also had the highest proportion of shrubs and exotic understorey species.

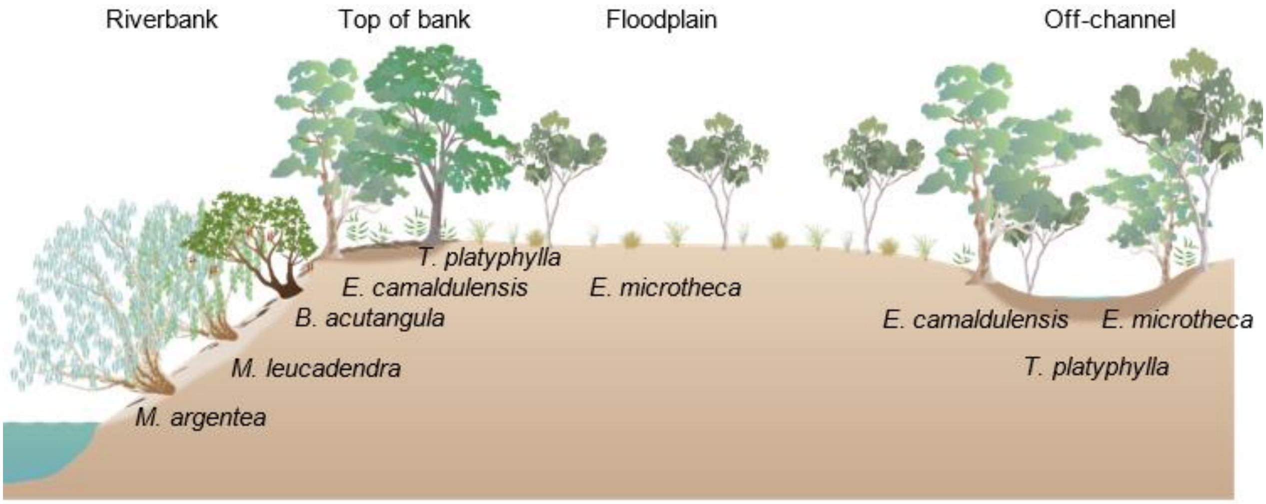


Figure 27 Distribution of key tree species across riparian, floodplain and off-channel wetland habitats (courtesy UWA/NESP)

Figure 28 shows the likely distribution (modelled occurrence) of four dominant and important tree species across the lower Fitzroy floodplain, as modelled by Canham et al (2021a).

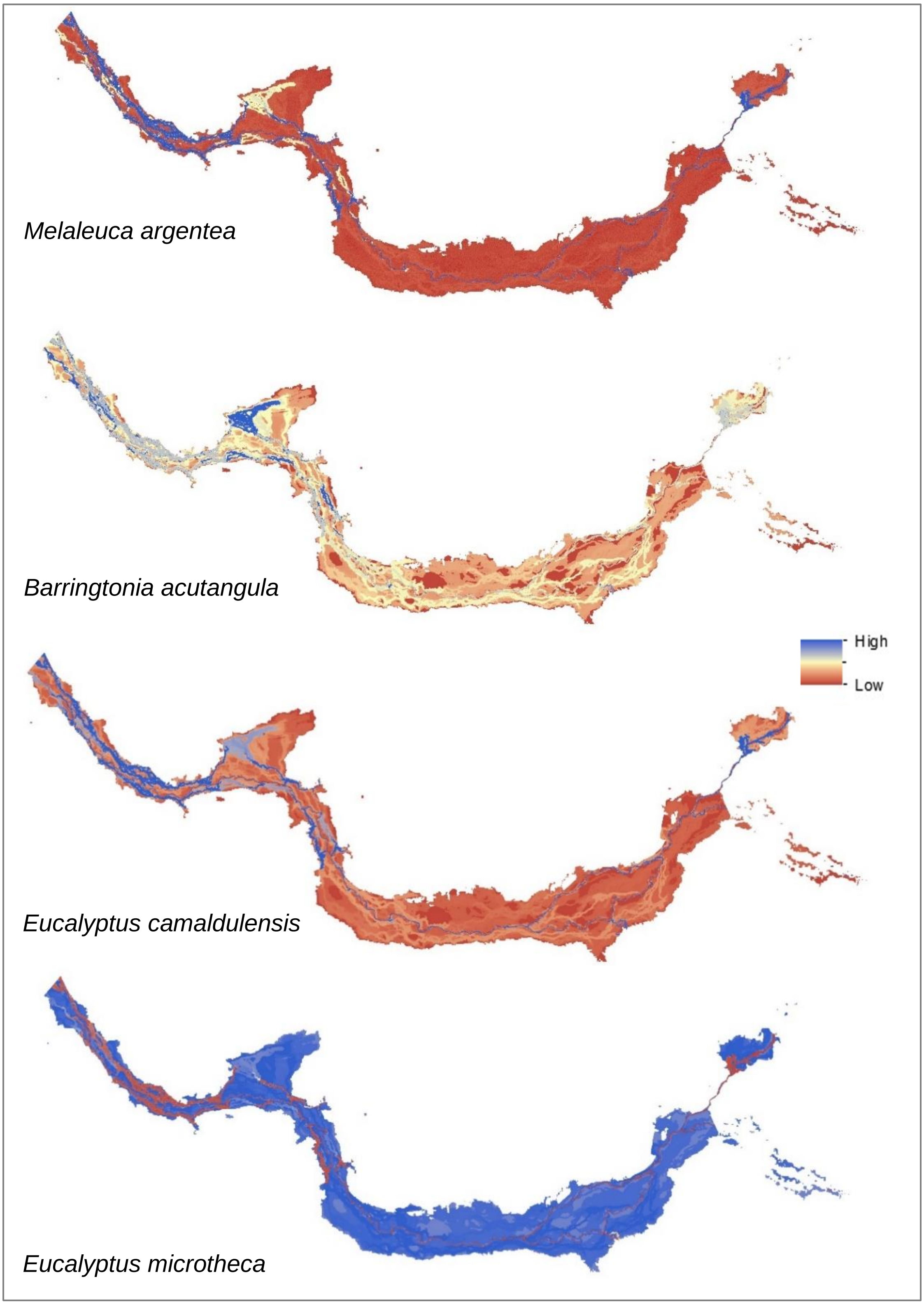


Figure 28 Probability of occurrence of four dominant Fitzroy tree species (UWA/NESP)

Water sources

UWA investigated the water sources of riparian and floodplain tree species on the lower Fitzroy. They used plant water relations – specifically leaf water potential and stomatal conductance – to determine if plants had access to sufficient water at the end of the dry season after 130+ days of no rainfall (August 2019) (Canham et al. 2021b). They then explored potential water sources by comparing the stable isotopes oxygen-18 ($\delta^{18}O$) and deuterium ($\delta^{2}H$) in groundwater, river water and soil water (shallow and deep) with plant xylem water (Canham et al. 2021b).

Two sites were investigated: Myroodah which is connected only to the alluvial aquifer; and Noonkanbah, where older regional groundwater from the Liveringa Group sandstone flows into the alluvium. The study examined riverbank, top-of-bank and floodplain habitats at each site. Researchers investigated the riparian species *Barringtonia acutangula* and *Melaleuca argentea* at both sites and *Ficus coronulata* at the Noonkanbah site only (Canham et al. 2021b).

At the Myroodah alluvial site, trees were found to use a mix of water from shallow and deep soils, groundwater (Alluvial) and river water. In contrast, at the Noonkanbah regional riverbank site, groundwater (Alluvial and Grant-Poole combined) accounted for 75 per cent of tree water use (Canham et al. 2021b).

Floodplain vegetation

The lower Fitzroy floodplain is a large, flat, open area up to 30 km wide with vegetation extending outwards from the main channel and riparian zone across the floodplain and along off-channel wetlands (Freestone et al. 2020).

Floodplain vegetation distribution strongly reflects the area inundated during flooding and the frequency of high-flow events (Pettit et al. 2001) (Figure 28). Depth to groundwater is less a driver of distribution but has a role in areas over shallow aquifers.

Off-channel wetlands include wetlands on the floodplain and flood-runner channels. These experience greater periods of inundation than the floodplain itself and provide important refuge habitat.

Recruitment and growth

Floodplain species on the lower Fitzroy, including *Eucalyptus microtheca* (Coolibah) are adapted to short periods of flooding, needing periods of inundation for seed set, distribution, germination and to replenish local soil moisture (Freestone et al. 2020; Canham et al. 2021a).

Researchers recorded fewer seedlings at floodplain sites on the lower Fitzroy and trees were shorter with smaller basal areas than in other habitats (Freestone et al. 2020). Although tree condition was good, canopy cover was the lowest of all habitats – reflecting the relatively low water availability on the floodplain.

Off-channel wetland species recruit when seeds are carried out along creeklines or across the floodplain during large flood events and deposited in the clay soils. It is likely that these wetlands are important for tree recruitment in the lower Fitzroy (Freestone et al. 2020).

UWA noted that off-channel wetlands supported greater numbers of seedlings and a higher proportion of saplings than other habitat types, with the second-largest ‘stand areas’.

Species distribution

UWA’s species distribution study found that *Eucalyptus microtheca* was the most dominant floodplain species, occurring at 82 per cent of 17 Fitzroy floodplain study sites (Freestone et al. 2020; Canham et al. 2021a). Although it has a large inundation range, modelling suggests the species is strongly associated with floodplain and off-channel creekline sites and rarely with riverbanks (Figure 28) (Canham et al. 2021a).

Understorey species richness was relatively high with Poaceae (grasses) being the most common family recorded.

Off-channel wetlands of the Fitzroy River also support woody vegetation, predominantly *Eucalyptus microtheca and E. camaldulensis* with some *Terminalia platyphylla* (Wild plum) (Freestone et al. 2020). *E. camaldulensis* germinates in large numbers when conditions are favourable and can dominate in some areas.

Understorey species richness was greatest at off-channel wetland habitats; however, the exotic grass *Cynodon dactylon* (couch) was most common. Floodplain species may also be adapted to tolerate long dry periods and to use soil moisture or groundwater if available. The UWA functional traits study (Canham et al. 2022) found that trees on the floodplain can increase water use efficiency in response to lower water availability.

Water sources

UWA’s water source study also investigated tree species of floodplain sites at Myroodah (alluvial) and Noonkanbah (regional groundwater). Species studied at the alluvial sites were *M. leucadendra, B. acutangula, Nauclea orientalis, T. platyphylla* and *E. microtheca* (Canham et al. 2021b). At the regional floodplain site, the species studied were *M. leucadendra, E. microtheca* and *Ficus coronulata*. The study found that deep soil water accounted for 39 per cent of tree water use at the Myroodah alluvial floodplain site and alluvial groundwater 25 per cent. At the Noonkanbah regional floodplain site, groundwater was dominant with 85 per cent sourced from the combined alluvial and Grant-Poole sources (Canham et al. 2021b).

Threats to vegetation

Many threats to riparian and floodplain vegetation are associated with water resource development and pastoral activities, as well as broader phenomena such as climate change.

Surface water abstraction or diversion could reduce flows required for seed set, distribution and germination. Reduced flows could also lead to less recharge of alluvial aquifers and lower soil-moisture availability for phreatophytic species.

Groundwater abstraction could directly reduce the water available in alluvial and regional aquifers for both riparian and floodplain species.

Dams or other irrigation structures, road crossings and raised roadways could also alter surface water flows with the same consequences described above.

Changes in land use, including the intensification of irrigated agriculture, could lead to direct loss of vegetation through clearing, as well as degradation associated with increased cattle grazing. Increased nutrient and/or pesticide runoff into the river could also negatively affect vegetation health.

Climate change may result in greater rainfall variation and higher temperatures, in turn reducing surface flows, groundwater recharge and soil-moisture availability. It is also probable that the frequency and intensity of fires will increase. With more fires, declining water availability and clearing, invasive flora species – especially agricultural weeds – can out-complete and replace native plant species. Sea-level rise may also lead to salt water moving further up the main channel, affecting water quality in pools and the alluvial aquifer.

Threats may also interact or compound. For example, water resource development may exacerbate drying of river pools, which may increase fire penetration into these ecosystems and/or the frequency and intensity of fires, which would likely have substantial impacts. This may include invasion of weedy grasses and plant disease.

Summary

Parts of the water regime most important to riparian and/or floodplain vegetation are:

- groundwater
  - alluvial groundwater available to dependent riparian and floodplain species (Canham et al. 2021a; Canham et al. 2021b)
  - regional groundwater available to dependent riparian and floodplain species (Canham et al. 2021b)
- annual wet season flows
  - in-channel flows to support riparian species on the riverbank (Canham et al. 2021b; Freestone et al. 2021)
  - overbank flows to support riparian and floodplain species on the top-of-bank and floodplain species on floodplain and off-channel wetlands (Canham et al. 2021a; Canham et al. 2002)
  - replenish local soil moisture (Canham et al. 2021b)
  - recharge alluvial and regional aquifers (DWER 2023b)
- occasional very high-volume wet seasons
  - inundate floodplain vegetation for seed set, distribution and germination (Pettit et al. 2001)
  - recharge alluvial and regional aquifers (DWER 2023b).

8.4 Springs

Available mapping has identified more than 400 springs in the Fitzroy planning area (Figure 14). However, it is likely that many more are unmapped, including those occurring along the shoreline of King Sound. Several springs, including Pillara and Udialla springs, are located on the Fitzroy River floodplain. Others, such as the Big Springs complex and the Oodinjil, Lupar and Ngooderoodyne springs, are located north of the May and Meda rivers near the coast, while the North Kimberley mound springs complex is found at the top of the catchment (Figure 14). Still other springs are thought to have formed where artesian bores have broken or are uncapped.

Groundwater input into the springs of the Fitzroy is neither well studied nor understood. Yet the nature of springs is that they are groundwater fed (CSIRO 2009). UWA research supports this – recently finding evidence that nutrients from groundwater sustain fauna living in the springs (L. Beesley, pers comm. April 2022).

The Queensland Government has described numerous mechanisms supporting different types of springs in the Great Artesian Basin (DNRME 2006). It is likely that some of these (e.g. contact, fault and erosion mechanisms) support springs in the Fitzroy planning area.

Springs can be present where faults form preferential pathways for groundwater to flow from deeper aquifers to the surface. These springs may occur in the Grant-Poole aquifer across anticlinal features where faults facilitate groundwater flow to the surface (i.e. around Noonkanbah). The North Kimberley Mound springs, which may be fault springs in the fractured rock aquifer, occur in the north of the catchment where high pressures in interconnected fractures may force the upward movement of groundwater. There are also known faults at this location which could be facilitating groundwater movement to the surface, through any overlying alluvial sediments. However, a number of the springs are in the alluvial aquifer and it is possible the springs are forming where the landscape intersects the water table.

Contact Springs form where a higher permeability layer is in contact with a lower permeability layer (DWER 2023c). Under these conditions groundwater flow across the boundary can be restricted, forcing water to the surface (DNRME 2016). These springs are often present along geological boundaries. The Big Springs TEC Complex is located on and around the boundary of the coastal salt flats where the Grant-Poole aquifer is near the surface. It may be a contact spring where the Poole Formation (higher permeability) meets the Grant Group (lower permeability). It could also be where the landscape intersects the groundwater table.

Springs can also form where the landscape and the watertable intersect. This can happen through a several mechanisms including erosion from surface water flows, wind erosion and in natural depression such interdunal depressions. These springs are common in the Fitzroy plan area. Lindsay and Commander (2005) described groundwater discharge from the Wallal aquifer to the Fitzroy River around Willare. Another series of springs at the foot of the Devonian Reef complex may also have formed where the landscape and watertable intersect. Springs over the Alluvial aquifer on the Fitzroy River floodplain and in the riverbed itself where there has been erosion from surface water flows.

Threats to springs

Numerous threats to springs are associated with water resource development and pastoral activities, as well as broader phenomena such as climate change.

Groundwater abstraction could reduce water levels or pressure in aquifers that support springs. Direct take of surface water from springs and/or irrigation infrastructure would reduce habitat area and quality.

Cattle frequently use springs as drinking locations, and their pugging destroys macrophytes and increases water turbidity. Pigs have been observed living in springs in the Fitzroy River catchment, also causing serious damage (L. Beesley, pers. comm. April 2022).

Climate change may lead to more frequent and intense fires and degradation and/or loss of habitat. Too-frequent fires and grazing or clearing impacts may also lead to invasive flora and fauna species competing with and replacing native species.

Threats may also interact or compound. For example, water resource development may exacerbate drying of springs, which may increase fire penetration into these ecosystems and/or the frequency and intensity of fires, which would likely have substantial implications for springs. This may include invasion of weedy grasses and plant disease.

Summary

The parts of the water regime most important to springs are:

- groundwater:
  - water level and pressure heads in all aquifers likely to support different types of springs (DNRME 2016; DWER 2023b)
  - input into springs supports aquatic life and contributes to the food web.
- annual wet season flows recharge alluvial and regional aquifers (DWER 2023b).

8.5 Aquifers and subterranean habitats

Subterranean fauna that spend their entire lives below the earth's surface belong to two groups:

- stygofauna – aquatic and living in groundwater
- troglofauna – air breathing and living in voids and caves above the watertable; depend on humid conditions caused by proximity to groundwater (Tomlinson & Boulton 2010).

Investigations of stygofauna in the Fitzroy planning area and the broader Kimberley region are limited and further work is likely to reveal many new species (Pusey &

Kath 2015). Many of these will be short-range endemic species or restricted to particular aquifers. Sampling to date shows a diversity of such fauna (Low Ecological Services 2020). This includes nine species identified from the Ellendale diamond mine within the Fitzroy planning area, 18 species from the proposed Browse LNG development on the Dampier Peninsula, and 15 species from the Argyle diamond mine (Low Ecological Services 2020).

Only very few records of troglofauna surveys exist for the Kimberley. However, the WA Museum does list records from some cave complexes, including caves in the Oscar Ranges and Napier Range (Low Ecological Services 2020).

The occurrence of stygofauna is influenced by abiotic habitat characteristics including hydrological connectivity, salinity, dissolved oxygen levels and geology (Gibson 2018). Yet there is limited knowledge of their micro-habitat requirements, such as the size, degree and distribution of interconnected void spaces within geological formations, which determine the transmissivity of an aquifer (Gibson 2018). There is also a poor understanding of the fine-scale variation in suitable habitat over spatial and vertical scales, and the degree of habitat connectivity is difficult to determine linked to geology, hydrology and the presence of suitable habitat (Gibson 2018). Stygofauna are known to occur in several different geological units, including unconsolidated, fractured rock, karstic and calcrete (Tomlinson & Boulton 2010; Adam et al. 2015; Gibson 2018).

Unconsolidated geologies of differing ages occur across the Fitzroy planning area and are likely to contain different types of stygofauna. Karstic areas are restricted to the Napier and Oscar ranges and the Geike Gorge area of the Wunaamin Miliwundi Ranges (formerly King Leopold Ranges) (Pusey & Kath 2015). Calcretes are known from the south-east part of the catchment.

In groundwater, oxygen and nutrients generally decrease with depth. As a result, stygofauna are often most abundant and diverse just below the watertable. Richness and abundance then generally decrease with distance below the watertable (Korbel et al. 2019). They are generally most abundant and diverse within 30 m of the surface and are not found beyond depths of 100 m, nor where the oxygen concentration is <0.3 mg/L. Grain and pore size are also a good indication of occurrence (Korbel et al. 2019), with most stygofauna found where pore size is greater than 1 mm.

The department’s hydrogeologists have reviewed the known properties of aquifers in the Fitzroy planning area. They identified the following formations (see also Figure 29) as potentially hosting stygofauna:

- Erskine Sandstone – zones of large pore space (e.g. gravels)
- Devonian Reef – a karstic system that has discrete cave systems that may contain endemic species
- Grant Group and Poole Sandstone
- shallow unconfined Broome and Wallal Sandstones

- alluvials of the Fitzroy and other waterways, where permanently saturated.

They noted the following formations did not meet the criteria for hosting stygofauna or otherwise needed further assessment (Figure 29):

- Noonkanbah Formation – local aquifers only, not suitable
- Liveringa Group – need to understand which sandy units are outcropping – further assessment required
- Blina Shale – not suitable
- Millyit Sandstone – further assessment required
- Barbwire Sandstone – further assessment required
- Wallal Sandstone – might be suitable if not too deep
- Alexander Formation – might be suitable, silty
- Jarlemai Siltstone – not suitable
- Broome and Mowla Sandstones – further assessment required
- Meligo Sandstone – not suitable, silicified.

Threats to aquifer and subterranean habitat

Many threats to aquifer and subterranean habitats are associated with water resource development and pastoral activities, as well as broader phenomena such as climate change. Groundwater abstraction and climate-change-induced lower rainfall could reduce water levels or pressure in aquifers, which could reduce available habitat. Changes in land use, including the intensification of irrigated agriculture and increased stock numbers, could lead to reduced groundwater quality.

Summary

The part of the water regime most important to aquifer and subterranean habitats is:

- groundwater
  - water levels or pressure in suitable shallow alluvial or regional aquifers
  - water quality in suitable shallow alluvial or regional aquifers.

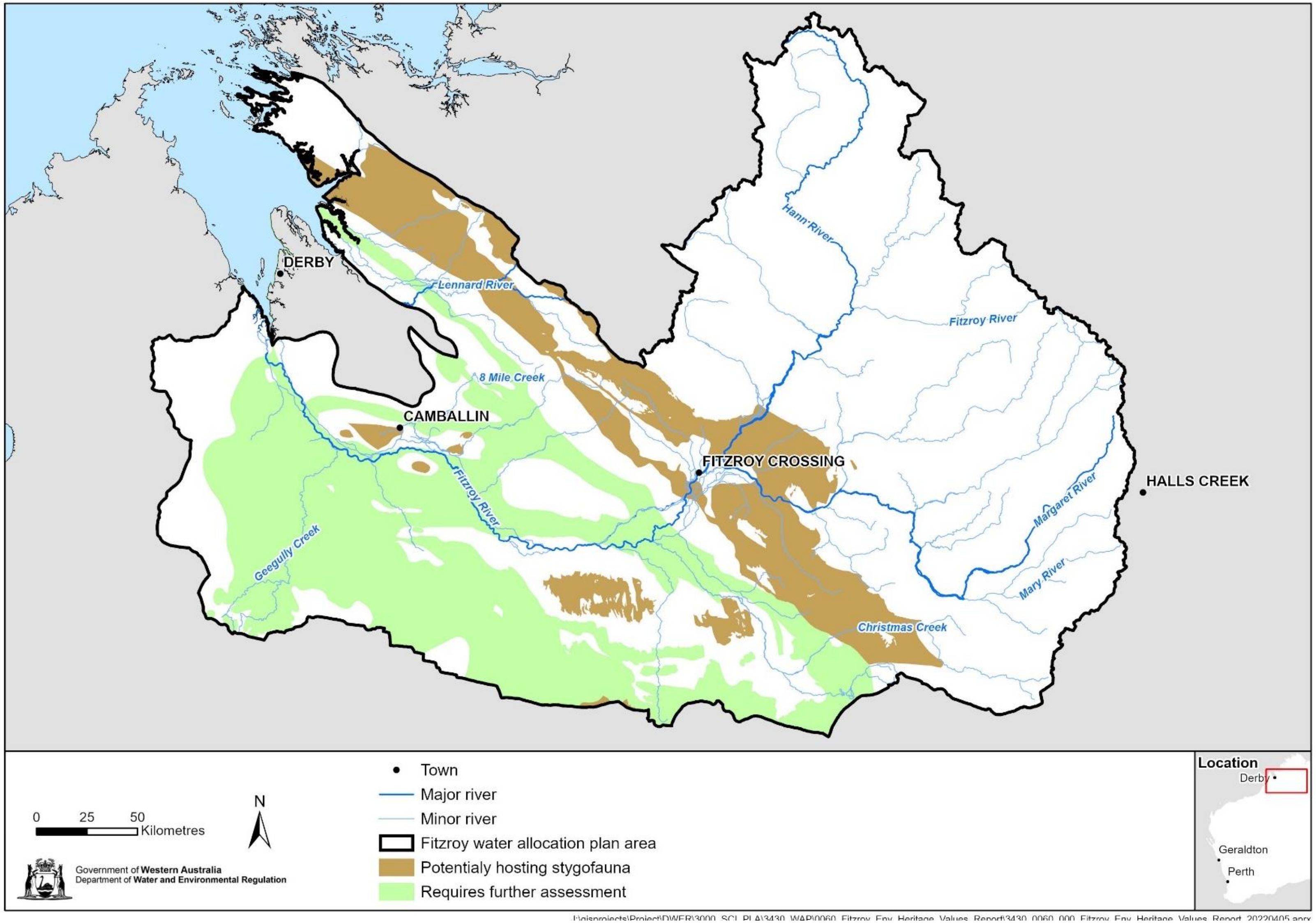


Figure 29 Potential stygofauna habitat in the Fitzroy planning area

8.6 Estuarine and near-shore marine habitats

Fresh water from the Fitzroy, May, Meda (Lennard) and Robinson rivers flows into King Sound, bringing carbon and nutrients for numerous estuarine and near-shore marine ecosystems such as seagrass meadows, mangroves, coral beds and saltflats.

Research on Gulf of Carpenteria rivers – the Mitchell, Flinders and Gilbert – found primary productivity rates increased in the estuaries of all three rivers in response to nutrient inputs, both in the dry and wet seasons (Burford et al. 2021). But it was nutrients delivered during the wet season that were critical to stimulating primary production in chronically nutrient-deficient mudflats (Burford at al. 2021). Although the concentration of nutrients did not vary between wet seasons of different magnitude, the volume of nutrients was higher in medium to large wets due to larger discharges (Burford et al. 2021).

Flows of varying size throughout the year (e.g. first flush and in-channel flows) that connect the river to King Sound are also important for spawning and recruitment of fish and other fauna with estuarine life phases, including sawfish species and Barramundi. These flows also flush nutrients and chlorophyll *a* into the estuary and King Sound. Smaller, recessional flows at the end of the wet season also support the movement of some species, including Cherabin.

Groundwater flow into King Sound is not well understood. However, inputs from the Wallal, Broome and Grant-Poole aquifers are possible where they intersect or underlie the coast.

Seagrass beds are mapped in the northern reaches of King Sound, with mangrove and saltflat ecosystems fringing much of the broader sound (Figure 15). These ecosystems are important habitat and/or provide food for various fauna including Snubfin dolphins, turtles and migratory shorebirds.

Seagrass

Existing mapping shows seagrasses around the outer area of King Sound, in Cascade, Cone and Strickland bays (Figure 15). They are also known to occur around One Arm Point on the northern tip of the Dampier Peninsula – an area studied by the Western Australian Marine Science Institute (WAMSI) – and in Goondenough Bay and off Valentine Island on the peninsula’s eastern side (Bayliss & Hutton 2017).

It is likely that seagrass meadows in the high energy, highly turbid environment of King Sound are transitory and made up of opportunistic or colonising species (McMahon et al. 2017). Unlike other permanent meadows they are not necessarily reliant on, or driven by annual river flow cycles and can respond to changes in flow that are short term (months) or longer (years) (Kilminster et al. 2015).

The loss of seagrass habitat is often linked to nutrient and organic loading. Blooms of phytoplankton and excessive growth of macroalgae are both symptoms of eutrophication and reduce the light available for seagrass growth. In extreme cases seagrass loss occurs due to shading effects (Kilminster & Forbes 2014).

The importance of fresh groundwater inputs providing nutrients to seagrass is generally accepted (Green & Short 2003). A groundwater investigation in the La Grange area is using geochemical tracers to identify hot spots of groundwater input into the near-shore marine environment (Antao et al. 2020). If groundwater is found to be discharging near seagrass beds in the area, it is likely that groundwater inputs are also important to seagrasses in King Sound.

Mangroves

Mangroves act as a buffer between land and sea and have an important role in nutrient and carbon recycling, foodwebs and stabilisation of coastal foreshores, while providing habitat both below and above ground level (Gibson 2014; Pollino et al. 2018a). There is increasing evidence that freshwater inputs – such as rain, river flow and/or groundwater – support above-ground growth in mangroves and that they use this in preference to saline water (Hayes et al. 2018).

Existing mapping shows that the estuary and King Sound support a thin band of mangroves around their margins (Figure 15) covering a total area of about 165 km^2 (Wolanski & Spagnol 2003; Semenuik & Brocx 2011). Mangrove communities have also been recorded on Long Island in the sound (Gibson 2014).

Eleven mangrove species are recorded in the sound. Of these *Avicennia* dominates the seaward zone, *Rhizophora* the middle zone and *Ceriops* the landward zone (MScience 2011).

Acrostichum aureum, a priority 1-listed perennial fern, has been recorded in an area of mangroves north of Doctors Creek.

Saltflats

Saltflats border the Fitzroy River estuary and parts of King Sound (Figure 15). Saltflats are generally too high in the landscape to be influenced by daily tidal movements and remain dry most of the year (Pollino et al. 2018a). When flood events or rainfall inundate saltflats during the wet season, the algal crusts that cover them begin to photosynthesise and produce carbon. This process supports food webs crucial to fish, including Barramundi and other species, which use the flooded areas as nursery and habitat (Pollino et al. 2018a).

The margins of King Sound saltflats support samphire species which often form dense communities (MScience 2011). Near the Derby Jetty, samphire species include *Tecticornia halocnemoides* subsp. *halocnemoides*, *T. indica*, *Sesuvium portulacastrum*, *Suaeda arbusculoides* and *Trianthema turgidifolia*. The salt-tolerant grass *Sporobolus virginicus* is also common (MScience 2011). Other samphire species likely to occur include *T. halocnemoides*, *T. indica* subsp. *leiostachya*, *Batis argillicola*, *Hemichroa diandra*, *S. australis* and *Threlkeldia diffusa* (MScience 2011).

Chlorophyll a

Although little is known about the importance of river inputs into King Sound, good data is available on chlorophyll *a* concentrations across the sound. Chlorophyll *a* is used by phytoplankton to convert solar energy into organic matter and largely drives the high productivity of the estuarine and marine waters (Figure 31). Phytoplankton in turn is consumed by higher-order fauna including fish and ultimately whales and dolphins.

Long-term observations after higher-flow events suggest sediments and other materials from the Fitzroy River move along the western side of King Sound to the mouth, where they are caught in the southern current and carried down the western side of the Dampier Peninsula as far south as Willie Creek (J. Fowler pers. comm. September 2019).

These observations are supported by a research program in which tracers, added to modelling of discharge into King Sound, suggested the Fitzroy River's influence during high-flow years extends as far as Roebuck Bay in the south and Collier Bay in the north (Hipsey et al. 2017).

It is thought that flows from the Fitzroy River are critical to the transfer of nutrients from the floodplain and the river into the estuary and King Sound, promoting chlorophyll *a* production. It is likely that concentrations decrease with distance from the river mouth as fresh water mixes with marine water (Figure 1,Figure 30).

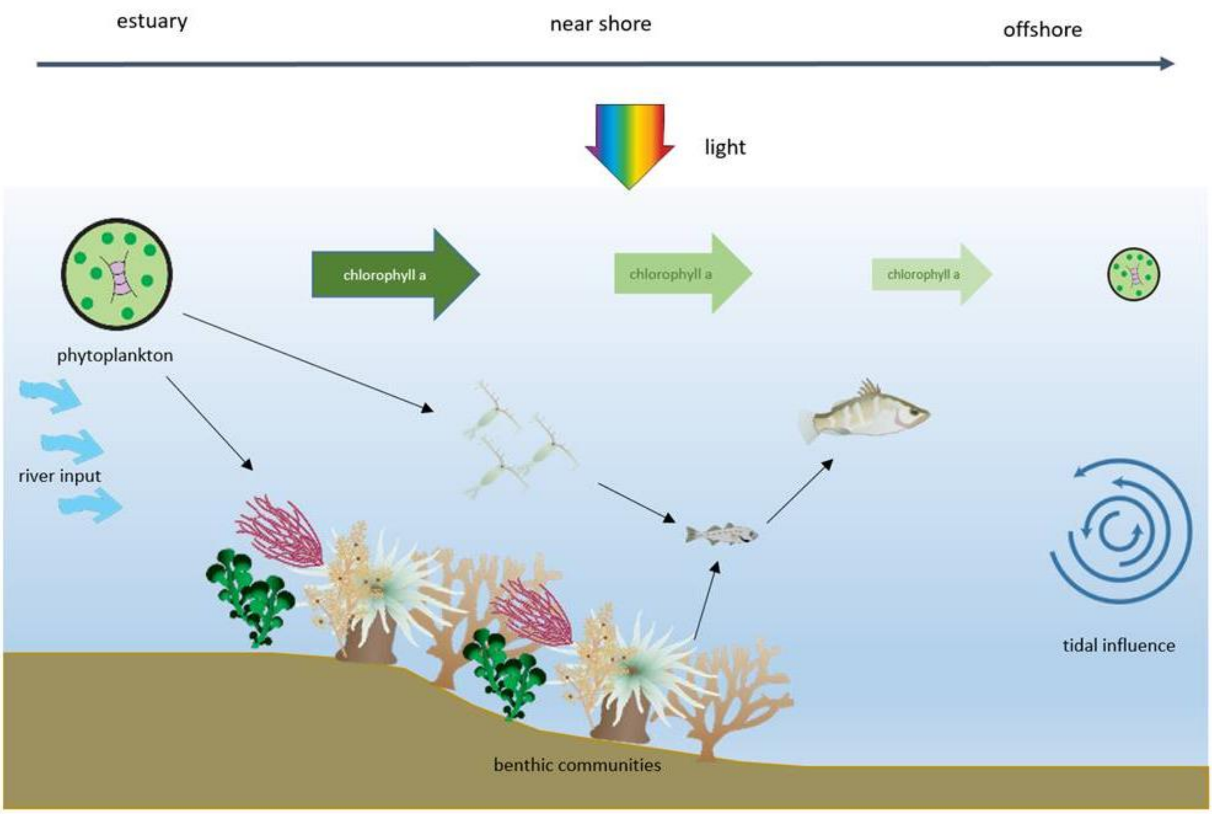


Figure 30 Role of chlorophyll a and its movement from the river to the estuary and near-shore marine habitats in King Sound

Threats to estuarine and near-shore marine habitat

Many threats to estuarine and near-shore marine habitats are associated with water resource development and pastoral activities, as well as broader phenomena such as climate change.

Surface water abstraction or diversion could lessen connectivity between the Fitzroy's main channel through the estuary and into King Sound. This could reduce freshwater inputs available to seagrass, mangrove and salt flat habitats. It could also negatively affect the recruitment and migration of species with a marine life phase, including Freshwater sawfish, Barramundi and Cherabin.

Groundwater abstraction could impact on freshwater discharge into near-shore mangrove and seagrass habitats.

Changes in land use, including intensification of irrigated agriculture, could lead to increased nutrient, sediment and/or pesticide runoff into the estuary and King Sound.

Sea-level rise may affect estuarine ecosystems in the mouths of the Fitzroy and other rivers in the King Sound by shifting the estuarine shoreline, altering the tidal range and inundating lowland coastal areas, potentially salinising wetlands and river reaches that were previously freshwater-dominated.

Summary

Parts of the water regime most important to estuarine and near-shore marine habitats are:

- groundwater
  - inputs to the estuary and King Sound to support mangrove (Hayes et al. 2018) and seagrass (Green & Short 2003) communities
- annual wet season flows
  - first-flush, in-channel and recessional flows to support various spawning and recruitment requirements for fish and other fauna with estuarine life phases (Lear et al. 2019; Morrongeillo et al. 2020; Lear et al. 2021; Morgan et al. 2021)
  - freshwater flows in-channel to connect the river and estuary and support nutrient inputs into King Sound (Pollino et al. 2018a)
  - freshwater inputs into the estuary and King Sound to support mangrove communities (Hayes et al. 2018)
- occasional high-volume wet seasons
  - scour sediment from channel and estuary (Pollino et al. 2018a)
  - support nutrient and carbon inputs into King Sound (Hipsey et al. 2017)
  - inundate saltflats (Pollino et al. 2018a).

9 Important species

In this section we provide background on important water-dependent fauna and flora species in the Fitzroy River catchment and highlight their value to Aboriginal people. Using the four main parts of the water regime as previously described by UWA researchers (Douglas et al. 2019), we then identify which components (surface or groundwater) support dependent fauna and flora. Finally, we describe threats to each species, both water and development related. Where available, we focus on the results of recent investigations specific to the Fitzroy's ecosystems.

9.1 The importance of plants and fish to the Indigenous harvest

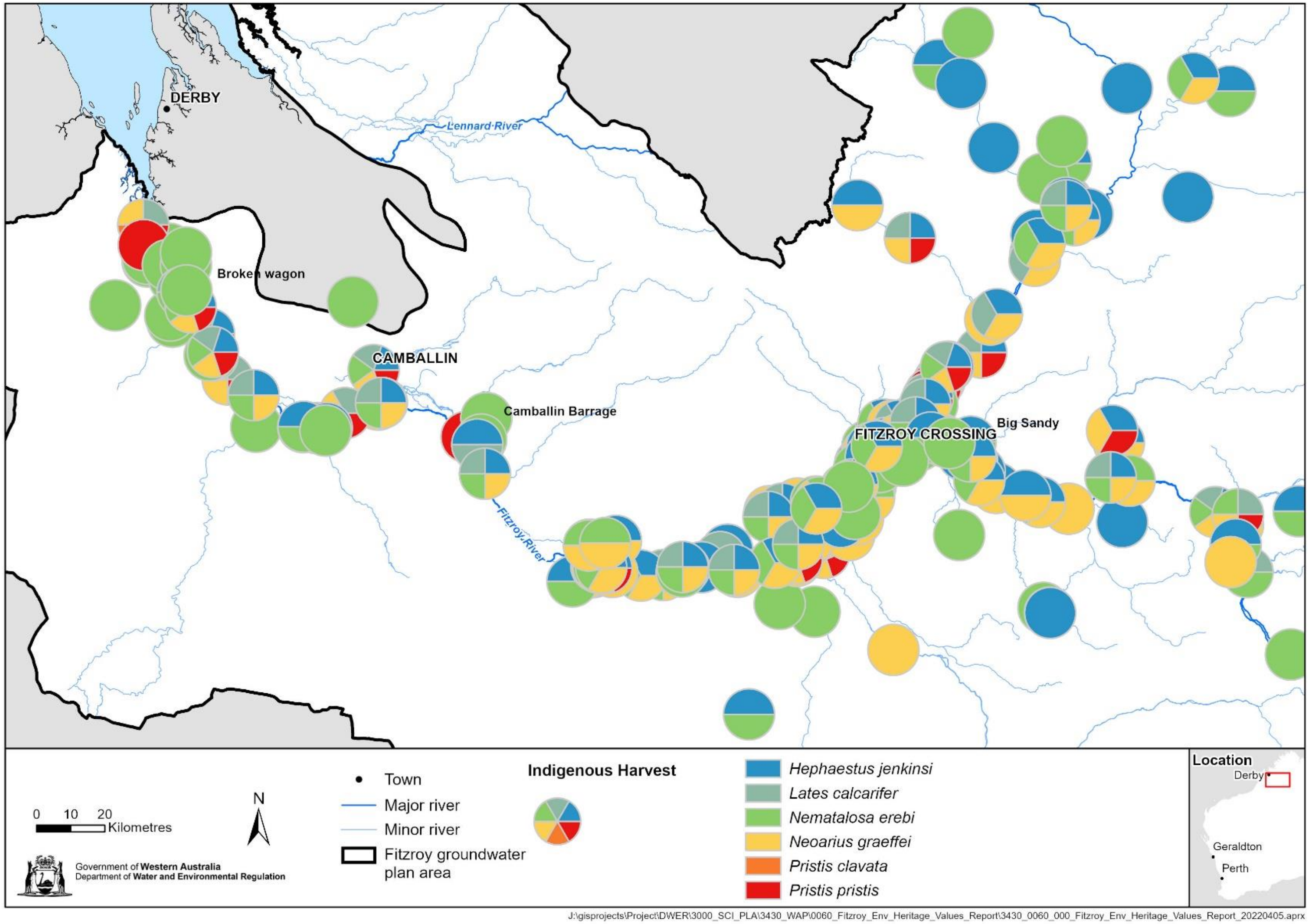
The cultural values of Traditional Owners extend to use of the river and its ecosystems for the Indigenous harvest – food and medicine and their preparation. Fish and other freshwater species are a key component of the diet of Aboriginal people in the Kimberley region – supplementing and, in many cases, replacing food that would otherwise be purchased (Jackson et al. 2011).

In addition to being an important food source, the act of fishing, cooking and sharing fish with family is also a central part of 'jaminyjarti', a ritual that emerges during 'sorry business' after the death of a loved one (Toussaint 2014).

Barramundi (*Lates calcarifer)*, Freshwater sawfish (*Pristis pristis*) and Fork-tailed catfish (*Neoarius graeffei*) and are among the most important species to the Indigenous harvest in the Fitzroy River catchment (Jackson et al. 2011; Douglas et al. 2019). Other important food species include smaller fish such as black bream (*Hephaestus jenkinsi*). Figure 31 shows the recorded distributions of these and other key harvest species.

Small-bodied species including Bony bream (*Nematolosa erebi*) and Spangled perch (*Leiopotherapon unicolor*) are used as bait (Jackson et al. 2011; Jackson 2015) and are crucial prey species for larger fish. Bony bream represents about 30 per cent of the total catch on the Fitzroy River catchment. These smaller species are found both in river pools and off-channel wetlands (Beesley et al. 2020; Lear et al. 2020).

Cherabin (*Macrobrachium spinipes*) and the Long-necked turtle (*Chelodina rugosa*) also make up a major component of the Indigenous harvest, with the Northern burrowing frog (*Neobatrachus aquilonius*) used as bait (Jackson et al. 2011).



Note: pie shapes are used to represent presence of species and not proportions of harvest

Figure 31 Recorded distributions of key Indigenous harvest fish species

Vegetation such as the waterlily (*Nymphaea* sp*.)* and fig tree (*Ficus coronulata* and *F. racemosa*), as well as the fruits and berries of *Bridelia tomentosa,* are also important for the Indigenous harvest. The bark of *Melaleuca leucadendra* is used to wrap fish before it is placed in a campfire (Milgin et al. 2020) and leaves of the river red gum (*Eucalyptus camaldulensis)* can add flavour to fish and meat (Toussaint et al. 2001).

Leichhardt pine (*Nauclea orientalis*) grows along the river and has many uses. Its soft wood is used to build rafts and to carve wommeras and other artefacts. When ripe the orange fruits fall to the ground and are good to eat (Gooniyandi Aboriginal Corporation and Kimberley Land Council 2015).

The flowering of various tree and shrub species along the river can also tell people when certain foods are available. For example, when paperbarks (*Melaleuca argentea* and *M. leucadendra*) flower, it is a sign to collect honey from their bark and freshwater mussels from the river (Nugget et al. 2011).

Other vegetation species have medicinal benefits. Emu-bush (*Eremophila* sp.) bark is used to treat ringworm and sores, snake vine (*Tinospora smilacina*) is bound around the head to cure headaches and arthritis, and burning branches of the Konkerberry bush (*Carissa lanceolata*) creates smoke for health and healing rituals (Toussaint et al. 2001).

Other species have cultural significance. The spread of the Freshwater mangrove (*Barringtonia acutangula)* along the river and larger creeks is an important part of the Woonyoomboo narrative of the Nyikina and Mangala people. This small tree is vital to people of the river. Its bark is used to make a poison to stun fish, which then float to the surface (Jackson & O'Leary 2006). The bark and fruits are also used to treat various ailments including coughs, colds and infections (Jackson et al. 2011).

9.2 Freshwater sawfish (*Pristis pristis)*

The Fitzroy River and its estuary provide a critical nursery for the iconic high-conservation-value Freshwater sawfish (*Pristis pristis*) (Figure 32) (Morgan et al. 2011; Pollino et al 2018b). Each of the Dwarf (*Pristis clavata*), Green (*Pristis zijsron*) and Narrow sawfish (*Anoxypristis cuspidata*) have also been recorded in the Fitzroy River estuary and King Sound (Morgan et al. 2021), but little is known about these species.

The Freshwater sawfish has been recorded along the Fitzroy River, the Margaret River and other tributaries, as well as the Lennard River (Figure 33). They have also been observed in off-channel wetlands and creeklines on the Camballin floodplain.

Figure 32 Freshwater sawfish (courtesy of David Morgan, Harry Butler Institute, Murdoch University)

Recruitment and growth

The Freshwater sawfish (*Pristis pristis*) has a marine and a freshwater phase. Pupping happens in estuaries and river mouths with females birthing up to 12 young (Morgan 2018). During most wet seasons juveniles move into the river and flood runners (Whitty et al. 2017). However, successful recruitment events – as indicated by a high number of larger juveniles caught in freshwater pools – are much less frequent (Lear et al. 2019).

The long-term monitoring program run by Murdoch University's Freshwater Fish Group recorded recruitment success in only three out of 17 years between 2002 and 2018. These recruitment events in 2008–09, 2010–11 and 2016–17 corresponded with the three highest-flow years in the 17-year period (Lear et al. 2019). It was also noted that during the most successful recruitment years of 2010–11 and 2016–17, two large flood pulses occurred.

Freshwater sawfish grow rapidly, reaching lengths of 140–150 cm within the first year of life. When individuals are four to five years of age, at about 250 cm in length, they return to the sea and mature in the marine environment (Morgan 2018).

Diet

Research on the diet of Freshwater sawfish found that during the dry season, its main food source was bony fish (teleost) (67 per cent), along with filamentous algae (14 per cent) and Cherabin (10 per cent) (Thorburn et al. 2014). In the late dry season this switched to biofilm/silt (66 per cent) and bony fish (21 per cent). No data was available for its wet season diet.

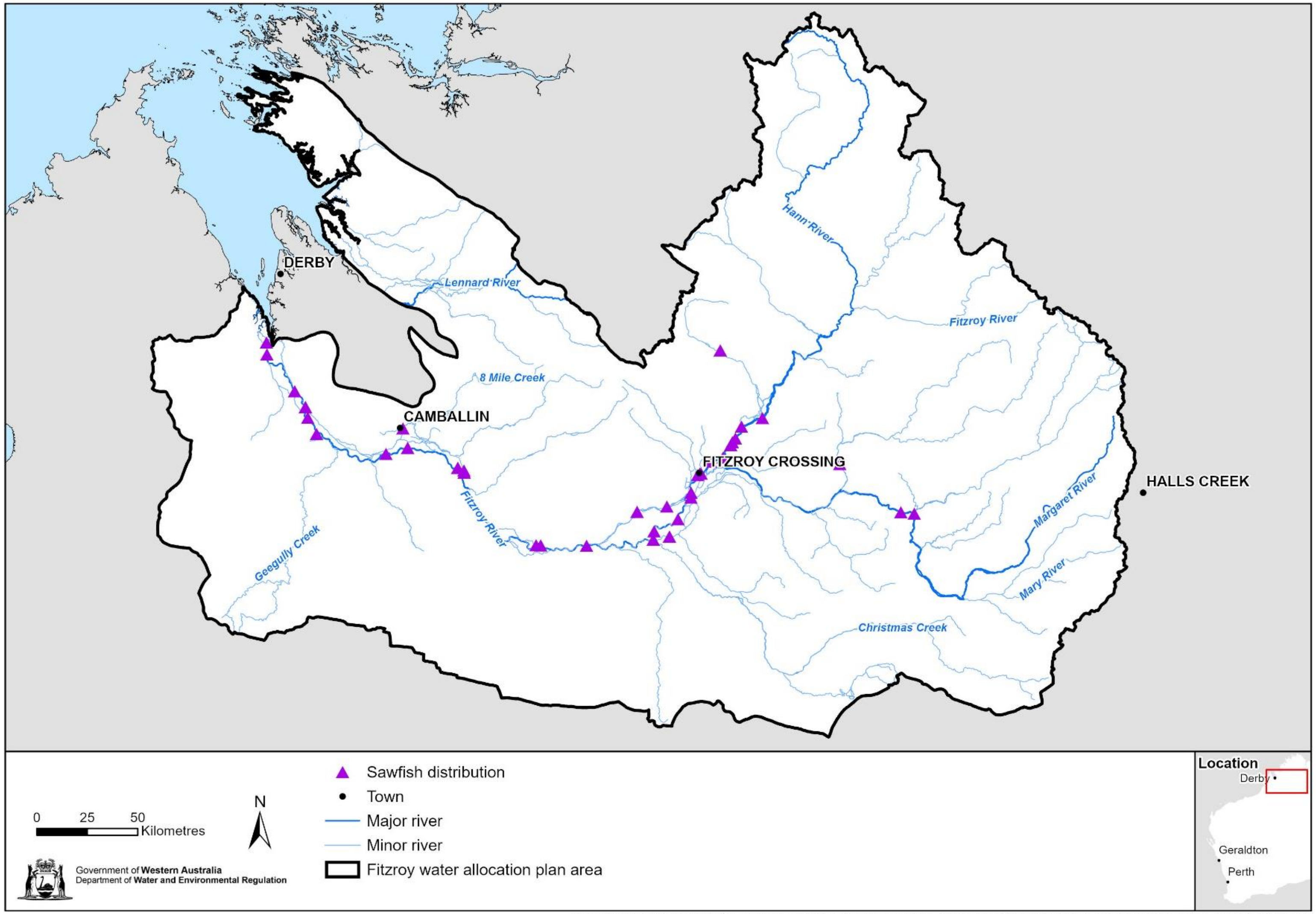


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Figure 33 Recorded distribution of freshwater sawfish (Pristis pristis) in the Fitzroy River catchment

Life in the river

While in the river Freshwater sawfish inhabit large pools and sometimes off-channel wetlands for four to five years, before moving downstream and out into King Sound (Morgan et al. 2016). However, the Camballin Barrage is a substantial barrier to movement in the river. It is thought the barrage may prevent the movement of sawfish up and down the river for up to nine months of the year (Morgan et al. 2004; Morgan et al. 2011; Morgan et al. 2016). However, it is also possible that sawfish bypass the barrage by moving into Uralla/Snake Creek (Morgan 2019).

There is a second, less substantial barrier where Myroodah Road crosses the main river downstream of Camballin. Sawfish are also known to become stranded in drying floodplain wetlands after large wet seasons.

During the dry season the lower Fitzroy River supports a sequence of pool, glide, run and riffle habitats connected by longitudinal baseflow (groundwater). Freshwater sawfish were found to occupy deep pools and runs near large woody debris during the day and then move into shallow water in glides, pool edges and runs at night to feed (Whitty et al. 2017).

A prolonged dry season can lead to harsh conditions in river pools including elevated temperatures and competition for food. Using long-term historical data, the Freshwater Fish Group found the body condition of sawfish was significantly better after high-volume wet seasons, yet it was lost at the same rate every dry season, regardless of the preceding wet season (Lear et al. 2020; Lear et al. 2021).

Figure 34 illustrates that the magnitude of wet-season flows is an important driver of sawfish resilience to prolonged dry and drought conditions (Lear et al. 2020).

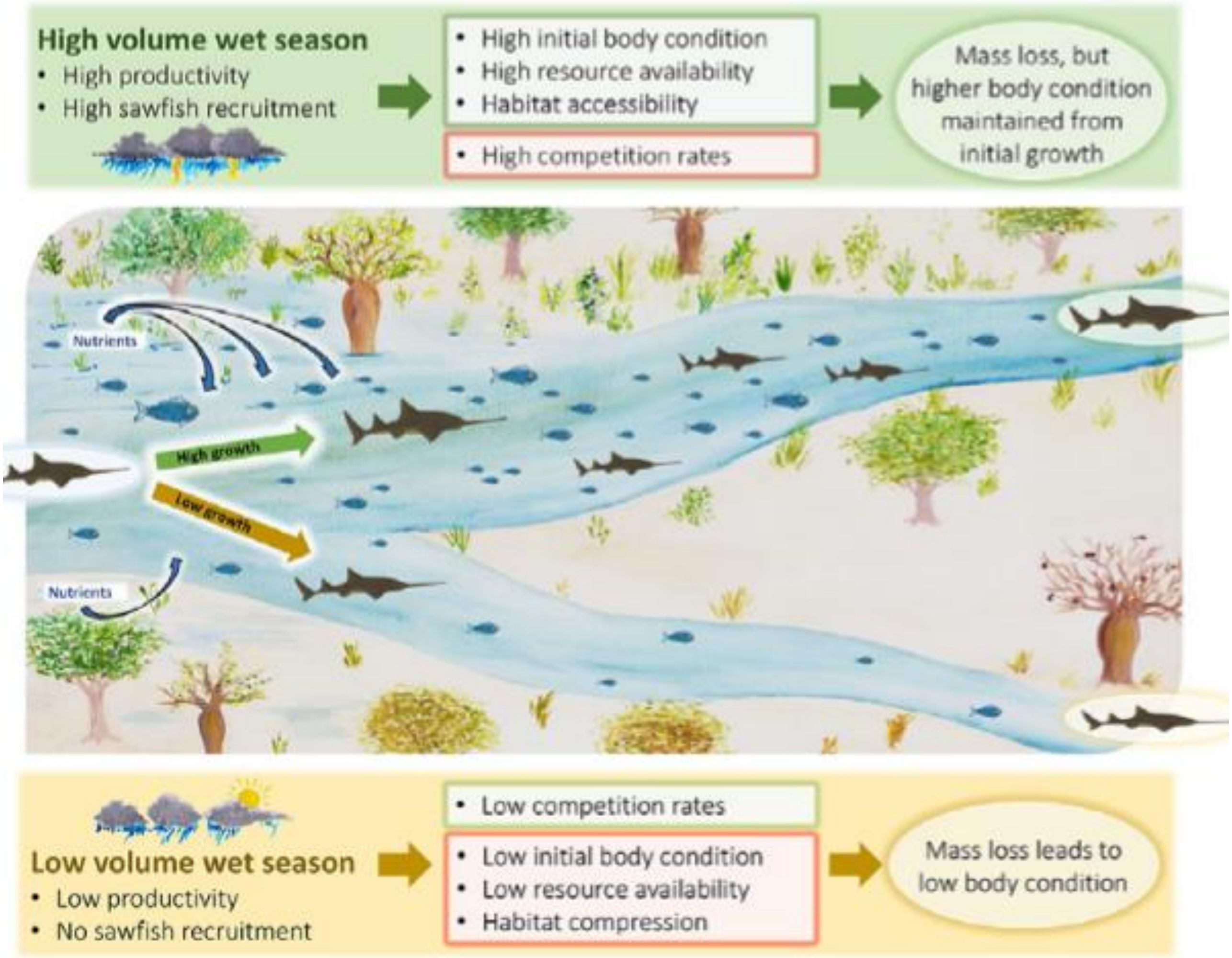

Figure 34 Relationship between flood magnitude and dry season resilience of sawfish from Lear et al. 2021

Threats to Freshwater sawfish

Many threats to Freshwater sawfish in the Fitzroy River and its tributaries are associated with water resource development and pastoral activities, as well as broader phenomena such as climate change.

Surface water abstraction or diversion from the main river channels could reduce the size, depth and persistence of pools and off-channel wetlands during the dry season. This would reduce available habitat and potentially impact on water quality.

Connectivity between pools and the floodplain would likely decline if water were taken during low-flow periods, restricting sawfish movement up and down the river. Reduced flows during the high-volume wet seasons that are critical for sawfish recruitment (e.g. 2008–09, 2010–11 and 2016–17) could also have negative impacts.

Recreational fishing is also a threat, as sawfish can become tangled in nets. To avoid damage to nets in the past, sawfish were hauled onto land and left to die or had their rostra removed (and sometimes kept as souvenirs), only to be thrown back into the river.

Dams or other structures (e.g. Camballin Barrage and road crossings) on the main channel and floodplain could:

- impact on smaller wet-season flows
- prolong dry-season conditions
- reduce the duration of sawfish passage over structures and inhibit their movement up and down the river and on and off the floodplain.

Changes in land use, including intensification of irrigated agriculture and higher stocking rates, could lead to clearing and/or degradation of vegetation and increased nutrient and/or pesticide runoff into the river and tributaries. This could negatively affect water quality in pools and off-channel wetlands.

Climate change may result in higher temperatures, causing pools to heat and increasing energy (food) requirements which can be depleted rapidly in drying pools. This could exacerbate body-condition loss in sawfish over the dry season. Sea-level rise may impact estuarine ecosystems at the mouth of the Fitzroy, altering the tidal range and potentially salinising river pools and wetlands that are habitat for sawfish and which were previously freshwater-dominated.

Summary

The parts of the water regime of most importance to freshwater sawfish are:

- groundwater input
  - maintaining deep river pools during the dry season (Whitty et al. 2017)
- occasional very high-volume wet seasons
  - recruitment (Lear et al. 2019)
- frequent high-volume wet seasons
  - growth and maintenance of body condition (Lear et al. 2020)
  - movement out of river into creeklines and wetlands (Lear et al. 2021)
- annual wet season flows
  - movement over the Camballin Barrage and Myroodah Crossing (Morgan et al. 2016; Morgan 2019)
- recessional (end of wet season) flows
  - maintaining depth of river pools during the dry season (Whitty et al. 2017).

9.3 Barramundi (*Lates calcarifer*)

Barramundi (*Lates calcarifer*) (Figure 35) is the most important fish species to cultural, recreational and commercial fishing in the Fitzroy River catchment. NESP's Northern Hub at UWA synthesised the known distribution of Barramundi across the area and created a distribution map.

Overall, Barramundi have a broader distribution than sawfish and have been recorded along the main channel of the Fitzroy River from Willare to Hann River, and in Uralla/Snake Creek, the Margaret River and the Cunningham Anabranch. However, anecdotally their distribution is much wider than current mapping suggests (Figure 36).

Figure 35 Barramundi (courtesy of Leah Beesley, UWA/NESP)

Recruitment and growth

Barramundi is a migratory species which generally spawns in saline water near the river mouth. In the Fitzroy River this occurs from January to February (Morgan 2018). Juveniles then move upstream into freshwater habitats where they grow and mature (Pollino et al. 2018a). However, in the Fitzroy River considerable variation in this migration strategy exists within populations, with some fish never entering the freshwater habitat and others staying in the river for many years (Crook et al. 2016; Morgan 2018).

It is thought that fish movement may depend on the body condition and growth rate of individuals, their interactions with prey and predator species, and environmental conditions (Crook et al. 2016).

A recent study by Melbourne, La Trobe, Murdoch and Charles Darwin universities (Morrongeiollo et al. 2020; Roberts et al. 2021) analysed ‘growth rings’ in otoliths (ear stones) of fish caught in the Fitzroy River each year from 2001–04. It found better recruitment during years with high wet-season flows, followed by relatively high dry-season flows with a short no-flow duration (Morrongeiollo et al. 2020). This was similar to previous findings from four rivers in the Northern Territory although the researchers emphasised the importance of local conditions (Crook et al. 2016).

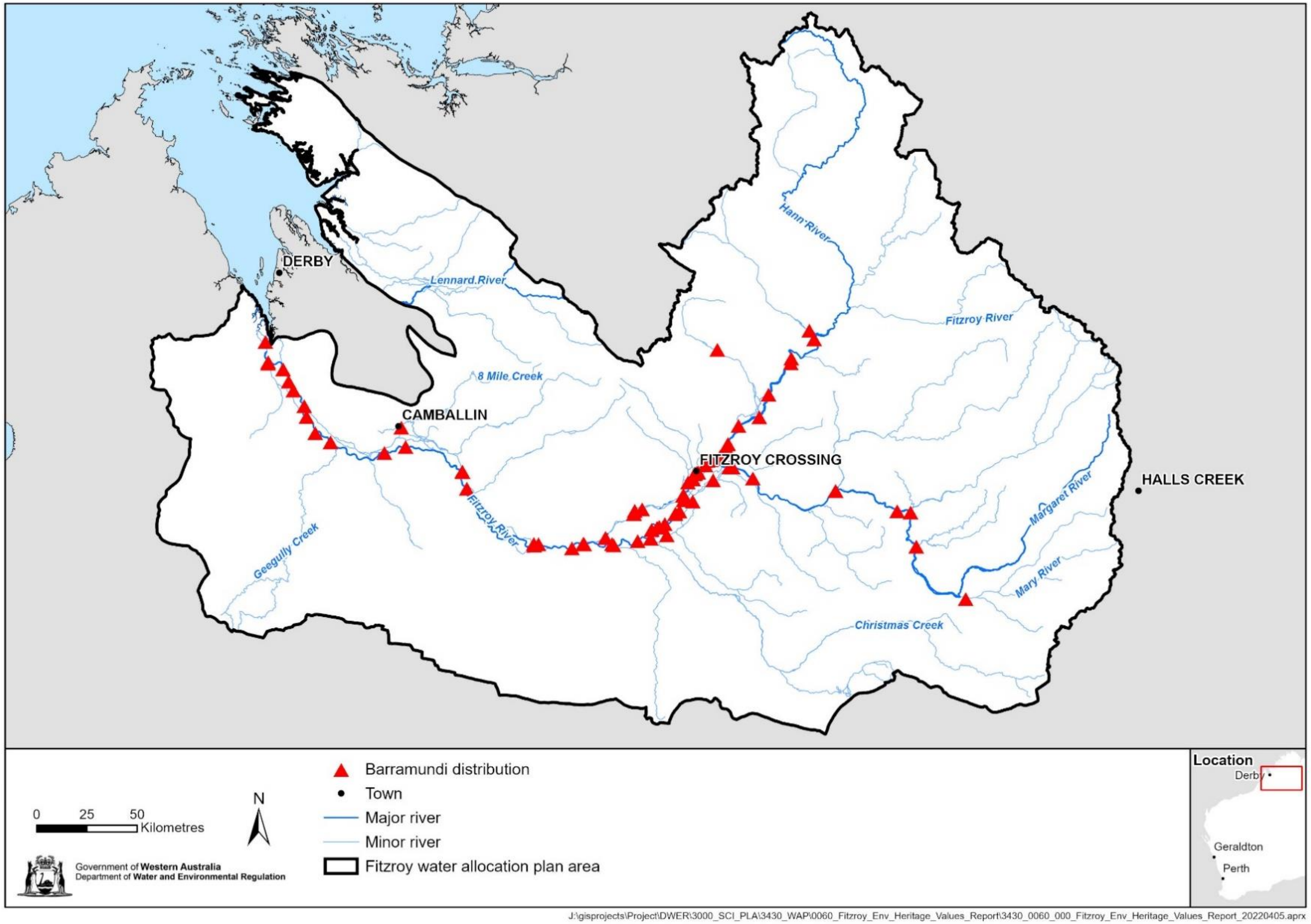

Figure 36 Recorded distribution of barramundi (Lates calcarifer) in the Fitzroy River catchment

In addition to variation in the Barramundi's recruitment and migration, the life history of the species is also complex. In general, individuals initially develop as male at ~400 mm length, then swap to being female at 700–900 mm (Morrongeiollo et al. 2020). Yet considerable overlap can occur in male and female sizes, with some males never changing sex and some fish being spawned as females (Roberts et al. 2021). It is possible that this degree of variation in life history may optimise recruitment in the Fitzroy River's unpredictable environment (Roberts et al. 2021).

Research on estuaries in the Gulf of Carpentaria found that successive poor wet seasons reduced the area of aquatic habitats, negatively affecting the recruitment, growth and survival of Barramundi (Burford et al. 2021). Barramundi and other species using estuaries were found to be most sensitive to changes in river flow during and immediately after successive years of below average (median) flow (Burford et al. 2021).

Diet

Research on the diet of Barramundi found bony fish (teleost) were the main food source throughout the year, representing 79 per cent of total stomach contents in the early dry season, 81 per cent in the late dry and 47 per cent in the wet season (Thorburn et al. 2014). Cherabin was the second-most important, making up 21 per cent in the early dry season, 19 per cent in the late dry and 40 per cent in the wet season. During the wet season Barramundi also consumed fruits (3 per cent), terrestrial vegetation (4 per cent) and crickets (6 per cent) (Thorburn et al. 2014).

Life in the river

Overbank flows allow Barramundi to move out of the main channel onto the floodplain and into off-channel wetlands. At the end of the wet/start of the dry most fish move back into the river, where permanent deep pools are important dry season and drought refuges (Lear et al. 2020).

Researchers in the Northern Territory used pool depth and temperature thresholds of >0.25 m deep and <25°C respectively in tracking the movement of Barramundi over a full wet season (Crook et al. 2016; Crook et al. 2019). They found the species commonly returned to the same refugial river pools at the end of each wet, even when potential habitat was available much closer to its wet-season activity areas (Crook et al. 2019).

Threats to Barramundi

The Camballin Barrage is a barrier to the movement of barramundi up and down the river. Juvenile barramundi become trapped on the downstream side of the barrage during the late wet season, while some mature individuals cannot move back downstream to the estuary if flows over the barrage are not high enough (Morgan et al. 2005).

Barramundi may be vulnerable to water resource development that affects the connectivity of the river and floodplain during the wet season, and the depth and persistence of river pools and off-channel wetlands during the dry season.

Pressure from over-fishing is a serious threat to Barramundi. Targeting of large individuals, which are generally breeding females, may favour the survival of younger fish and thereby negatively affect the reproductive success of the species (Roberts et al. 2021).

As also described for Freshwater sawfish, changes in land use, including intensification of irrigated agriculture and higher stocking rates, could lead to clearing and/or degradation of vegetation and increased nutrient and/or pesticide runoff into the river and tributaries. This could negatively affect water quality in pools and off-channel wetlands. Climate change may result in higher temperatures, causing pools to heat and increasing energy (food) requirements which can be depleted rapidly in drying pools. Sea-level rise may impact estuarine ecosystems at the mouth of the Fitzroy, altering the tidal range and potentially salinising river pools and wetlands that are habitat for Barramundi and which were previously freshwater-dominated.

Summary

Parts of the water regime of most importance to Barramundi are:

- groundwater input
  - maintain river pools during the dry season (Lear et al. 2020)
- frequent high-volume wet seasons
  - facilitate recruitment (Crook et al. 2016; Morrongeiollo et al 2020)
  - movement out of river into creeklines and wetlands (Crook et al. 2019)
- annual wet season flows
  - movement over the Camballin Barrage and Myroodah Crossing (Morgan et al. 2005)
- recessional (end of wet season) flows
  - movement to refugial river pools (Crook et al. 2019)
  - maintain river pools during the dry season (Lear et al. 2020)
- antecedent conditions
  - successive poor wet seasons reduce the area of aquatic habitats (Burford et al. 2021).

9.4 Cherabin (*Macrobrachium spinipes*)

Cherabin or the freshwater prawn (*Macrobrachium spinipes*) is a large-bodied decapod crustacean (Figure 37) found in main river channels and off-channel wetlands. This species makes up a major component of the Indigenous harvest in the Fitzroy River catchment (Jackson et la. 2011). Smaller-sized Cherabin are used for bait, while the larger-bodied individuals are eaten. Cherabin are also a critical part of the diet of Freshwater sawfish, Barramundi and other species in the Fitzroy River (Thorburn et al. 2014).

Recruitment and growth

Cherabin are described as perennial wet-season spawners (Lear et al. 2020). The species is amphidromous, releasing larvae (Figure 37) in freshwater reaches of the Fitzroy during the wet season and relying on flood pulses to carry larvae back into estuarine/brackish waters where they develop (Lear et al. 2020; Beesley et al. in prep). Post-larval young then migrate upstream (Novak et al. 2017).

a) *b)*

Figure 37 Cherabin a) berried female (courtesy of Peter Novak) b) adult Cherabin (courtesy of Leah Beesley, UWA/NESP)

A UWA study sampled Cherabin across a 350 km reach of the Fitzroy River's main channel and floodplain pools in the dry seasons of 2018 and 2019 (Beesley et al. 2022). Although the findings supported an estuarine nursery and amphidromous life history, small individuals were also collected in the main channel late in the dry season, suggesting some level of within-river recruitment (Beesley et al. 2022).

Recent genetic analyses show Kimberley Cherabin are distinct from those of the Northern Territory (Mather & De Bruyn 2003). They also have larger eggs (Short 2004), which may increase larval survival in fresh water for individuals unable to reach the estuary (Bauer 2013).

A study on the Daly River in the wet-dry tropics of the Northern Territory found that Cherabin reproduction was restricted to the wet-season months of November to April, followed by a recruitment pulse three to four months later during the early dry season (Novak et al. 2015). Length, body condition and relative abundances peaked for both sexes immediately after the wet season, before declining throughout the dry season.

Unlike other *Macrobrachium* species in similar rivers, the abundance of females increased along the entire length of the Daly River during the reproductive season and reproductive effort occurred far upstream, over a restricted time period (Novak et al 2015). This result highlights the importance of maintaining river connectivity for the reproductive success of this species and further recruitment into upstream reaches.

Life in the river

The UWA study was conducted after two markedly different wet seasons (2018 and 2019) and showed Cherabin numbers increased following the larger wet season of 2018. Lear et al. (2020) also found that recruitment rates in Uralla Creek went up with increasing flows. This may be due to an increased abundance of larvae drifting back to the estuary nursery with higher/longer flows, increased nutrient input or possibly the greater availability of pool habitat (Beesley et al. 2022).

Habitat type also influenced abundances of different age-classes, with juveniles most abundant in main-channel pools in the lower river and adults dominant in floodplain pools higher in the river (Beesley et al. in prep). Deeper floodplain pools also seem to support greater densities of large Cherabin than shallow pools.

During recessional flows, which are lower than early wet-season flows, Cherabin move through the main river and, in some instances, out into nearby off-channel wetlands to avoid predation (Novak et al. 2015). While data on the migration of Cherabin in the Fitzroy River catchment is lacking, there is anecdotal evidence that individuals move upstream and climb the barrage wall at about the same time each year towards the end of the wet season – February to April (ABC Kimberley, 19 February 2019). This is supported by studies on the Daly River (Novak et al. 2015; Novak et al. 2017) which found that the greatest movement of young cherabin occurred in April and May each year, thus highlighting the importance of recessional flows.

Threats to Cherabin

Cherabin may be vulnerable to water resource development that affects the connectivity of the river during recessional flows in the late wet season, given their larvae likely migrate upstream from the estuary (Beesely et al. 2021). The barrage is an added obstacle and specific flows may be required for Cherabin to move over it.

Reductions in wet season flows may affect downstream migration and potentially increase salinity in spawning areas, reducing larval survival (Jackson et al 2011).

Predation by Barramundi could impact Cherabin abundances in some settings (Morgan et al. 2014). The red claw crayfish (*Cherax quadricarinatus*) has not been recorded in the Fitzroy to date but if it were established, it would likely have substantial impacts on Cherabin (A. Pinder pers. comm. Dec 2022).

Summary

Parts of the water regime of most importance to Cherabin are:

- annual wet season flows
  - larvae drift to the estuary's brackish habitat during the early wet season (Jackson et al. 2011; Lear et al. 2020; Beesley et al. 2022)
  - larvae develop in the estuary (Novak et al. 2017; Lear et al. 2020; Beesley et al. 2022)

  - adults migrate out of the main channel into floodplain habitats to avoid predation
- recessional (end of wet season) flows
  - move upstream (over the barrage) and potentially out onto floodplain (Novak et al. 2015; Lear et al. 2020; Beesley et al. 2022).

9.5 Fork-tailed catfish (*Neoarius graeffei*)

The Fork-tailed catfish (*Neoarius graeffei*) is a medium- to large-sized freshwater fish that is highly valued as an Indigenous harvest species in the Fitzroy River catchment (Jackson et al. 2011; Beesley et al. 2021a).

The species also has symbolic importance in local belief systems and fishing for them helps maintain social relationships, customary behaviour and strengthening of Indigenous identity (Jackson et al. 2012; Toussaint 2014; Beesley et al. 2021a). UWA researchers have synthesised the known distribution of Fork-tailed catfish across the Fitzroy River catchment and created distribution maps (Figure 38).

Recruitment and growth

Fork-tailed catfish spawn in the main river or creeklines in the late dry or early wet season (Jackson et al. 2011), possibly in response to an increase in temperature, day length and enhanced production in the river systems (Pusey et al. 2004). At the very end of the dry season, they start carrying and laying eggs. Males then stay in deeper water during incubation and exhibit a high degree of parental care (Jackson et al. 2011).

Migration upstream occurs throughout the year at a wide range of discharge rates and flow conditions. However, fish movement is highest during low flows and greatly reduces in the cooler months of July and August (Jackson et al. 2011).

Diet

Murdoch researchers studied the diet of Fork-tailed catfish and found the species consumed a broader range of foods than Freshwater sawfish and Barramundi, and that the diet varied depending on an individual’s size (Thorburn et al. 2014). Smaller individuals (<150 mm) consumed relatively large proportions (~40 per cent) of small aquatic invertebrates throughout the year along with filamentous algae (34 per cent wet season; 6 per cent early dry). Other foods consumed in the early dry included terrestrial vegetation, snails, worms and molluscs (Thorburn et al. 2014).

Bigger fish (>150 mm) consumed larger food items including terrestrial/adult insects (~40 per cent) and cherabin (5–10 per cent) year-round and terrestrial vegetation (11 per cent) and figs (20 per cent) during the wet season. Northern Australian fish have previously been reported to eat fruit at times of the year when it is available (Davis et al. 2010).

Life in the river

Fork-tailed catfish can occur in fresh and estuarine habitats and are likely to access floodplain habitats during floods (Jackson et al. 2011) (Figure 38).

A recent study by UWA/NESP investigated the influence of river flow on the energy (fat) reserves of *Neoarius graeffei* during the dry season (Beesley et al. 2021a). It found that catfish body condition decreased as the dry season progressed, and that it was greatest in years following moderate to high wet-season flows and lowest after poor wet seasons. Aboriginal people know this well and search out 'fat catfish' after a good wet season has washed food into the river from the floodplain. For this reason, the catch is greater at the end of the wet or early dry when rivers and creeks are running (Jackson et al. 2011).

Threats to Fork-tailed catfish

Fork-tailed catfish may be vulnerable to water resource development that reduces movement along the river channel. If the abundance of the species were to reduce, this would substantially affect the Indigenous harvest (Jackson et al. 2011).

More generally, river regulation or flow alterations that reduced both the frequency of flooding and the area inundated and longitudinal and lateral connectivity, would likely have a negative impact on catfish (Pusey et al. 2004). Note that the low fecundity (reproductive potential) of catfish could restrict the recovery of populations impacted by water resource development (Pusey et al. 2004).

Summary

Parts of the water regime of most importance to Fork-tailed catfish are:

- groundwater input
  - maintaining depth of river pools during the dry season (Beesley et al. 2021a)
- annual wet season flows
  - fish spawn in the main channel and creeks/flood runners (Lear et al. 2020)
  - important for growth and maintenance of body condition during the dry season (Beesley et al. 2021a).
- overbank flows
  - fish move out into floodplain habitats (Jackson et al. 2011; Beesley et al. 2021a).

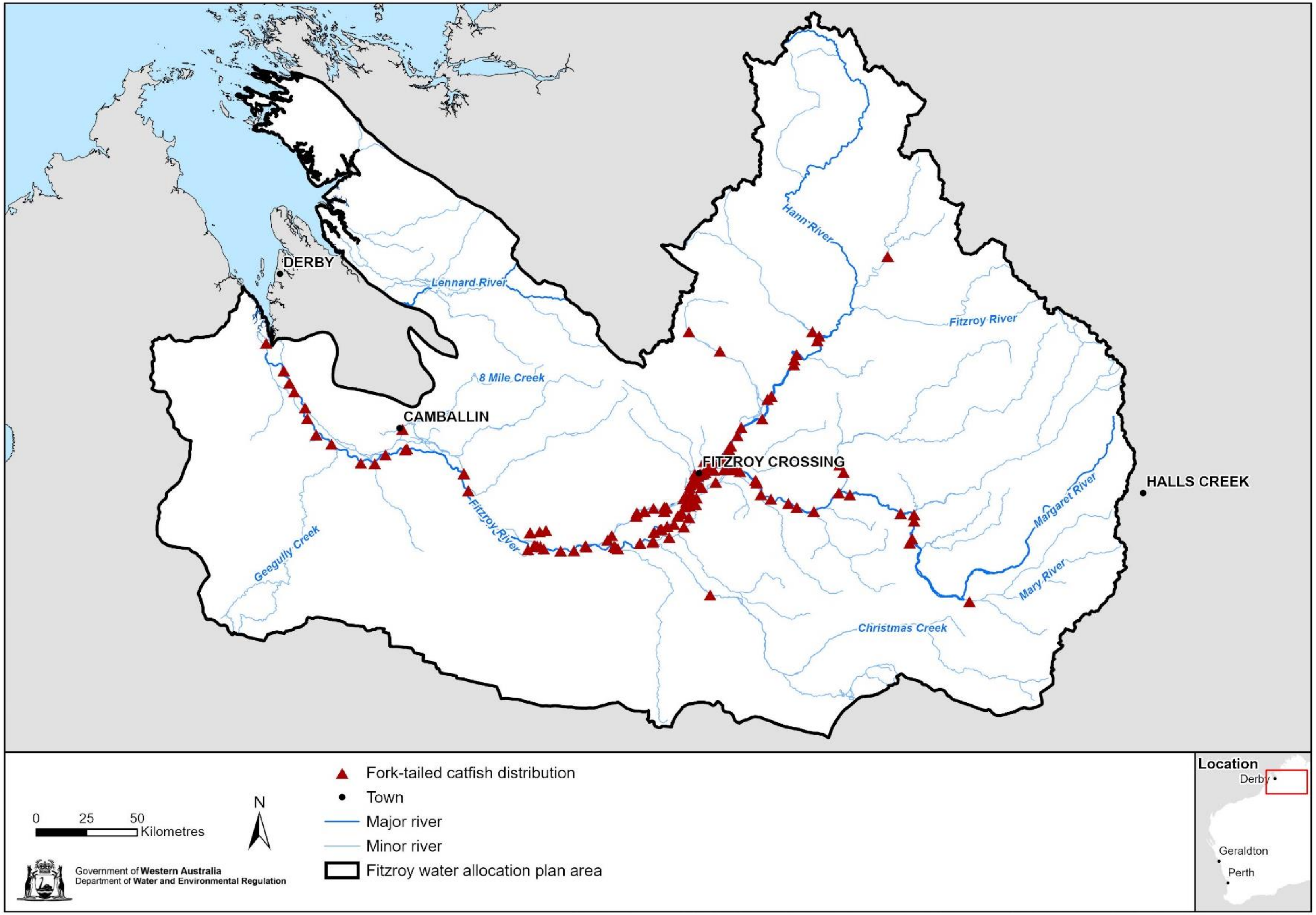

Figure 38 Recorded distribution of Fork-tailed catfish (Neoarius graeffei) in the Fitzroy River catchment

9.6 Freshwater mangrove (*Barringtonia acutangula*)

The small multi-stemmed Freshwater mangrove (*Barringtonia acutangula*) (Figure 39) is a common tree on riverbanks of the Fitzroy River and is found at lower densities on top-of-bank and off-channel wetland sites (Freestone et al. 2020). It is adapted to tolerate flooding during the wet season and can potentially be inundated to a depth of 3.5 m for up to 1.5 months of the year (Freestone et al. 2020).

The Freshwater mangrove is culturally important to Aboriginal people of the Fitzroy. Nyikina and Walmajarri people crush 'majala' bark for use as a fish poison and chew new green stems to make an anaesthetic to treat painful catfish spike injuries (Jackson & O'Leary 2006). Gooniyandi people also use 'gooroo' bark as a fish poison and know that when it is flowering in the dry season, sawfish are getting fat (Davis et al. 2011). Bunuba people use 'mala' to treat toothache (DBCA 2019).

Recruitment and growth

The Freshwater mangrove is semi-deciduous, shedding leaves in the late dry season to reduce leaf area and therefore transpiration and water loss (Canham et al. 2022). Its short-lasting, relatively weak leaves are easily lost during high flows but regrow quickly in the early dry season when conditions improve (to lower flow velocity and increased water availability) (Canham et al. 2022).

Figure 39 Freshwater mangrove (Barringtonia acutangula)

Tree water-use investigations suggest Freshwater mangroves access a mix of sources including river water, shallow and deep soil moisture, and alluvial and/or regional groundwater where available (Canham et al. 2021b). During the dry season they rely on shallow groundwater (< 5 m deep) in the absence of other sources (Lamontagne et al. 2005).

Threats to Freshwater mangrove

Surface water abstraction or diversion from the main river could reduce recharge to the alluvial aquifer and soil moisture availability to freshwater mangroves during the dry season.

Groundwater abstraction from regional aquifers in areas where Freshwater mangroves access them could have a direct impact and potentially reduce groundwater input into the alluvial aquifer.

Changes in land use, including intensification of irrigated agriculture and higher stocking rates, could lead to direct clearing and/or degradation of riparian vegetation.

Summary

Parts of the water regime of most importance to Freshwater mangroves are:

- groundwater input
    - from alluvial and/or regional aquifers (DWER 2022a)
- annual wet-season flows
    - in-channel flows allow direct access to river water and recharge soil water and alluvial groundwater
    - overbank flows fill off-channel wetlands and creeklines and recharge regional groundwater.

9.7 Silver-leafed (*Melaleuca argentea*) and Green (*M. leucadendra*) paperbarks

The Silver-leafed and Green paperbarks – *Melaleuca argentea* and *M. leucadendra* respectively – are common on the narrow banks of the Fitzroy's main channel (Figure 40) (Canham et al. 2021a). However, only *M. leucadendra* is also found along the river's major tributaries and at some wetlands.

On the main channel both species can potentially be inundated to a depth of 3.5 m for up to 1.5 months of the year. Having flexible stems, hard leaves and the ability to grow fibrous or adventitious 'breathing' roots around their lower trunks (Figure 41), both are physiologically adapted to such long periods of inundation and high-velocity flows (Canham et al. 2021a).

Both species are important to Aboriginal people. The bark of the Silver paperbark is stripped and used to make containers for cooking and carrying food and *M. leucadendra* bark is used to wrap fish for cooking (Toussaint et al. 2001). In addition, both species provide habitat for honeybees (Barber & Woodward 2017).

Paperbarks have crucial system-wide ecological roles including provision of direct habitat for reptiles, amphibians, bats, birds (e.g. purple fairy wren) and insects. Old trees that have fallen into the river provide habitat for fish and aquatic species and fallen leaves are a source of energy in aquatic food webs. The thick root mats of both species support bank stability (Canham et al. 2021a).

Silver-leafed melaleuca (M. argentea) *Green melaleuca (M. leucadendra)*

Figure 40 Large melaleuca species of the Fitzroy riverbank

Recruitment and growth

On the Fitzroy and its tributaries *M. leucadendra* is found in both riverbank and top-of-bank habitats (Freestone et al. 2022) and individuals can grow to 30 m. Studies from the lower Ord River indicate the species flowers and fruits between August and January, followed by peak seed fall from February to April (Pettit et al. 2001). Seed fall coincides with receding floodwaters when sediments are moist and likely to support germination (Pettit et al. 2001) (Figure 42).

The few years following seed germination are critical as water availability largely determines survival to maturity (McLean 2014). Seedlings must grow quickly while water is available to establish roots deep and large enough to follow the watertable.

Once established, *M. leucadendra* does not regulate water loss through leaf stomatal closure, which can lead to the water column breaking and ultimately cut the plant off from its water supply in the soil. The species can therefore only occur where it has sufficient access to permanent water. Isotope analysis shows that groundwater or deep soil water are the most important water sources to *M. leucadendra* (Canham et al. 2021b).

M. argentea is restricted to riverbank habitats on the Fitzroy River and can grow to 18 m (Freestone et al. 2020). The species flowers from July to November each year and is also likely to time seed fall to coincide with receding floodwaters. Under glass-house conditions seedlings are highly tolerant of saturated soil conditions and grow quickest in partially waterlogged conditions (80 per cent saturation) (McLean 2014).

Once established, this species can grow shallow roots rapidly in response to pulses of high water availability, while maintaining older, deeper tap roots for dryer conditions (McLean 2014). Root plasticity allows *M. argentea* to switch between groundwater, surface water or soil-moisture sources (Canham et al. 2021b).

Figure 41 *Adventitious roots allow M. argentea and M. leucadendra to breathe while inundated*

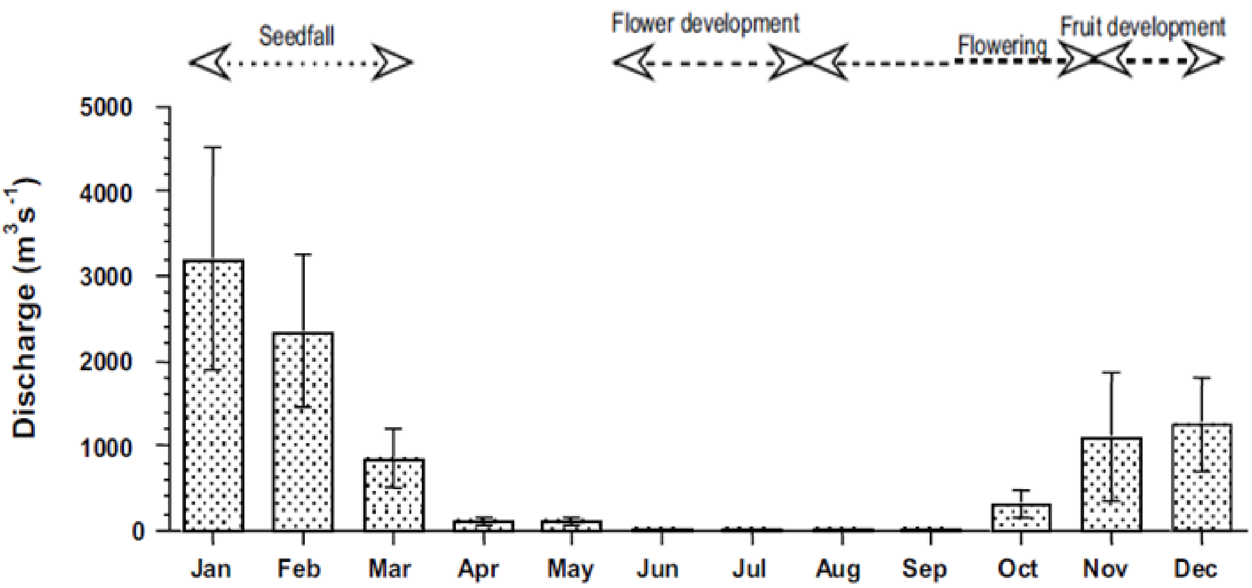

Figure 42 *Timing of flowering, fruiting and seed fall in Melaleuca leucadendra on the lower Ord River (from Pettit et al. 2001)*

M. argentea commonly occur where depth to groundwater is less than 5 m (Lamontagne et al. 2005; Loomes 2010) but will tolerate depths up to 7.5 m for short periods (Loomes 2010). Despite the plastic root response of the species to changes in water availability, it maintains a high level of water use throughout the year which makes it susceptible to drying conditions (O'Grady et al. 2002; Lamontagne et al. 2005; McLean 2014).

Threats to Silver-leafed and Green paperbarks

Groundwater abstraction from regional aquifers in areas where the paperbarks access them could have a direct impact and potentially reduce groundwater input into the alluvial aquifer.

Surface water abstraction or diversion from the main river channel could reduce recharge to the alluvial or unconfined aquifers and soil-moisture availability to paperbarks during the dry season.

Bank and sediment erosion could expose and/or destroy roots which may reduce water uptake and potentially a tree's stability and anchorage (McLean 2014).

Changes in land use, including intensification of irrigated agriculture and higher stocking rates, could lead to direct clearing and/or degradation of riparian vegetation.

Climate change may result in greater rainfall variation and higher temperatures, in turn reducing surface flows, groundwater recharge and soil-moisture availability. It is also probable that the frequency and intensity of fires will increase. With more fires, declining water availability and clearing, invasive flora species – especially agricultural weeds – can out-complete and replace native plant species. Sea-level rise may also lead to salt water moving further up the main channel, affecting water quality in pools and the alluvial aquifer.

Summary

Parts of the water regime of most importance to *Melaleuca argentea* and *M. leucadendra* are:

- groundwater input
  - from alluvial and regional aquifers (McLean 2014; Canham et al. 2021b)
- annual wet season flows
  - in-channel flows allow direct access to river water and recharge soil water and alluvial groundwater (McLean 2014; Canham et al. 2021b)
  - overbank flows fill off-channel wetlands and creeklines and recharge regional groundwater (Pettit et al. 200; Canham et al. 2021b)
- late wet season – recessional flows
  - keep sediments moist to support seed germination and growth (Pettit et al. 2001; McLean 2014).

9.8 Coolibah (*Eucalyptus microtheca)*

Coolibah *(Eucalyptus microtheca)* is widespread on floodplains across the arid interior of Australia (Roberts & Marston 2000). In the Fitzroy, the species is generally shorter (5–10 m), with a smaller canopy than the other main-channel tree species (Beesley et al. 2021b) (Figure 43).

UWA/NESP's species distribution model found *E. microtheca* was the most common tree in its Fitzroy study area, covering more than 2,800 km^2 compared with the second-most-common species *E. camaldulensis* at 1,400 km^2 (Canham et al. 2022). Although Coolibah was recorded across the four habitat types surveyed – riverbank, top-of-bank, floodplain and off-channel wetlands – it was the most abundant species in areas not inundated for long periods, occurring at 82 per cent of surveyed floodplain sites and 78 per cent of off-channel sites (Freestone et al. 2020).

Recruitment and growth

The recruitment of Coolibah is not well understood. However, the closely related *E. coolabah* requires a sequence of flood years for seedling establishment (Roberts & Marston 2000) as do many other floodplain species. This allows seed to be distributed across the floodplain and for soil moisture levels to be maintained over the extended period of time needed for germination and seedling establishment.

Coolibah is also likely to require periodic flooding although it does tolerate long dry periods. Although stable isotope studies show it accesses shallow groundwater and deep soil water, individuals will continue to photosynthesise even when water availability is low (Canham et al. 2021b) This suggests the species is physiologically adapted to tolerate drier conditions (Canham et al. 2022).

It is the long periods of limited water availability punctuated by periods of inundation that are likely to favour coolibah's domination of floodplain habitats (Freestone et al. 2022).

Threats to Coolibah

Numerous threats to *E. microtheca* are associated with water resource development and pastoral activities, as well as broader phenomena such as climate change.

Surface water abstraction or diversion could reduce the overbank flows required for seed distribution and germination. Reduced flows could also lead to less groundwater recharge and lower soil-moisture availability. Groundwater abstraction could also directly reduce water availability for the species.

Dams or other irrigation structures, road crossings and raised roadways could also alter surface flows with the same consequences described above.

Changes in land use, including intensification of irrigated agriculture, could lead to the direct loss of Coolibah through clearing and degradation through grazing. Increased nutrient and/or pesticide runoff into the river could also negatively affect the species.

Climate change may result in greater rainfall variation and higher temperatures, in turn reducing surface flows, groundwater recharge and soil-moisture availability. It is also probable that the frequency and intensity of fires will increase. With more fires, declining water availability and clearing, invasive flora species – especially agricultural weeds – can out-complete and replace native plant species. Sea-level rise may also lead to salt water moving further up the main channel, affecting water quality in pools and the alluvial aquifer.

Figure 43 Coolibah (Eucalyptus microtheca) on the Fitzroy floodplain

Summary

Parts of the water regime of most importance to *E. microtheca* are:

- groundwater availability from regional aquifers (Canham et al. 2021b)
- annual wet season flows (sequence of flood years)
  - overbank flows to distribute seed and recharge regional groundwater and localised soil moisture (Roberts & Marston 2000; Canham et al. 2021b).

10 Summary – water-dependent habitats and species

This section describes the four main parts of the water regime and how they support water-dependent habitats (Section 8) and important species (Section 9). The four main parts of the water regime are:

- in-channel
- overbank
- recessional
- low flow/groundwater input.

Figure 44 depicts these water regime components (Douglas et al. 2019) against a hydrograph and annual flow periods for the early wet, wet, wet/dry transition and dry seasons. The figure shows what the river level could look like during each season. The figure also summarises the way in which each part of the water regime supports specific habitats and species.

Figure 44 shows that no single part of the flow regime is more important than another. Even though water availability for most habitats and species is restricted during the long dry season, this is heavily influenced by the size of the flows in the preceding wet season. For example, large wet seasons fill river pools and off-channel wetlands and recharge the alluvial aquifer and soil moisture. Pools and wetlands act as dry season refugees for fauna. Groundwater and soil moisture not only sustains riparian and floodplain vegetation but also provides direct inputs into numerous pools and wetlands.

In-channel flows

e. connect pools, estuary and King Sound to support:
- recruitment of fish, Cherabin and Sawfish
- nutrient inputs
- flushing of 'old' water

f. connect flood-runner creeks to support movement of fauna out of main channel

g. recharge alluvial and regional groundwater and soil moisture

h. support riparian vegetation species on the riverbank.

Overbank flows

c. connect the river and floodplain to support:
- movement of fish into off-channel wetlands
- recruitment of floodplain vegetation
- off-channel wetlands
- nutrient exchange

d. occasional high-volume flows to:
- support sawfish recruitment and productivity (growth)
- scour sediment from channel and estuary
- inundate saltflats.

Recessional flows

b. low flows at the end of the wet season to support:
- migration of Cherabin upstream and onto the floodplain
- movement of Sawfish and Barramundi back into main channel
- depth and persistence of river pools during the dry season.

Groundwater

e. regional aquifers support water-dependent reaches of Fitzroy and Margaret rivers and Snake/Uralla Creek

f. alluvial aquifer supports river pools and off-channel wetlands (and dependent biota), riparian and floodplain vegetation

g. regional aquifers support springs

h. alluvial and suitable regional aquifers support stygofauna.

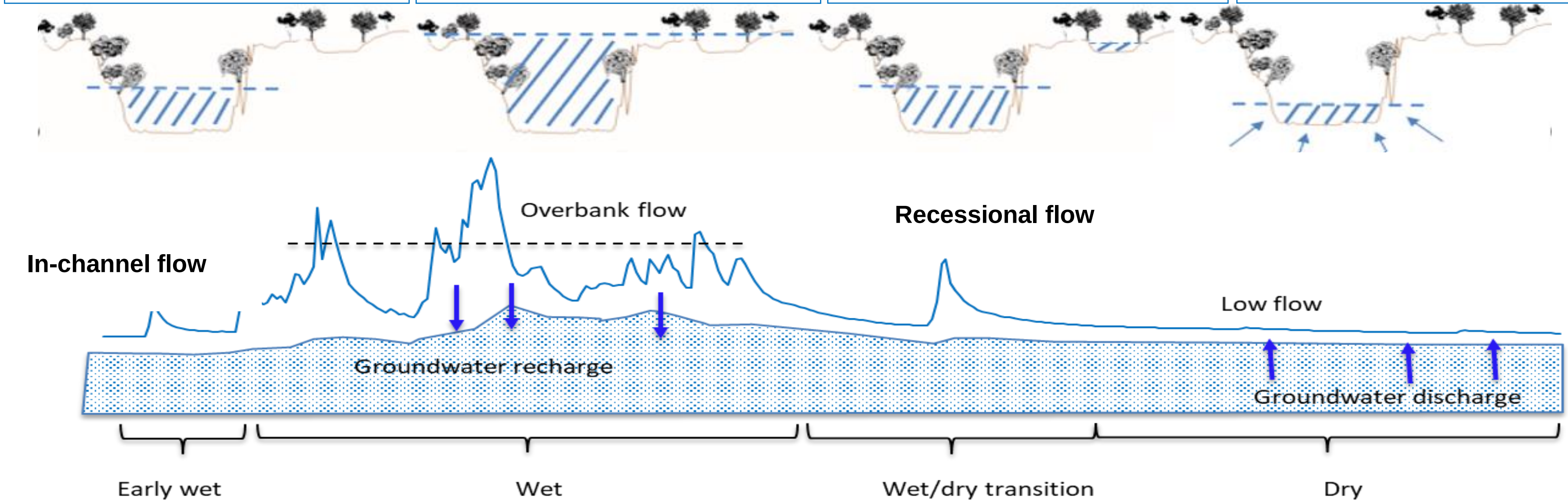

Figure 44 Summary of four main parts of the water regime and how they support habitats and important species

11 Next steps – ecological water requirements

The environmental and heritage values described in this report have helped us identify important water-dependent habitats and species in the Fitzroy planning area. New science from investigations in the Fitzroy River catchment have also helped us to understand how these interact with, and are supported by, surface water and/or groundwater.

Such knowledge underpins the description of ecological water requirements – the water regimes needed to maintain water-dependent ecosystems at a low level of risk (Water and Rivers Commission 2000). These are reported in a companion report: *Ecological water requirements of water-dependent ecosystems in the Fitzroy water planning area (DWER 2023a)*. This will present an approach to apply ecological water requirements at a catchment or allocation plan scale to support water resource management.

We will consider the critical relationships between water-dependent habitats and surface water and groundwater regimes to describe hydro-ecological outcomes. Outcomes will consider the main flow events/periods and our new understanding of how these support habitats and important species (Figure 45).

To develop ecological water requirements for the Fitzroy River we will identify the flow regimes needed to maintain habitats and important species. For example, the daily flow volume needed to support permanent deep river pools on the main channel or the depth-to-groundwater needed to support important riparian tree species.

The report will identify where there is insufficient information and data to develop ecological water requirements and will recommend actions, further scientific investigation or projects where required.

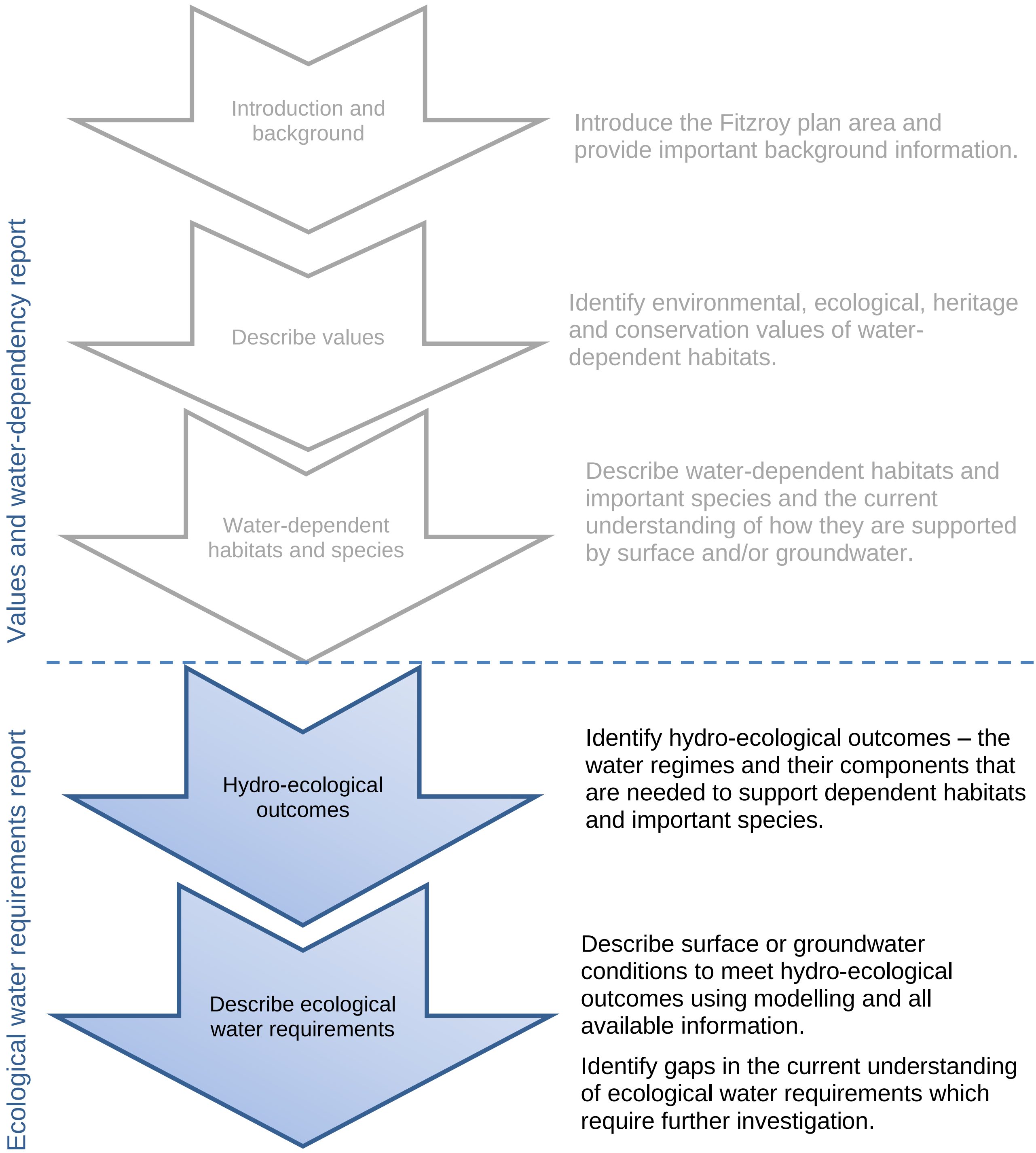

Figure 45 Next steps in the ecological water requirement process for Fitzroy water planning

Appendices

Appendix A Listed fauna and flora of the Fitzroy planning area

Table A1 Listed fauna and their habitats in the Fitzroy planning area and out into King Sound

LISTED FAUNA: ***Scientific name***	**Common name**	**Class**	**Conservation category code**	**Terrestrial**	**Marine**	**Mudflat**	**Freshwater**	**GDE**	**Surface water habitat**	**Island**
Actitis hypoleucos	Common sandpiper	Bird	IA			X	X	X	X	
Amytornis housei	Black grasswren	Bird	P4	X						
Apus pacificus	Fork-tailed swift	Bird	IA	X						
Botaurus poiciloptilus	Australasian bittern	Bird	EN				X	X	X	
Calidris acuminata	Sharp-tailed sandpiper	Bird	IA			X	X	X	X	
Calidris ferruginea	Curlew sandpiper	Bird	CR			X	X	X	X	
Calidris ruficollis	Red-necked stint	Bird	IA			X	X	X	X	
Calidris subminuta	Long-toed stint	Bird	IA			X	X	X	X	
Charadrius leschenaultii	Greater/ Large sand plover	Bird	VU			X	X	X	X	
Charadrius mongolus	Lesser sand plover	Bird	EN			X	X	X	X	
Charadrius veredus	Oriental plover	Bird	IA			X	X	X	X	
Chlidonias leucopterus	White-winged black tern	Bird	IA		X	X	X	X	X	
Cuculus optatus	Oriental cuckoo	Bird	IA	X						
Elanus scriptus	Letter-winged kite	Bird	P4	X						
Erythrotriorchis radiatus	Red goshawk	Bird	VU	X				X	X	
Erythrura gouldiae	Gouldian finch	Bird	P4	X				X	X	
Falco hypoleucos	Grey falcon	Bird	VU	X				X	X	
Falco peregrinus	Peregrine falcon	Bird	OS	X				X	X	

LISTED FAUNA: ***Scientific name***	**Common name**	**Class**	**Conservation category code**	**Terrestrial**	**Marine**	**Mudflat**	**Freshwater**	**GDE**	**Surface water habitat**	**Island**
Fregata ariel	Lesser frigatebird	Bird	IA		X	X				
Gallinago megala	Swinhoe's snipe	Bird	IA			X	X	X	X	
Gelochelidon nilotica	Gull-billed tern	Bird	IA		X	X	X	X	X	
Geophaps smithii blaauwi	Partridge pigeon (western)	Bird	VU	X						
Glareola maldivarum	Oriental pratincole	Bird	IA	X		X	X	X	X	
Hydroprogne caspia	Caspian tern	Bird	IA		X	X			X	
Limicola falcinellus	Broad-billed sandpiper	Bird	IA			X			X	
Limosa lapponica	Bar-tailed godwit	Bird	IA			X			X	
Limosa limosa	Black-tailed godwit	Bird	IA			X			X	
Malurus coronatus coronatus	Purple-crowned fairy-wren (western)	Bird	EN	X			X	X	X	
Numenius madagascariensis	Eastern curlew	Bird	CR			X			X	
Numenius minutus	Little curlew; Little whimbrel	Bird	IA			X	X	X	X	
Numenius phaeopus	Whimbrel	Bird	IA			X	X	X	X	
Pandion cristatus	Osprey, Eastern osprey	Bird	IA	X	X	X	X		X	
Plegadis falcinellus	Glossy ibis	Bird	IA	X		X	X	X	X	
Pluvialis fulva	Pacific golden plover	Bird	IA			X			X	
Pluvialis squatarola	Grey plover	Bird	IA			X			X	
Polytelis alexandrae	Princess parrot	Bird	P4	X						
Rostratula australis	Australian painted snipe	Bird	EN				X	X	X	

LISTED FAUNA: ***Scientific name***	**Common name**	**Class**	**Conservation category code**	**Terrestrial**	**Marine**	**Mudflat**	**Freshwater**	**GDE**	**Surface water habitat**	**Island**
Tyto novaehollandiae kimberli	Northern masked owl	Bird	IUCN-vulnerable					X		
Tringa glareola	Wood sandpiper	Bird	IA			X	X	X	X	
Tringa nebularia	Common greenshank, Greenshank	Bird	IA			X	X	X	X	
Tringa stagnatilis	Marsh sandpiper; Little greenshank	Bird	IA			X	X	X	X	
Craterocephalus lentiginosus	Prince Regent hardyhead	Fish	P2				X		X	
Hypseleotris kimberlensis	Barnett River gudgeon	Fish	IUCN - EN				X		X	
Glyphis garricki	Northern river shark	Fish	P1						X	
Hannia greenwayi	Greenway's grunter	Fish	P1				X		X	
Himantura chaophraya	Freshwater whipray	Fish	IUCN				X			
Pristis clavata	Dwarf sawfish	Fish	VU						X	
Pristis pristis	Freshwater sawfish	Fish	VU				X		X	
Cristilabrum spectaculum	Camaenid land snail (Jeremiah Hills)	Invertebrate	EN	X				X		
Kimboraga micromphala	Camaenid land snail (Windjana and Geiki gorges)	Invertebrate	P2	X				X		
Mouldingia occidentalis	Camaenid land snail (eastern Napier Ranges)	Invertebrate	CR	X				X		
Pilsbrycharopa tumida	Charopid land snail (Noonkanbah)	Invertebrate	P1	X				X		
Westraltrachia alterna	Camaenid land snail (McSherry Gap and Cyclad Hill)	Invertebrate	VU	X				X		

LISTED FAUNA: ***Scientific name***	**Common name**	**Class**	**Conservation category code**	**Terrestrial**	**Marine**	**Mudflat**	**Freshwater**	**GDE**	**Surface water habitat**	**Island**
Westraltrachia inopinata	Camaenid land snail (Yammera Gap)	Invertebrate	VU	X				X		
Westraltrachia lievreana	Le Lievre Ridge camaenid land snail	Invertebrate	P2	X				X		
Westraltrachia recta	Camaenid land snail (Limestone Billy Hills)	Invertebrate	P1	X				X		
Westraltrachia subtila	Camaenid land snail (Ninety Seven Mile Creek)	Invertebrate	P2	X				X		
Westraltrachia turbinata	Camaenid land snail (Yammera Gap)	Invertebrate	VU	X				X		
Dasyurus hallucatus	Northern quoll	Mammal	EN	X				X	X	
Hydromys chrysogaster	Water rat; Rakali	Mammal	P4	X		X	X	X	X	
Isoodon auratus auratus	Golden bandicoot (mainland), wintarru	Mammal	VU	X						
Lagorchestes conspicillatus leichardti	Spectacled hare-wallaby (mainland)	Mammal	P4	X						
Leggadina lakedownensis	Northern short-tailed mouse; Lakeland Downs mouse; Kerakenga	Mammal	P4	X						
Macroderma gigas	Ghost bat	Mammal	VU	X				X		
Macrotis lagotis	Bilby; dalgyte; ninu	Mammal	VU	X						
Mesembriomys macrurus	Golden-backed tree-rat	Mammal	P4	X						
Petrogale lateralis subsp. (West Kimberley)	West Kimberley black-footed rock-wallaby	Mammal	EN	X				X	X	
Petropseudes dahli	Rock ringtail possum; wogoit	Mammal	P3	X						

LISTED FAUNA: ***Scientific name***	**Common name**	**Class**	**Conservation category code**	**Terrestrial**	**Marine**	**Mudflat**	**Freshwater**	**GDE**	**Surface water habitat**	**Island**
Phascogale tapoatafa kimberleyensis	Kimberley brush-tailed phascogale	Mammal	VU	X						
Rhinonicteris aurantia	Orange leaf-nosed bat	Mammal	P4	X				X	X	
Trichosurus vulpecula arnhemensis (Kimberley)	Northern brushtail possum (Kimberley)	Mammal	VU	X		X				
Vespadelus douglasorum	Yellow-lipped cave bat	Mammal	P2	X						
Wyulda squamicaudata	Scaly-tailed possum	Mammal	P4	X		X				
Anilios micromma	Small-eyed blind snake (Leopold Downs)	Reptile	P1	X						
Anilios troglodytes	Sandamara blind snake (Napier Range)	Reptile	P1	X						
Crocodylus johnstoni	Australian freshwater crocodile	Reptile	OS	X		X	X	X	X	
Crocodylus porosus	Salt-water crocodile	Reptile	OS	X	X	X	X			
Cryptagama aurita	Gravel dragon	Reptile	P1	X						
Ctenotus uber johnstonei	Spotted ctenotus (northeast)	Reptile	P2	X						
Lerista robusta	Broad-eyed slider (Kimberley)	Reptile	P1	X						
Lerista separanda	Dampierland plain slider	Reptile	P2	X						
Likely to occur										
Arenaria interpres	Ruddy turnstone	Bird	IA			X			X	
Calidris alba	Sanderling	Bird	IA			X			X	

LISTED FAUNA: ***Scientific name***	**Common name**	**Class**	**Conservation category code**	**Terrestrial**	**Marine**	**Mudflat**	**Freshwater**	**GDE**	**Surface water habitat**	**Island**
Calidris melanotos	Pectoral sandpiper	Bird	IA			X	X	X	X	
Hirundo rustica	Barn swallow	Bird	IA	X						
Limnodromus semipalmatus	Asian dowitcher	Bird	IA			X			X	
Phalaropus lobatus	Red-necked phalarope	Bird	IA			X	X	X	X	
Gallinago stenura	Pin-tailed snipe	Bird	IA				X	X	X	
Calidris canutus	Red knot, knot	Bird	EN and IA			X			X	
Tringa brevipes	Grey-tailed tattler	Bird	IA			X				
Xenus cinereus	Terek sandpiper	Bird	IA			X				
Sternula albifrons	Little tern	Bird	IA		X	X	X		X	
Anoxypristis cupidata	Narrow sawfish	Fish	IUCN		X					
Pristis zijsron	Green sawfish	Fish	IUCN		X					
Mormopterus (Ozimops) cobourgianus	North-western free-tailed bat	Mammal	P1	X		X				
Dugon dugong	Dugong	Mammal	MI		X					
Hipposideros stenotis	Northern leaf-nosed bat	Mammal	P2							X
Isoodon auratus barrowensis	Barrow Island golden bandicoot	Mammal	VU							X
Leggadina lakedownensis	Northern short-tailed mouse; Kerakenga	Mammal	P4							X
Orcaella heinsohni	Australian snubfin dolphin	Mammal	IA		X					
Petrogale concinna monastria	Nabarlek	Mammal	EN and IA							X
Sula leucogaster	Brown booby	Bird	IA		X					

LISTED FAUNA: ***Scientific name***	**Common name**	**Class**	**Conservation category code**	**Terrestrial**	**Marine**	**Mudflat**	**Freshwater**	**GDE**	**Surface water habitat**	**Island**
Thalasseus bergii	Crested tern	Bird	IA		X	X				
Anous stolidus	Common noddy	Bird	IA		X					
Sterna dougallii	Roseate tern	Bird	IA		X	X				
Sterna hirundo	Little tern	Bird	IA		X					
Philomachus pugnax	Ruff; Reeve	Bird	IA		X					
Caretta caretta	Loggerhead turtle	Reptile	EN and IA		X					
Chelonia mydas	Green turtle	Reptile	VU and IA		X					
Natator depressus	Flatback turtle	Reptile	VU and IA		X					

EPBC – listed under the Environment Protection and Biodiversity Conservation Act 1999 (Cth)
BC Act – listed under the Biodiversity Conservation Act (WA)
IA – international agreements
T – threatened – critically endangered, endangered or vulnerable
EN – endangered
CR – critically endangered
VU – vulnerable
P1, P2 and P3 – maybe threatened or near threatened but are data deficient and have not yet been adequately surveyed to be listed
P4 – rare, near threatened and others in need of monitoring.

Table A2 Listed flora of the Fitzroy planning area and out into King Sound, and their likely dependence on ground or surface water

LISTED FLORA	Conservation code (status) (WA Herbarium)	Likely dependence on ground or surface water				
Scientific / common name		Definite	Likely	Possible	Unknown	Unlikely
Pandanus spiralis var. flammeus	Endangered (BC Act, EPBC Act)	X				
Acacia camptocarpa	Priority 1					X
Acacia gloeotricha	Priority 1			X		
Acacia hypermeces	Priority 1				X	
Acacia manipularis	Priority 1					X
Acacia smeringa	Priority 1					X
Acacia sp. Edgar Range (S.D. Hopper 1763)	Priority 1			X		
Acrostichum aureum	Priority 1		X			
Aphyllodium parvifolium	Priority 1		X			
Aristida polyclados	Priority 1			X		
Aristida sciuroides	Priority 1					X
Clerodendrum inerme	Priority 1					X
Corymbia x pedimontana	Priority 1					X
Corymbia sp. Yampi Peninsula (R.L. Barrett and A.N. Start RLB 2280)	Priority 1					X
Cucumis sp. Bastion Range (A.A. Mitchell et al. AAM 10710)	Priority 1					X
Cullen candidum	Priority 1		X			
Cyperus unioloides	Priority 1		X			
Cyperus victoriensis	Priority 1		X			
Eragrostis petraea	Priority 1			X		
Eriocaulon inapertum	Priority 1	X				
Eucalyptus distans	Priority 1			X		

LISTED FLORA	Conservation code (status) (WA Herbarium)	Likely dependence on ground or surface water				
Scientific / common name		Definite	Likely	Possible	Unknown	Unlikely
Fimbristylis dictyocolea	Priority 1		X			
Fimbristylis sp. D Kimberley Flora (A.C. Beauglehole 52448)	Priority 1				X	
Fimbristylis subaristata	Priority 1				X	
Goodenia lunata	Priority 1					X
Goodenia malvina	Priority 1			X		
Grevillea maherae	Priority 1					X
Helicteres sp. Mt Shadforth (I.R. Telford 11609)	Priority 1			X		
Heliotropium aenigmatum	Priority 1				X	
Heliotropium calvariavis	Priority 1					X
Heliotropium foveolatum	Priority 1		X			
Heliotropium geocharis	Priority 1				X	
Heliotropium parviantrum	Priority 1				X	
Heliotropium synaimon	Priority 1				X	
Ipomoea johnsoniana	Priority 1					X
Lobelia leucotos	Priority 1		X			
Mitrasacme sp. I Kimberley Flora (K.F. Kenneally s.n. PERTH 04115058)	Priority 1		X			
Nymphaea carpentariae	Priority 1	X				
Nymphaea kimberleyensis	Priority 1	X				
Pentalepis linearifolia subsp. Nudibranchoides	Priority 1					X
Poranthera coerulea	Priority 1				X	
Rhynchosia rostrata	Priority 1					X
Rhynchospora gracillima	Priority 1		X			

LISTED FLORA	Conservation code (status) (WA Herbarium)	Likely dependence on ground or surface water				
Scientific / common name		**Definite**	**Likely**	**Possible**	**Unknown**	**Unlikely**
Sorghum plumosum var. teretifolium	Priority 1					X
Spiranthes sinensis	Priority 1				X	
Tephrosia cardiophylla	Priority 1					X
Thespidium basiflorum	Priority 1		X			
Trachymene oleracea subsp. Sedimentum Rye	Priority 1					X
Trianthema kimberleyi	Priority 1					X
Triodia diantha	Priority 1					X
Triodia pascoeana	Priority 1			X		
Triodia sp. Kurungal (A.B. Craig ABC 1675)	Priority 1					X
Triumfetta hapala	Priority 1					X
Urochloa polyphylla	Priority 1					X
Utricularia circumvoluta	Priority 1	X				
Vincetoxicum polyanthum	Priority 1					X
Viscum articulatum	Priority 1					X
Whiteochloa sp. Hann River (Aplin et al. 917)	Priority 1				X	
Acacia capillaris	Priority 2					X
Alysicarpus suffruticosus	Priority 2			X		
Arivela kenneallyi	Priority 2					X
Blumea pungens	Priority 2					X
Cayratia cardiophylla	Priority 2					X
Eragrostis filicaulis	Priority 2			X		
Erpodium coronatum var. australiense	Priority 2					X

LISTED FLORA	Conservation code (status) (WA Herbarium)	Likely dependence on ground or surface water				
Scientific / common name		Definite	Likely	Possible	Unknown	Unlikely
Eucalyptus fitzgeraldii (Broad-leaved box)	Priority 2					X
Eucalyptus ordiana	Priority 2					X
Eucalyptus revelata	Priority 2					X
Hibiscus calcicola	Priority 2			X		
Ipomoea racemigera	Priority 2		X			
Minuria macrorhiza	Priority 2					X
Olax spartea	Priority 2					X
Paspalidium retiglume	Priority 2					X
Pterocaulon globuliflorum	Priority 2					X
Schoenoplectiella humillima	Priority 2			X		
Synostemon judithae	Priority 2			X		
Tephrosia sp. Kununurra (T. Handasyde TH00 250)	Priority 2			X		
Viscum whitei subsp. Flexicaule	Priority 2					X
Warnstorfia fluitans	Priority 2		X			
Acacia monticola x tumida var. kulparn	Priority 3					X
Alysicarpus major	Priority 3					X
Boronia pauciflora	Priority 3					X
Colocasia esculenta var. aquatilis	Priority 3		X			
Corchorus fitzroyensis	Priority 3			X		
Dasymalla chorisepala	Priority 3					X
Decaisnina biangulata	Priority 3					X
Dendrolobium cheelii	Priority 3					X

LISTED FLORA	Conservation code (status) (WA Herbarium)	Likely dependence on ground or surface water				
Scientific / common name		Definite	Likely	Possible	Unknown	Unlikely
Dicarpidium sp. Mt Leake (T. Willing 469)	Priority 3					X
Eleocharis ochrostachys	Priority 3	X				
Eragrostis spartinoides	Priority 3					X
Eriachne sp. Carson Escarpment (R.L. Barrett and M.D. Barrett RLB 4884)	Priority 3					
Eriochloa fatmensis	Priority 3		X			
Eulophia bicallosa	Priority 3			X		
Fimbristylis sieberiana	Priority 3		X			
Gardenia gardneri	Priority 3					X
Glycine falcata	Priority 3		X			
Glycine pullenii	Priority 3		X			
Gomphrena cucullata	Priority 3		X			
Gomphrena leptophylla	Priority 3			X		
Goodenia byrnesii	Priority 3					X
Goodenia pumilio	Priority 3		X			
Goodenia sepalosa var. glandulosa	Priority 3					X
Helminthostachys zeylanica	Priority 3		X			
Indigofera ammobia	Priority 3					X
Isotropis browniae	Priority 3					X
Leptospermum madidum subsp. Sativum	Priority 3		X			
Limnophila aromatica	Priority 3					X
Lysiandra fuernrohrii	Priority 3					X
Maireana prosthecochaeta	Priority 3					X

LISTED FLORA	Conservation code (status) (WA Herbarium)	Likely dependence on ground or surface water				
Scientific / common name		**Definite**	**Likely**	**Possible**	**Unknown**	**Unlikely**
Nymphoides beaglensis	Priority 3	X				
Olearia arguta var. arguta	Priority 3					X
Paranotis halfordii	Priority 3			X		
Pterocaulon xenicum	Priority 3					X
Rhynchospora rubra	Priority 3		X			
Rothia indica subsp. Australis	Priority 3					X
Schoenus punctatus	Priority 3		X			
Solanum leopoldense	Priority 3					X
Stylidium costulatum	Priority 3			X		
Stylidium pindanicum	Priority 3			X		
Stylidium rubriscapum	Priority 3			X		
Synostemon hubbardii	Priority 3			X		
Synostemon rigidulus	Priority 3			X		
Tephrosia funicularis	Priority 3					X
Tephrosia pedleyi	Priority 3					X
Tephrosia rosea var. Napier Range (C.R. Dunlop 7760 and B.K. Simon)	Priority 3					X
Tephrosia sp. Mistake Creek (A.C. Beauglehole 54424)	Priority 3					X
Trachymene dusenii	Priority 3					X
Triodia acutispicula	Priority 3					X
Utricularia bidentata	Priority 3	X				
Utricularia muelleri	Priority 3	X				
Zornia sp. West Kimberley (C.A. Gardner 9942)	Priority 3					X

LISTED FLORA	Conservation code (status) (WA Herbarium)	Likely dependence on ground or surface water				
Scientific / common name		Definite	Likely	Possible	Unknown	Unlikely
Borya subulata	Priority 4					X
Eucalyptus mooreana (Mountain White Gum)	P4		X			
Grevillea adenotricha	Priority 4					X
Grevillea miniata	Priority 4					X
Polygala parviloba	Priority 4					X
Triodia aeria	Priority 4					X

EPBC Act – listed under the Environment Protection and Biodiversity Conservation Act 1999 (Cth)

BC Act – listed under the Biodiversity Conservation Act (WA)

IA – international agreements

T – threatened – critically endangered, endangered or vulnerable

EN – endangered

CR – critically endangered

VU – vulnerable

P1, P2 and P3 – maybe threatened or near threatened but are data deficient and have not yet been adequately surveyed to be listed

P4 – rare, near threatened and others in need of monitoring.

Glossary

Term	Meaning
Abstraction	The taking of water from any source of supply.
Aboriginal cultural value	This report does not provide a definition of Aboriginal cultural value. This term has many definitions for Aboriginal people and when we use it, we mean it in the widest possible use of the term.
Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock. Aquifer types include unconfined, confined, and artesian.
Aquitard	A geological formation that may contain groundwater but is not capable of transmitting significant quantities of it under normal hydraulic gradients.
Artesian aquifer	A confined aquifer in which the hydraulic pressure will cause water to rise in a bore or spring above the land surface. If the pressure is insufficient to cause the well to flow at the surface, it is called a sub-artesian aquifer.
Artesian bore	A well, including all associated works, from which water flows, or has flowed, naturally to the surface.
Biodiversity	Biological diversity or the variety of organisms, including species themselves, genetic diversity and the assemblages they form (communities and ecosystems). Sometimes includes the variety of ecological processes within those communities and ecosystems.
Bore	A narrow, normally vertical hole drilled in soil or rock to monitor or withdraw groundwater from an aquifer.
Catchment	The area of land from which rainfall runoff contributes to a single watercourse, wetland or aquifer.
Confined aquifer	An aquifer lying between confining layers of low-permeability strata (such as clay, coal or rock) so that the water in the aquifer cannot easily flow vertically.
Confluence	Running together, flowing together, e.g. where a tributary joins a river.
Country (when used in connection with Aboriginal people)	Country means the lands, waterways, seas and skies to which Aboriginal peoples are intrinsically linked. Wellbeing, law, place, custom, language, spiritual belief, cultural practice, material sustenance, family and identity are all interwoven as one.
Cultural value	Cultural values are the core principles and value systems that underpin a community, a society or, in the case of Traditional Owners, a nation, clan or language group. They may be associated with a site of cultural significance or associated with the living, historical and traditional observances, practices, customs, beliefs, values, knowledge, relationships and skills of Aboriginal people. Cultural values of Traditional Owners can only be determined by them

Term	Meaning
	and are expressed in many ways such as narrative, songlines, art and maps.
Dam	An embankment constructed to store or regulate surface water flow. A dam can be constructed in or outside a watercourse.
Discharge	The water that moves from the groundwater to the ground surface or above, such as a spring. This includes water that seeps onto the ground surface, evaporation from unsaturated soil, and water extracted from groundwater by plants (see Evapotranspiration) or engineering works.
Discharge rate	Volumetric outflow rate of water, typically measured in cubic metres per second.
Dissolved oxygen	The concentration of oxygen dissolved in water normally measured in milligrams per litre (mg/L).
Ecological values	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems.
Ecological water requirement	The water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.
Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact, e.g. a lake, to include all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
Environment	Living things, their physical, biological, cultural and social surroundings, and interactions between all of these as defined under section 3, *Environmental Protection Act 1986* (WA).
Evaporation	Loss of water from the water surface or from the soil surface by vaporisation due to solar radiation.
Evapotranspiration	The combined loss of water by evaporation and transpiration. It includes water evaporated from the soil surface and water transpired by plants.
Flow	Streamflow in terms of m^3/a, m^3/d or ML/a. May also be referred to as discharge.
Groundwater	Water which occupies the pores and crevices of rock or soil beneath the land surface.
Groundwater area	A water resource management area proclaimed under the *Rights in Water and Irrigation Act 1914* (WA) and used for licensing, planning and managing the groundwater resources in that area.
Groundwater-dependent ecosystem	An ecosystem that is at least partially dependent on groundwater for its existence and health.
Hydrogeology	The hydrological and geological science concerned with the occurrence, distribution, quality and movement of groundwater,

Term	Meaning
	especially relating to the distribution of aquifers, groundwater flow and groundwater quality.
Hydrograph	A graph showing the height of a water surface above an established datum plane for level, flow, velocity, or other property of water with respect to time.
Licence (or licensed entitlement)	A formal instrument granted under the *Rights in Water and Irrigation Act 1914* (WA) to: • construct or alter a well (bore), including monitoring bores, production bores, and replacing collapsed bores or decommissioning abandoned bores (section 26D). • take water (the licensed entitlement) from a water resource in accordance with the specified terms, conditions and restrictions on the licence (Section 5C).
Native title	The recognition that a group of Aboriginal people have rights and interests to land and waters according to their traditional law and customs as set out in Australian law – *Native title Act 1993* (Cth).
Native title party	In relation to an area of land where a water licence or permit is applied for, the relevant Native title party has the meaning given in section 24HA(7)(a) of the *Native title Act 1993* (WA), including: • a representative Aboriginal/Torres Strait Islander body • a registered Native Title body corporate, or • a registered Native Title claimant. In the case of the Fitzroy planning area, the representative body is the Kimberley Land Council.
Precautionary principle	Taking a cautious approach to development and environmental management decisions when information is uncertain, unreliable or inadequate.
Recharge	Water that infiltrates into the soil to replenish an aquifer.
Reliability	The frequency with which water allocated under a water access entitlement is able to be supplied in full. Referred to in some states as ‘high security’ and ‘general security’.
Salinity	The measure of total soluble salt or mineral constituents in water. Water resources are classified based on salinity in terms of total dissolved salts (TDS) or total soluble salts (TSS). Measurements are usually in milligrams per litre (mg/L) or parts per thousand (ppt).
Social value	Social values are the behaviours and beliefs that people share within a community or social group that contributes to wellbeing, sustainability, society and diversity.
Soak	An excavation below ground level that usually intercepts groundwater. Where a wall is also constructed above ground, a combination of surface runoff and groundwater may be captured. Soaks may also be constructed close to a watercourse to obtain water. Other names for soaks may include excavations, dugouts or sumps.

Term	Meaning
Spring	As defined in s 2(1) of the *Rights in Water and Irrigation Act 1914*, a spring means a spring of water naturally rising to and flowing over the surface of land but does not include the discharge of underground water directly into a **watercourse**, **wetland**, reservoir or other body of water.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Traditional Owner	An Aboriginal person/s is a Traditional Owner if they are: • a **Native title holder** • a registered Native title claimant or claim group • a member of a regional Aboriginal Corporation established under a settlement agreement with the government • a person who is recognised as having the cultural authority to speak for a place.
Watercourse	As defined in section 3(1) of the *Rights in Water and Irrigation Act 1914,* a watercourse means: a) any river, creek, stream, or brook in which water flows b) any collection of water (including a reservoir) into, through or out of which any thing coming within paragraph (a) flows c) any place where water flows that is prescribed by local by-laws to be a watercourse d) and includes the bed and banks of any thing referred to in paragraph (a), (b) or (c).
Water-dependent ecosystems	Those parts of the environment, the species composition and natural ecological processes, of which are determined by the permanent or temporary presence of water resources, including flowing or standing water and water within groundwater aquifers.
Water regime	A description of the variation of flow rate or water level over time. It may also include a description of water quality.
Watertable	The saturated level of the unconfined groundwater. Wetlands in low-lying areas are often seasonal or permanent surface expressions of the watertable.
Waterways	All streams, creeks, stormwater drains, rivers, estuaries, coastal lagoons, inlets and harbours.
Wetland	As defined in section 2 of the *Rights in Water and Irrigation Act 1914*, a wetland is a natural collection of water, whether permanent or temporary, on the surface of any land and includes — a) any lake, lagoon, swamp or marsh; and b) a natural collection of water that has been artificially altered but does not include a watercourse.

Volumes of water

One litre	1 litre	1 litre	(L)
One thousand litres	1000 litres	1 kilolitre	(kL)
One million litres	1 000 000 litres	1 megalitre	(ML)
One thousand million litres	1 000 000 000 litres	1 gigalitre	(GL)

Units of measure

^oC	Degrees centigrade, a unit of measure for temperature
ha	Hectares
km^2	Kilometres squared
m	Metres
mm	Milimetres
m^3s^{-1}	Cubic metres per second, a unit of discharge or flow
mS/cm	Millisiemens per centimetre, a unit of measure used for salinity
mbgl	Metres below ground level

Shortened forms

ACHIS	Aboriginal Cultural Heritage Inquiry System
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ANZECC	Australian and New Zealand Environment and Conservation Council
BC Act	*Biodiversity Conservation Act 2016* (WA)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	Department of Biodiversity, Conservation and Attractions
DPLH	Department of Planning, Lands and Heritage
DWER	Department of Water and Environmental Regulation
EP Act	*Environmental Protection Act 1986* (WA)
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
IUCN	International Union for Conservation of Nature
NAWRA	Northern Australian Water Resource Assessment
NESP	National Environmental Science Program (NESP) researchers, based at the University of Western Australia (UWA) and Griffith University, and the Centre for Sustainable Aquatic Ecosystems at Murdoch University.
PEC	priority ecological community
TEC	threatened ecological community

Map information

Datum and projection information

Projection: GDA94 MGA zone 51

Spheroid: GRS 1980

Map Author: Hisayo Thornton

Filepath: J:\gisprojects\Project\DWER\3000_SCI_PLA\3430_WAP\0060_Fitzroy_Env_Heritage_Values_Report

Compilation date: June 2022

Disclaimer

The maps in this report are a product of the Department of Water and Environmental Regulation. These maps were produced with the intent that they be used for information purposes within this document and at the scale shown when printing.

While the department has made all reasonable efforts to ensure the accuracy of this data, we accept no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Map sources

The department is custodian of the following datasets used in production of the maps in this report:

Coastline – DWER 2006

Fitzroy water planning area – DWER 2019

Groundwater connectivity – DWER 2022

NDVI – DWER 2018, derived from Sentinel 2 data

Potential stygofauna habitat – DWER 2019, derived from DMIRS 2019

Rivers – DWER 2019

Springs – DWER 2020, derived from Landgate 2020, DBCA 2022 and DWER 2022

Surface geology – DWER 2019, derived from DMIRS 2019

Stream gauging stations – DWER 2022

Wild rivers – DWER 2022

The department acknowledges the following datasets and their custodians in the production of the maps in this report:

Aboriginal communities and town reserves – DPLH 2020

Aboriginal sites and heritage places – DPLH 2019

Coastal habitats – Geoscience Australia 2013

Commonwealth heritage listed area – Department of Agriculture, Water and the Environment 2018

Conservation estate – DBCA 2022

Declared Indigenous Protected Area – Department of Agriculture, Water and the Environment 2022

EPA redbook reserves – DBCA 2017

Fish distribution on the Fitzroy River catchment – NESP unpublished

Floodplain – Landgate 2011

Historical heritage place – DPLH 2019

Imagery – Landgate 2022

Indigenous fish harvest – NESP unpublished

Mangroves – Landgate 2019

National heritage list– Department of Agriculture, Water and Environment 2020

Persistent waterholes – CSIRO 2018, derived from Landsat archive

Roads – Landgate 2022

Towns – Landgate 2022

Threatened and priority flora, fauna, ecological communities – DBCA 2022

The vegetation of tropical savannas – Environmental Protection Agency, Queensland Government 2001

Turtle nesting beaches – DBCA 2008

Wetlands (DIWA) – Department of Agriculture, Water and the Environment 2021

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