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A review of the status of water resources and fish communities within the Marne Saunders Prescribed Water Resource Area

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Report to the Murraylands and Riverland Landscape Board

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1. Executive Summary

Background

The Marne Saunders Prescribed Water Resource Area (PWRA) covers an area of ~743 km^2 across the Eastern Mount Lofty Ranges (EMLR), in the lower reaches of the Murray Darling Basin in South Australia. The Marne Saunders PWRA is comprised of two catchments: the Marne River and Saunders Creek catchments with the major waterway being the Marne River. The Marne Saunders PWRA is largely divided into two zones, the higher elevated Hills Zone and the lowland Plains Zone; headwater streams originate in the higher rainfall Hills Zone before flowing downstream to the eastward Plains Zone. Annual rainfall for the Marne Saunders PWRA is not uniform throughout the catchment, with most of the catchment's rainfall occurring in the Hills Zone. Generally, the status of rainfall and associated streamflow in the Marne Saunders PWRA is significantly lower than other catchments of the region. The prescription of water resources through the licensing of water usage for specific purposes was implemented to provide sustainable management in the Marne Saunders PWRA. Formalisation of the Water Allocation Plan (WAP) for the Marne Saunders PWRA was achieved in 2010 with revision taking place in 2019.

Over 2002–2021, a total of 21 freshwater fish species (15 native; six alien) have been sampled across the Marne Saunders PWRA. Knowledge of fish communities within the Marne Saunders PWRA has been gained through an initial inventory and surveys as part of projects across the broader EMLR. During 2007, fish communities of the EMLR, including the Marne Saunders PWRA were reviewed, with the fish-related assets identified and the development of an annual monitoring plan to evaluate the condition of these fish-related assets, annual fish monitoring has occurred since 2007.

Aims and Methods

This project aimed to review of the status of water resources and fish communities within the Marne Saunders PWRA. Three main objectives were to:

- Evaluate trends in water quality and flow regime data (including flow metrics);
- Review the long-term fish monitoring dataset and provide a summary of fish community condition and trends; and

- Assess the effectiveness of water management and provide recommendation to assist with further refining of the environmental water requirements and water allocation planning.

The objectives of this report were achieved through the collation and evaluation of existing data including, fish survey and water quality data collected throughout the Marne Saunders PWRA over a 20-year period from 2002–2021; rainfall, ground water and surface flow data collected from gauging stations strategically placed throughout the catchment.

Key findings

The findings of the present review revealed a picture of substantial decline across the Marne Saunders PWRA. Namely, the review highlights that over 2002–2021 the Marne Saunders PWRA experienced, the:

- Decline in rainfall and runoff;
- Reduced surface flow and groundwater levels;
- Reduction of flow days at gauged sites;
- Reduced water quality, specifically an increase in salinity.
- EWRs for fish related assets not being delivered; and
- Shift in fish communities with reduction and likely future loss of fish-related assets.

The demonstrated decline in condition at most sites, indicate that environmental water requirements (EWRs) are not being supplied for the support of fish-related assets of the Marne Saunders PWRA. The primary factor contributing to decline is reducing rainfall and runoff that as resulted in the lack of surface flow and deterioration of groundwater and surface water quality. Unless the natural flows of the Marne Saunders PWRA can be restored (or replicated), further decline in the condition of waterways and fish communities can be expected.

Recommendations

For the mitigation of further decline of fish-related assets of the Marne Saunders PWRA, it is recommended that, where possible considering climatic pressures, WAP principals are followed to ensure that the environmental water provisions are provided for each of the fish-related assets within all reaches of the Marne Saunders PWRA.

2. Background

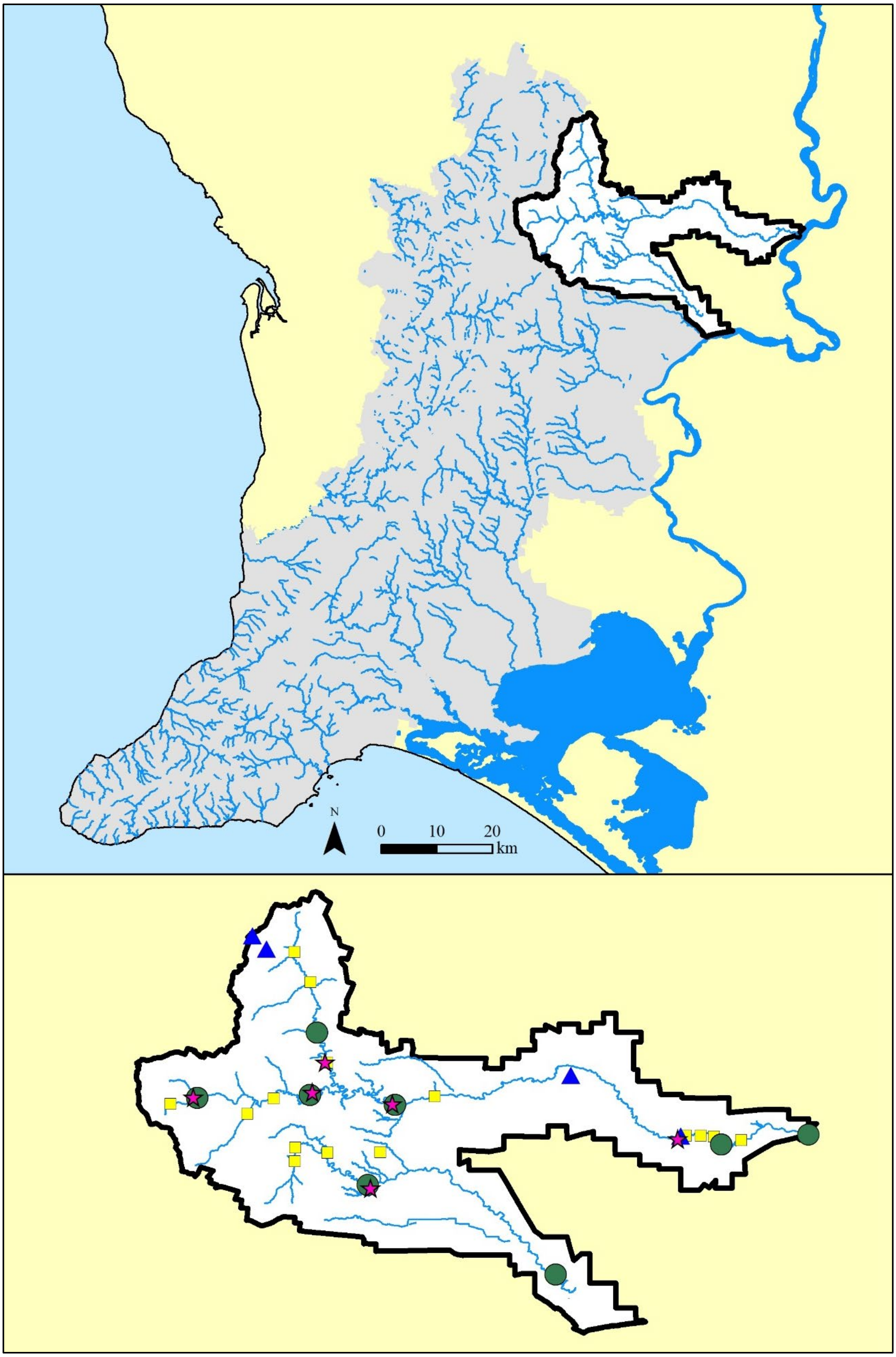
South Australia experiences a Mediterranean climate, with hot, dry summers and relatively mild winters. South Australia is also Australia's driest state and largely depends on three major resources of fresh water: the River Murray, catchments of the Mount Lofty Ranges and groundwater (Cox et al. 2016). Historical and enduring anthropogenic impacts are prevalent throughout much of South Australia and include land clearing, habitat degradation, water use and reduced water quality, resulting in diminished ecosystem function and loss of biodiversity. In response to such environmental threats, the Murraylands and Riverlands Landscape Board (along with other landscape boards) has developed a regional landscape plan with a range of regional priorities aimed at sustainable management and protection of natural resources within each region across the state. In addition, water allocation plans (WAP) have been developed, which specifically seek to balance the environmental water requirements of the ecosystem with the needs of consumptive water users as set out under the *Landscape South Australia Act* 2019. WAPs have been developed for Prescribed Water Resource Areas (PWRA) across the state, including the Barossa (AMLRNRM Board 2009; AMLRNRM Board 2014), Western Mount Lofty Ranges (WMLR: AMLRNRM Board 2013), Eastern Mount Lofty Ranges (EMLR: SAMDBNRM Board 2013) and the Marne Saunders (SA MDB NRM Board 2019).

The Mount Lofty Ranges is a prominent region of waterways, which includes four PWRA: WMLR, EMLR, Barossa and the Marne Saunders. The EMLR supports diverse stream and swamp habitats, as well as linking habitats with the lower reaches of the Murray-Darling Basin (MDB) (Hammer 2004; Whiterod and Hammer 2014; Whiterod et al. 2015). In turn, these habitats support many native aquatic species, including freshwater fish, which represent a vital component of the aquatic biodiversity of the region (Hammer 2004; Whiterod and Hammer 2014; Whiterod et al. 2015). In relation to water resources, the EMLR region is separated into two PWRAs, EMLR and Marne Saunders PWRA.

Freshwater fish are considered useful indicators of environmental condition (Fausch et al. 1990), and knowledge of fish communities provides a means to assess changes over time (Green et al. 2014; McNeil and Hammer 2007). An understanding of the requirements and condition of fish communities has been a central aspect of the definition of objectives within WAPs. The assessment of spatial patterns and temporal trends in fish communities has proved useful in assessing of the status of catchment areas and has an provided opportunity to evaluate in the Barossa PWRA (Green et al. 2014; Whiterod et al. 2018) and EMLR (Whiterod and Hammer 2014; Whiterod et al. 2015). The present project draws on a long-term dataset (2002–2021) to review flow, water quality and fish communities across the Marne Saunders PWRA.

2.1 Marne Saunders Prescribed Water Resources Area (PWRA)

The Marne Saunders Prescribed Water Resources Area (PWRA) represents one of six PWRAs in South Australia (SA MDB NRM Board 2019). The Marne Saunders PWRA covers an area of ~743 km^2 across the EMLR, in the South Australian section of the lower reaches of the MDB. The Marne Saunders PWRA is topographically characterised by hills and valleys in the west of the PWRA before extending into flat plains in the east, terminating at the Murray River (Figure 2-1). Within its extent, the Marne Saunders PWRA supports several townships including Cambrai, Eden Valley and Springton. The climate of the PWRA is characterised as Mediterranean; summers are typically hot and dry, with seasonal rainfall largely occurring during winter and spring. Annual rainfall for the Marne Saunders PWRA is not uniform throughout the catchment and shows significant difference between the upper reaches in the west with the lowland reaches in the east of the PWRA (Figure 4-1). Within the Marne Saunders PWRA, the long-term (1908–2021) mean annual rainfall for upper reaches (Keyneton) was 528.8 mm whereas the lowland reach (Black Hill) has a long-term (1936–2021) mean annual rainfall of 284.8 mm. Generally, the current status of rainfall and associated streamflow as defined by the Department of Environment and Water's Water Resource Status Reports in the Marne Saunders PWRA is significantly lower than other catchments of the region (DEW 2020).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Groundwater resources

Groundwater resources occur throughout the Marne Saunders PWRA and are comprised of two differing aquifer types, fractured rock aquifers and sedimentary aquifers (Table 2-1). The differing aquifer types shift geographically with the major regions of the Marne Saunders PWRA, fractured rock aquifers are found in the elevated hills zone and sedimentary aquifers found in the lowland plains zone. The fractured rock aquifers are recharged through rainwater percolating through sediments. Movement of groundwater within the aquifers is then largely dictated by topography of the catchment, with the water flowing from elevated to low areas. Groundwater from the fractured rock aquifers in the Marne Saunders PWRA Hills Zone discharges at lower elevations into streams and sedimentary aquifers of the Plains Zone. Discharge into streams is of particular importance as this discharge forms the baseflow component of flow in some reaches of the Marne Saunders PWRA. It can also lead to the presence of permanent pools, which are vital refuge habitat for obligate aquatic flora and fauna including freshwater fish. The sedimentary aquifers of the Plains Zone discharges water through evapotranspiration of deep-rooted vegetation such as River Red Gum (*Eucalyptus camaldulensis*) and via flow (both surface and subsurface) into lowland streams of the Marne Saunders PWRA and the River Murray.

Surface water resources

The Marne Saunders PWRA comprises of two catchments: the Marne River Catchment and the Saunders Creek Catchment (SA MDB NRM Board 2019). The main waterway is the Marne River, which includes several headwater streams that originate in higher rainfall areas east of the catchment, also known as the Hills Zone, before flowing downstream through upper (UPR) and mid pool-riffle (MPR) reaches, where tributaries such as the North Rhine River inflow, before reaching the constrained gorge reach (Table 2-1). The lowland reach of the Marne River contains an ephemeral River Red Gum lined channel through much drier lowland reach until it reaches the township of Black Hill. Surface water connection between the upper and lower sections is only facilitated by flows and flood spates with sufficient magnitude to traverse the ephemeral channel. The Marne River flows into the terminal wetland, which is influenced by both Marne River flows and Murray River flows (and inundation).

Table 2-1. Defined reach types of for Mount Lofty Range streams and major aquifer types (green shading) within the Marne Saunders PWRA (after VanLaarhoven and van der Wielen 2009).

Reach/Aquifer type	Description
Headwaters	Located high in catchment, rocky headwaters exhibit bedrock, cobble or gravel bed in steep areas whereas alluvial headwaters are usually featureless valleys of mud or sand and distinct channels may or may not exist.
Upper pool–riffle (UPR)	Characterised by a series of pools linked by short riffles or long runs in upper catchments. Sites in this reach experience seasonal episodic rainfall that creates surface flow through riffles and runs, connecting semi-permanent pools.
Mid pool–riffle (MPR)	Typified by strings of pools connected by short riffles or long runs in mid-catchment. The flow patterns are like those observed in UPR but with greater rates of flow due to increased size of the catchment area.
Gorge	Typified by a narrow steep gradient where flows passing over coarse substrates (e.g., bedrock and cobble) create a high energy flow environment.
Lowland	Characterised by a gradual gradient large channel emerging from hills and consists of a series of extensive pools separated by short-runs and infrequent riffle sections.
Terminal wetlands	Located where streams discharge (in this case to Murray River but also Lake Alexandrina) and under dual influence.
Fractured Rock aquifers	Located in the western elevated areas of the Marne Saunders PWRA (Hills Zone), fractured rock aquifers are tightly bound and impermeable with low porosity to hold groundwater.
Murray Group Limestone aquifer	Murray Group Limestone aquifer is sandy, contains high amounts of fossils and solution cavities are present. This forms the main aquifer within the Plains Zone

The Saunders Creek Catchment spans a relatively long narrow area from near Springton through to the Murray River northeast of Mannum (Figure 2-1). Only a small section of the catchment extends into higher elevations and hence rainfall is low and irregular across most of the catchment (and even here there appears to be a significant rain shadow effect). Its headwaters comprise two small tributary streams that flow in a northerly direction, before both turn to the east and join just before a steep rocky gorge (Table 2-1). From below the gorge, Saunders Creek is an ephemeral lowland channel that meanders in a roughly south-easterly direction until reaching a small section of spring fed, permanent pools lined with River Red Gum and Common Read (*Phragmites australis*) in the region of Lenger Reserve (~5 km upstream from the Murray River). Below here, the channel is once again ephemeral and shallow, with no significant defined wetland area where the creek joins the Murray River.

Rainfall and surface runoff is the primary supply of water availability and flow for the Marne Saunders PWRA (SA MDB NRM Board 2019). In the Upper Marne Catchment, the mean long-term runoff was 7710 megalitres (ML) for the 1973–1997 period, however, runoff amounts were variable and episodic (Savadamuthu 2002). Rainfall, and therefore runoff and streamflow, are highest in the upper catchment, while in the lower catchment little runoff is produced; streamflow is also reduced in the lower catchment due to aquifer recharge (SAMDBNRM Board 2013). Water resource development, largely through dam capture of runoff and flow, impacts water availability and flow in the catchment. It was estimated that there was an average reduction of flows by 18% for the 1975 to 1988 period (Savadamuthu 2002). Further, modelling estimates that the average annual adjusted streamflow without dams for the 1974–2003 period to be 8406 ML (SA MDB NRM Board 2019).

Due to the small size of the Saunders Creek Catchment, flow is infrequent and therefore little permanent flow stream habitat is maintained. Available stream habitat includes a few pools upstream in the gorge reach, and the small string of pools in the lowland reach. Flow gauge data for the Saunders Creek Catchment was not available for early years; however, modelled average annual adjusted flow based on runoff from the Upper Marne and localised rainfall, indicated 1003 ML of flow for the Upper Saunders during 1974–2003 (SA MDB NRM Board 2019). Stock access is common across considerable sections of the catchment; however, where water occurs some areas have been fenced or have no stock (e.g., Saunders Gorge Sanctuary and some areas upstream from there, Lenger Reserve and upstream pools).

The flow regime of the Marne Saunders PWRA (based on natural conditions) is defined across four flow seasons, namely low-flow season (LFS), transitional flow season 1 (T1), high-flow season (HFS), and transitional flow season 2 (T2) (Figure 1-2; VanLaarhoven and van der Wielen 2009). The LFS (December to April) is characterised by periods of low to zero flows, interspersed with infrequent higher pulse flows (i.e., freshes) following rainfall. The T1 season (May-June) reflects increasing flow level and duration during the transitions from the LFS to the HFS (July to October), which is characterised by higher baseflow and frequent higher flow freshes. Finally, decreasing flow level and duration over the transition between the HFS to LFS seasons characterise the T2 season (November). In the Marne Saunders PWRA, the flow year is deemed to run from the start of the LFS season (i.e., December) through to the end of the T2 season and can be schematically defined as LFS→T1→HFS→T2.

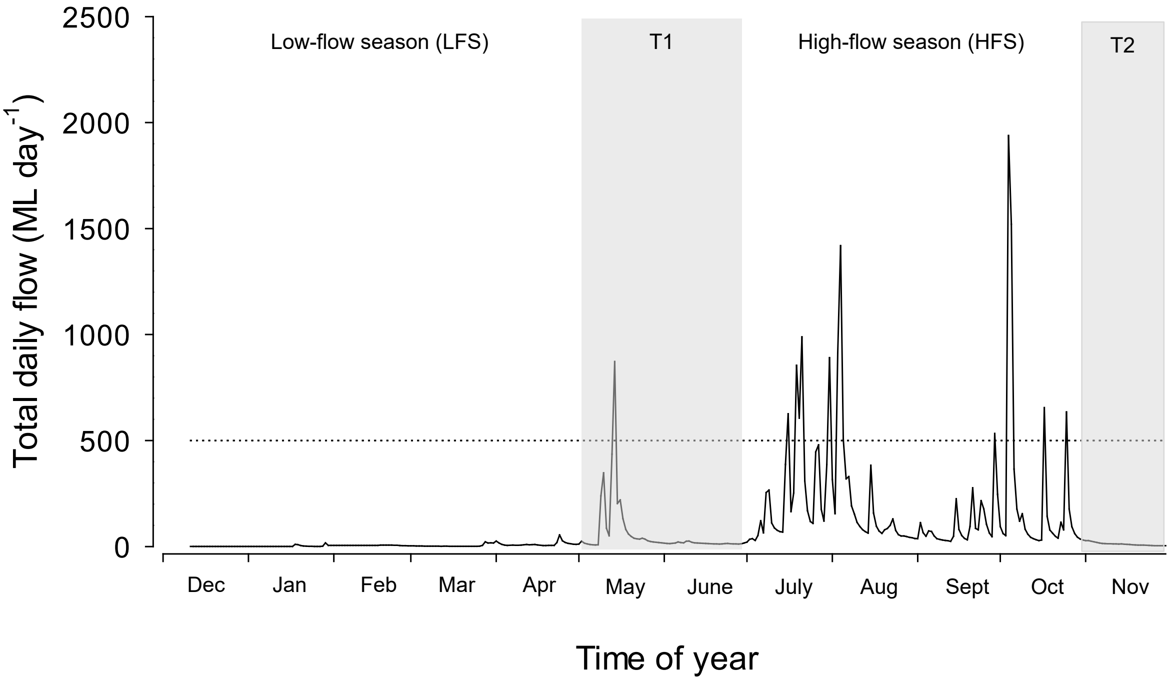

Figure 2-2. Representative flow regime for gorge reach of Marne Saunders PWRA (based on Marne River – Marne Gorge (A426065)). The flow year is deemed to run from the start of the low flow season (LFS) through the transition between low and high-flow seasons (T1), the high flow season (HFS), before ending with the transition between HFS and LFS flow seasons (T2).

Water resources management

Prescription of water resources by licensing of water usage for specific purposes was implemented to provide sustainable management in the Marne Saunders PWRA (SA MDB NRM Board 2019). Such regulation applies to surface water, watercourse water and wells within the Marne River and Saunders Creek PWRA and was first introduced in March 2003 (SA MDB NRM Board 2019). Formalisation of the WAP for the Marne Saunders PWRA was achieved in 2010 with revision taking place in 2019 to ensure compliance with the Murray Darling Basin Plan (SA MDB NRM Board 2019).

2.2 Freshwater fish in the Marne Saunders PWRA

Fish species and functional groups

Within the MLR, 47 freshwater fish species have been recorded (Hammer et al. 2012) of which 38 (30 native, eight alien) occur in the EMLR (Hammer 2004; Whiterod and Hammer 2014; Whiterod et al. 2015). Of the species recorded in the EMLR, three are nationally threatened whereas 16 species are protected or considered threatened at state level, according to the

Action Plan for SA Freshwater Fish (Hammer et al. 2009). Additionally, marine variants have been irregularly detected in the EMLR region (e.g., sandy sprat during 2004 baseline inventory: Hammer 2004). Knowledge of the fish communities in the Marne Saunders PWRA throughout the period 1999–2007 was gained through the initial inventory (Hammer 2004) and surveys as part of projects across the broader EMLR (Whiterod and Hammer 2014). In 2007, the fish community of the EMLR, including the Marne Saunders PWRA was reviewed, with identification of fish-related assets and the development of a monitoring approach to assess the condition of these fish-related assets (Hammer 2007b). Since 2007, annual monitoring has occurred to allow for the evaluation of the condition of the fish communities across the Marne Saunders PWRA and broader EMLR, with reviews undertaken in 2019 (Hammer 2009) and 2014 (Whiterod and Hammer 2014).

A total of 21 freshwater fish species (15 native; six alien) have been recorded across the Marne Saunders PWRA (Table 1-2: Hammer 2004). These species have been assigned to functional groups, based on their ecological requirements, which have been used to identify fish-related assets (Table 2-3 and Table 2-4) (Hammer 2007b; Hammer 2009; SAMDBNRM Board 2013; VanLaarhoven and van der Wielen 2009). Two species represent the main fish-related assets of the Marne Saunders PWRA; these species are the freshwater specialists Obscure Galaxias (*Galaxias oliros*) and River Blackfish (*Gadopsis marmoratus*). Obscure Galaxias are relatively widespread throughout UPR, lowland and gorge reaches, while River Blackfish are becoming increasingly rare within the catchment and in recent years have only been detected at one lowland reach sampling site in low abundance. Other fish-related assets of the Marne Saunders PWRA are the native freshwater generalist Carp Gudgeon (*Hypseleotris* sp.) population within lowland reach of the Saunders Creek Catchment and the terminal wetland of the Marne River Catchment. Freshwater generalist Carp Gudgeon are prevalent throughout the Marne Saunders PWRA, and freshwater generalist Dwarf Flathead Gudgeon (*Philypnodon macrostomus*) also occur at some sites in relatively good abundance. Alien species detected within the Marne Saunders PWRA are Common Carp (*Cyprinus carpio*) and Eastern Gambusia (*Gambusia holbrooki*), with Eastern Gambusia being the most abundant and widespread of the alien species. In the Marne River terminal wetland, species across several functional groups are infrequently detected.

Table 2-2. List of fish species recorded in the Marne Saunders PWRA. Functional groups are: FS = freshwater specialists; FG = freshwater generalist; FP = freshwater generalist, which is potamodromous; A = alien species.

Status	Functional Group	Common name	Scientific name	Notes on occurrence
Native	FS	Obscure Galaxias	*Galaxias oliros*	Marne: Dominant species in upper and mid pool-riffle reaches; Saunders: not documented
	FS	River Blackfish	*Gadopsis marmoratus*	Marne: historically common across lowland reach; now restricted to limited number of pools; Saunders: not documented
	FG	Australian Smelt	*Retropinna semoni*	Marne: terminal wetland only; Saunders: not documented
	FG	Bony Herring	*Nematalosa erebi*	Marne: terminal wetland only; Saunders: not documented
	FG	Carp Gudgeon	*Hypseleotris* sp.	Marne: lowland reach and terminal wetland; Saunders: lowland reach
	FG	Dwarf flathead Gudgeon	*Philypnodon macrostomus*	Marne: lowland reach and terminal wetland; Saunders: not documented
	FG	Flathead Gudgeon	*Philypnodon grandiceps*	Marne: terminal wetland only; Saunders: not documented
	FG	Unspecked Hardyhead	*Craterocephalus fulvus*	Marne: terminal wetland (last recorded in 2002); Saunders: not documented
	FG	Murray Rainbowfish	*Melanotaenia fluviatilis*	Marne: terminal wetland only; Saunders: not documented
	FP	Golden Perch	*Macquaria ambigua*	Marne: terminal wetland only; Saunders: not documented
	FS (wetland)	Olive Perchlet	*Ambassis agassizii*	Marne: terminal wetland (last recorded in 1983); Saunders: not documented
	FS (wetland)	Murray Hardyhead	*Craterocephalus fluviatilis*	Marne: terminal wetland (last recorded in 1983); Saunders: not documented
	DI	Common Galaxias	*Galaxias maculatus*	Marne: terminal wetland (last recorded in 1980s); Saunders: not documented
	DI	Congolli	*Pseudaphritis urvillii*	Marne: lowland and terminal wetland (last recorded in 1980s); Saunders: not documented
	DI	Silver perch	*Bidyanus bidyanus*	Marne: terminal wetland (last recorded in 1950s); Saunders: not documented
Alien	FG	Brown Trout	*Salmo trutta*	Marne: lowland reach (last recorded in 1910s); Saunders: not documented
	FG	Common Carp	*Cyprinus carpio*	Marne: lowland and terminal wetland; Saunders: not documented
	FG	Eastern Gambusia	*Gambusia holbrooki*	Marne: UPR, MPR, lowland, terminal wetland; Saunders: not documented
	FG	Rainbow Trout	*Oncorhynchus mykiss*	Marne: lowland reach (1990s); Saunders: not documented
	FG	Redfin Perch	*Perca fluviatilis*	Marne: lowland reach (2002); Saunders: not documented
	FG	Tench	*Tinca tinca*	Marne: lowland reach (1950s); Saunders: not documented

Table 2-3. Functional groups represented in the Marne Saunders PWRA.

Functional group	Description	Example fish species
Obligate freshwater specialist (stream)	Species that reside in freshwater habitats permanently (i.e. obligate), and that have particular stream habitat or environmental requirements. Are often found as the only species in a reach but are restricted to specific habitats.	Obscure Galaxias and River Blackfish
Obligate freshwater specialist (wetland)	Species that require particular habitats or environments for survival. Are often found as rare species in diverse fish assemblages, being restricted to specific habitats within lowland or terminal stream reaches	Murray Hardyhead
Freshwater generalist	Have generalised environmental requirements, often in association with other species and occupy multiple habitat types. The community composition (and therefore the water requirements) is determined by the types of habitats present.	Carp Gudgeon, Dwarf Flathead Gudgeon and numerous species from terminal wetlands.
Diadromous species	Require migration to and from the sea or estuary.	Congolli, Common Galaxias, and Lampreys (not yet recorded from Marne PWRA)
Potamodromous species	Known to make movements within freshwater systems to complete lifecycle.	Golden Perch

Table 2-4. Fish-related assets across reaches of the Marne Saunders PWRA.

Reach	Fish-related asset	Monitored location	Management objective	EWR Table
	Marne River			
Headwaters	Little or no aquatic habitat present, so permanent fish communities absent (Obscure Galaxias may be opportunistically present but unlikely to be sustainable)	Not actively monitored	Restore self-sustaining population	Table 2-5
UPR	Obscure Galaxias	Marne River – Vigars Road Marne River – Jutland Road	Maintain or restore a self-sustaining population	Table 2-5
MPR	No permanent populations present due to lack of summer refuge, connectivity and water quality (but Obscure Galaxias occurs intermittently)	North Rhine River – Pine Hut Road	Restore self-sustaining population	Table 2-5
Gorge	Obscure Galaxias	Marne River - Gorge	Maintain or restore a self-sustaining population	Table 2-5
Lowland	River Blackfish	Marne River – Black Hill Springs (b) & Marne River – Three sisters pool (2017 onwards)	Maintain or restore a self-sustaining population	Table 2-6 & 8
	Lower Marne diverse fish community		Maintain diversity, demographics and composition of fish community	Table 2-8
Terminal wetland	Lower Marne/Murray backwater diverse fish community	Marne River – Marne Mouth	Maintain diversity and composition of fish community	Table 2-9
	Potential for diadromous fish species (Congolli, Common Galaxias, Lamprey) to colonise lower Marne River		Restore community of diadromous/rare species	Table 2-9
	Saunders Creek			
Headwaters and UPR	No permanent populations present due to lack of summer refuge, isolation and water quality (but Obscure Galaxias may have been present historically)	Not actively monitored	Restore self-sustaining population	Table 2-5 if Obscure Galaxias discovered
Gorge	No permanent populations present due to lack of summer refuge, isolation and water quality (but Obscure Galaxias may have been present historically)	Saunders Creek – Saunders Creek Gorge	Restore self-sustaining population	Table 2-5 if Obscure Galaxias discovered
Lowland	Isolated population of Carp Gudgeon	Saunders Creek – Lenger Reserve	Maintain or restore self-sustaining population	Table 2-7 & Table 2-8
Terminal wetland	Lower Saunders/Murray backwater fish community (if present)	Not actively monitored	Restore diversity and composition of fish community	Table 2-9

Environmental water requirements for fish-related assets

For the fish-related assets identified across the Marne Saunders PWRA accompanying environmental water requirements (EWRs) have been defined (Table 2-5 to Table 2-9). These EWRs have been described in terms of the dominant species (as part of functional groups) or according to the fish community groupings. Summary tables detailing these EWRs highlight: (1) the natural processes required to support environmental objectives, (2) the parts of the water regime linked to those natural processes, and (3) the monitoring approach and indicators used to assess whether these natural processes are being supported. Note that several of the objectives or water requirements implicate monitoring of environmental variables and habitat condition; fish specific techniques only are mentioned but other relevant environmental data is also routinely collected (e.g. water quality, pool depth, habitat availability), with some techniques employed that are specific to other functional groups (e.g. indicators for vegetation health).

Table 2-5. Working environmental water requirements and relevant monitoring methods for Obscure Galaxias (obligate freshwater, stream specialist) in the Marne Saunders PWRA.

Environmental objective: Maintain or restore self-sustaining populations of *Obscure Galaxias*	Water requirements	Fish monitoring methods necessary at key nodes within river reaches (with indicator in brackets)
Habitat processes		
Habitat availability	Persistence of water in pools throughout the Low Flow Season (base flow ideal). Freshes during the Low Flow Season that refill pools are important. Maintain smaller habitats and tributaries especially when exotic predators occur.	Mapping distribution at key nodes during low flow seasons (population extent).
Water quality	Freshes during the Low Flow Season that refresh water quality.	Assessing survivorship through a snapshot of demographic structure (length data).
Deep pool structure	Bank full channel forming flows that occur at a frequency and duration to maintain channel form. Prevent vegetation encroachment.	Mapping distribution at key nodes during low flow seasons (population extent).
Clean substrate for egg deposition following spawning	Freshes during the Low Flow Season.	Assessing recruitment through a snapshot of demographic structure (length data), with studies of fish biology (larvae).
Biodiversity processes		
Recolonisation of vacant habitats and mixing of extant populations	Sustained low-high flows that allow movement between pools over relatively long distances.	Mapping distribution at key nodes in river reaches during low flow seasons (population extent) over time (temporal monitoring). Studies of fish biology (movement).
Successful spawning	Increase in flows over transitional period between Low and High Flow Season in June/July triggers spawning, oxygenates riffles and allows access to new habitats (spawning sites).	Assessing recruitment through a snapshot of demographic structure (length data). Studies of fish biology (spawning and larvae).
Habitat complexity and resistance to the impacts of exotic fishes	Low flows and base flow to maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes (trout and redfin) occur.	Mapping distribution at key nodes in reaches during low flow seasons (population extent) over time (temporal monitoring).
Riparian and edge vegetation (macroinvertebrate food resources, shading, cover)	Low flows and overbank flow to maintain shallow margins and banks to encourage emergent and riparian species (e.g. sedges, amphibious woody species, River Red Gums).	Standardised environmental measures.
Suppression of exotic species	Variable flows and zero flows discourage colonisation by exotic fish and favour natives. High flow disturbances can flush exotics like Gambusia.	Assessing fish community composition (species inventory/presence), snapshot of demographic structure for exotic species (length data).

Table 2-6. Working environmental water requirements and relevant monitoring methods for River Blackfish (obligate freshwater, stream specialist) in the Marne Saunders PWRA.

Environmental objective: Maintain or restore self-sustaining populations of river blackfish	Water requirements	Fish monitoring methods necessary at key nodes within river reaches (with indicator in brackets)
Habitat processes		
Habitat availability and quality	Permanent water in pools throughout the year (via baseflow). Maintain shallow pool margins or shelves for juvenile and young fish.	Determining that fish remain in the reach (presence), assessing survivorship through a snapshot of demographic structure (length data). Studies of fish biology (spawning and health).
Water quality	Cool and well oxygenated conditions (extended low flows or permanent baseflow).	Determining that fish remain in the reach (presence), assessing survivorship through a snapshot of demographic structure (length data). Studies of fish biology (spawning and health).
Deep pool structure	High channel forming flows that occur at a frequency and duration to maintain channel form.	Mapping distribution during low flow seasons (population extent).
Minimal siltation of underwater surfaces to allow feeding and successful egg hatching	Freshes during the Low Flow Season.	Assessing survivorship through a snapshot of demographic structure (length data). Studies of fish biology (spawning and larvae).
Biodiversity processes		
Recolonisation of vacant habitats and mixing of extant populations	Low flows or occasional freshes that allow movement between pools over relatively short distances.	Mapping distribution during low flow seasons (population extent) over time (temporal monitoring). Studies of fish biology (movement).
Spawning success	Spawning and recruitment require maintenance of shallows (larval habitat) during spring and sustained into early summer (low flows and raised pool levels); probably also below a salinity threshold (<4000 EC) required for successful recruitment (i.e. freshes). Spawning occurs in hollows or cavities with a long incubation time. Freshes and sustained flows in late spring will assist recruitment.	Assessing recruitment through a snapshot of demographic structure (length data). Studies of fish biology (spawning and larvae).

Table 2-7. Working environmental water requirements and relevant monitoring methods for Carp Gudgeon (freshwater generalist) in the Marne Saunders PWRA.

Environmental objective: Maintain or restore self-sustaining populations of gudgeons	Water requirements	Fish monitoring methods necessary at key nodes within river reaches (with indicator in brackets)
Habitat processes		
Habitat availability	Persistence of water in pools throughout the Low Flow Season (base flow ideal). Freshes during the Low Flow Season that refill pools are important.	Mapping distribution at key nodes during low flow seasons (population extent).
Water quality.	Freshes during the Low Flow Season that refresh water quality.	Assessing survivorship through a snapshot of demographic structure (length data).
Deep pool structure.	Bank full channel forming flows that occur at a frequency and duration to maintain channel form.	Mapping distribution at key nodes during low flow seasons (population extent).
Biodiversity processes		
Recolonisation of vacant habitats and mixing of extant populations.	Sustained low-high flows that allow movement between pools over relatively long distances.	Mapping distribution at key nodes in river reaches during low flow seasons (population extent) over time (temporal monitoring). Studies of fish biology (movement).
Spawning success.	Low flows and warmer temperatures during the Low Flow season, low flows to stabilise water levels.	Assessing recruitment through a snapshot of demographic structure (length data). Studies of fish biology (spawning and larvae).
Habitat complexity and resistance to the impacts of exotic fishes.	Low flows and base flow maintain shallower habitats and pool margins when exotic predatory fishes (trout and redfin) occur.	Mapping distribution at key nodes in river reaches during low flow seasons (population extent) over time (temporal monitoring).
Discourage colonisation and establishment of exotic species (negative impacts of predation, competition and disease)	Variable flows and zero flows discourage colonisation by exotic fish and favour natives. Larger disturbances can flush exotics.	Assessing fish community composition (species inventory) or specific investigation for species of concern (presence), snapshot of demographic structure for exotic species (length data).

Table 2-8. Working environmental water requirements for fish communities (generalist, diadromous, potamodromous and wetland specialist functional groups) in the lowland reaches of the Eastern Mount Lofty Ranges

Environmental objective: Maintain or restore diversity and composition of fish community	Water requirements:	Fish monitoring methods necessary at key nodes within river reaches (with indicator in brackets)
Habitat processes		
Habitat availability	Permanent water in channel, anabranches and refuges (e.g. billabongs) throughout the year.	Assessing fish community composition across habitat types (species inventory), determining that species diversity is maintained in a reach (presence), mapping distributions during low flow seasons (population extent).
Water quality.	Cool and well oxygenated conditions (extended low flows or permanent baseflow). Minimise salinity impacts on the tolerance (lethal and sub-lethal) of adult or juveniles stages of native fish – freshes and flushing flows.	Determining that fish remain in the reach (presence), assessing survivorship through a snapshot of demographic structure (length data). Studies of fish biology (spawning and health).
Habitat diversity (prevent encroachment of emergent vegetation, maintain submerged vegetation)	High flows that occur at a frequency and duration to prevent vegetation encroachment, shape channels, and provide water quality and flow requirements for plant species.	Mapping distribution during low flow seasons (population extent), assessing survivorship through a snapshot of demographic structure (length data).
Deep pool structure and availability of off channel habitats	High channel forming flows that occur at a frequency and duration to maintain form and diversity of channel and off-channel habitats.	Assessing fish community composition (species inventory).
Biodiversity processes		
Provide spatial and temporal variability	Flow related disturbance to provide a variety in the types of habitats present (mosaic) to allow species co-existence or cater for the requirements of multiple species (including Southern Purple-spotted Gudgeon). Provision of contrasting habitat to that of wetlands associated with the Murray River and Lower Lakes	Assessing fish community composition (species inventory), determining that species diversity is maintained in a reach (presence), mapping distributions during low flow seasons (population extent).
Attractant flows for diadromous/ migratory fish species from the Murray River.	High flows at natural time of year (winter-spring) for diadromous/migratory fish.	Assessing fish community composition (species inventory), with studies of fish biology (movement).
Suppress exotic species	Variable flows and continuous flowing cool water discourage exotic fish and favour natives, larger flows dislodge/flush exotics.	Assessing fish community composition (species inventory), assessing survivorship through a snapshot of demographic structure (length data). Studies of fish biology (habitat use).

Table 2-9. Working environmental water requirements and relevant monitoring methods for fish communities including diadromous species (e.g. Congolli) and potamodromous species (e.g. Golden Perch) in stream habitats and terminal wetlands of Marne Saunders PWRA.

Environmental objective: Maintain or restore populations of diadromous species	Water requirements	Fish monitoring methods necessary at key nodes within river reaches (with indicator in brackets)
Habitat processes		
Habitat availability	Persistence of water in stream pools and wetlands during Low Flow. Maintenance of permanent water in slow flow areas (larval lampreys). Encourage diversity of habitat types.	Assessing fish community composition, determining that species diversity is maintained in a reach (presence), mapping distributions during low flow seasons (population extent).
Water quality	Freshes during the Low Flow Season that refresh water quality, particularly around partial barriers to dispersal that can act as population bottlenecks. Maintenance of connectivity between stream, terminal wetland and receiving water body (Murray River).	Assessing survivorship through population structure. Studies of fish biology (movement and environmental tolerances). Evaluation of fish community composition.
Deep pool structure	Bank full channel forming flows that occur at a frequency and duration to maintain channel form.	Mapping distribution at key nodes during low flow seasons and assessing fish community composition
Connectivity.	Large flows to provide physical disturbance and improve pool connectivity along the stream corridor to the Murray River.	Mapping distribution at key nodes during low flow seasons (population extent).
Habitat diversity (prevent encroachment of emergent vegetation, maintain submerged vegetation).	High flows that prevent vegetation encroachment and provide water quality and flow requirements for plant species.	Evaluate population extent and assess persistence through population structure using length data.
Biodiversity processes		
Attractant flows and fish movement. Provide spatial and temporal variability	Attractant flows. Sustained low-high flows that allow inter and intra habitat movements. Requires appropriate timing and duration for different species. Flow related disturbance to provide a variety in the types of habitats present (mosaic) to allow species co-existence or cater for the requirements of multiple species.	Temporal monitoring of population extent during low flow seasons and community composition. Studies of fish movements. Assess dispersal barriers.
Spawning success.	Increased water levels to allow access to emergent vegetation, appropriate water quality, permanence and connectivity.	Assessing recruitment through length data. Studies of fish biology (spawning and larvae).
Habitat complexity and resistance to the impacts of exotic fishes.	Low flows and base flows maintain shallower habitats and pool margins when exotic predatory fishes (trout and redfin) occur.	Mapping species distribution at key nodes in river reaches during low flow seasons over time.
Suppress exotics	Variable flows and zero flows (if natural part of flow regime) to discourage colonisation by exotic fish and favour natives. High flows can flush out or suppress exotics.	Assessing fish community composition (species inventory) or species presence, snapshot of demographic structure for exotic species, studies of fish biology.

2.3 Review objectives

This project aimed to review of the status of water resources and fish communities within the Marne Saunders PWRA. The specific objectives were to:

- Evaluate trends in water quality and flow regime data (including flow metrics);
- Review the long-term fish monitoring dataset and provide a summary of fish community condition and trends; and
- Assess the effectiveness of water management and provide recommendation to assist with further refining of the environmental water requirements and water allocation planning.

The outcomes of this project will provide updated knowledge of the current status of aquatic habitats and fish communities, which will inform review of the WAP for the Marne Saunders PWRA.

3. Methods

3.1 Groundwater and flow data

The review utilised total daily flow and electrical conductivity (EC, μScm^{-1}; hereafter referred to as 'salinity') obtained from DEW gauging stations located across differing reaches of the Marne Saunders PWRA (Table 2.1). To explore long-term trends, the combined flow data from the two Marne Gorge gauging stations were used. Whilst these gauging stations were running for differing periods (e.g., A4260529: 1973 to 2007; A4260605: 2001 to 2020), the period of overlap has allowed them to be aligned to provide the combined flow data (labelled as 'virtual') from 1973 to 2020. For several sites, modelled daily flow data (1971–2020) was generated for a 'no dams' scenario (calibrated to 1999 levels of water resource development before the effects of farm dams removed) using from the Marne WaterCress model (Penney et al. 2019). The modelled data is only provided for illustrative purposes as it acknowledged that it reflects a historic calibration period so may not be reflective of current no dams flow regimes. For all flow data, the analyses of this report focused on the period of 2002 to 2020 (given the 2021 flow data was incomplete at the time of publication).

Table 3-1. List of gauging stations across the Marne Saunders PWRA. Reach types are upper pool–riffle (UPR), mid pool–riffle (MPR), gorge and lowland reaches

<table>
<tr><th>Waterway</th><th>Location</th><th>Reach</th><th>Gauging station</th><th>Period of data</th></tr>
<tr><td rowspan="2">Marne River</td><td rowspan="2">Vigars Road</td><td rowspan="2">UPR</td><td>A4261231</td><td>2013 to 2018</td></tr>
<tr><td>Modelled no dams (A4261232)</td><td>1971 to 2020</td></tr>
<tr><td rowspan="2">Marne River</td><td rowspan="2">Jutland Road</td><td rowspan="2">UPR</td><td>A4261030</td><td>2002 to 2020</td></tr>
<tr><td>Modelled no dams (A4261013)</td><td>1971 to 2020</td></tr>
<tr><td rowspan="2">North Rhine River</td><td rowspan="2">Kappalunta</td><td rowspan="2">MPR</td><td>A4261014</td><td>2001 to 2020</td></tr>
<tr><td>Modelled no dams (A4261014)</td><td>1971 to 2020</td></tr>
<tr><td rowspan="2">Marne River</td><td rowspan="2">Marne Gorge</td><td rowspan="2">Gorge</td><td>Combined (A4260529 + A4260605)</td><td>1973 to 2020</td></tr>
<tr><td>Modelled no dams (A4260605)</td><td>1971 to 2020</td></tr>
<tr><td>Marne River</td><td>Redbanks Road Ford Crossing</td><td>Lowland</td><td>A4261007</td><td>2001 to 2020</td></tr>
<tr><td rowspan="2">Marne River</td><td rowspan="2">Black Hill Springs</td><td rowspan="2">Lowland</td><td>A4261011</td><td>2001 to 2020</td></tr>
<tr><td>Modelled no dams (A4261011)</td><td>1971 to 2020</td></tr>
<tr><td>Saunders Creek</td><td>Saunders Creek Gorge (upper)</td><td>Gorge</td><td>A4261174</td><td>2009 to 2020</td></tr>
<tr><td>Saunders Creek</td><td>Lower Saunders Gorge</td><td>Gorge</td><td>A4261100</td><td>2006 to 2020</td></tr>
<tr><td>Saunders Creek</td><td>Lenger Reserve</td><td>Lowland</td><td>A4261029</td><td>2002 to 2016</td></tr>
</table>

3.2 Fish and water quality sampling

Across the 20-year time period (2002–2021), 25 sites have been sampled across Marne Saunders PWRA, with nine sites repeatedly sampled (in autumn, mostly annually) as part of annual condition assessment (Figure 2-1; Table 3-2). An additional 16 sites were infrequently (often once) sampled but do contribute to understanding of fish communities across the Marne Saunders PWRA. Of the 24 sites, data was collected from 18 sites within Marne River Catchment and six sites within the Saunders Creek Catchment. Much of the fish data presented was collected autumn sampling throughout assessment period; however, some data has been collected through other projects carried out during other seasons.

Most fish monitoring employed methods that matched the prevailing fish communities and the availability of habitat, which varied over the 20-year review period. Typically, fyke nets set overnight were utilised; however at some sites, methods used included bait traps, seine netting, dip netting and visual inspection (Figure 3-1) (see Whiterod and Hammer 2014 for more details). All sampled fish were identified to species level (Lintermans 2007), enumerated and observed to obtain general biological information (e.g. reproductive condition or parasites). Total length (mm) was measured for the first 50 individuals for fish-related asset species.

Environmental descriptors, such as extent of habitat cover submerged physical and biological structure, flow and pool condition, as well as water quality parameters (electrical conductivity, dissolved oxygen concentration, pH, water temperature and transparency) were also recorded to assist the interpretation of findings.

Table 3-2. List of sites sampled for as part condition monitoring of fish-related assets across Marne Saunders PWRA in the period 2002–2021. Reach types are upper pool–riffle (UPR), mid pool–riffle (MPR), gorge, lowland and terminal wetland (TW) reaches

Waterway	Location	Reach	Year																			
			2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Marne River	Vigars Rd	UPR	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Marne River	Jutland Road	UPR	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
North Rhine River	Pine Hut Road	MPR	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Marne River	Marne Gorge	Gorge	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Marne River	Black Hill Springs (b)	Lowland	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Marne River	Three sisters pool	Lowland																✓	✓	✓	✓	✓
Marne River	Marne Mouth	TW	✓										✓			✓			✓			✓
Saunders Creek	Saunders Creek Gorge (upper)	Gorge			✓									✓	✓		✓				✓	
Saunders Creek	Lenger Reserve	Lowland								✓		✓	✓	✓	✓	✓		✓		✓		✓

Figure 3-1. Fish sampling of the Marne Saunders PWRA (clockwise from top left): fyke netting in the Marne River – Marne Gorge; setting fyke nets by kayak in the Marne River – Three Sisters Pool; fyke netting in the Marne River – Marne Mouth; measuring water quality in the Marne River – Marne Gorge; preparing to seine net in the Saunders Creek – Saunders Creek Gorge; and visually inspecting the dry North Rhine River – Pine Hut Road.

3.3 Flow metric assessment

To assess change in the flow regime over the review period, established flow metrics were evaluated (Table 3-3). This evaluation was based on the annual 'flow year', which reflects the flow regime over the preceding flow year (e.g., the 2020 flow year encompasses December 2019 to November 2020).

These flow metrics - the total number of flowing days across the flow year and the number of fresh days with flows greater than two times the median of all non-zero flows (e.g. freshes) during the low-flow season (LFS) and the transition season (T1) between the high flow season (HFS) to the LFS - have been shown to influence fish communities across the region (Green et al. 2014; VanLaarhoven and van der Wielen 2009; Whiterod et al. 2017).

Table 3-3. Summary of metrics of the flow regime for the Marne Saunders PWRA.

Flow metric	Description
Total flowing period	Number of days of the year that the river is flowing (note: previously referred to by the inverse i.e., number of zero flow days)
LFS fresh days	Number of days over the low flow season (December – May) that have flow greater than the two times the median of all non-zero flows for the season
T1 fresh days	Number of days over the transition 1 (June to July) flow season that have flow greater than the two times the median of all non-zero flows for the season

Initially, the data from each gauging station was screened to ensure the flow data was of suitable quality and there was no more than 5% missing data in any given year. Suitable quality data was defined as data that was measured at the gauge and not interpolated using post processing. If any given year had more than 5% missing or unsuitable flow data, the year was dropped from the assessment (D. Green, DEW, unpublished data). The threshold for zero flow was set at 0.05MLday^{-1} as below this level the measurement of flow becomes unreliable at some gauging stations (D. Green, DEW, unpublished data). The three-flow metrics were estimated in each flow year (where suitable data existed) for each gauging station and temporal trends assessed. The flow data was processed and temporal trends analysed using the R language and environment, operated in R Studio (R Studio version 1.2.5042, running R version 4.0.0 (R Core Team 2014).

3.4 Reporting process

The annual fish monitoring data is incorporated into a report carding framework to provide assessment of the condition of each fish-related ecological asset in the Marne Saunders PWRA. The framework for report carding was initially developed in 2006 and has been routinely amended (Hammer 2006; Hammer 2007a; Hammer 2009; Whiterod and Hammer 2014). Most recently, the report carding process was automated using R v4.1.0 (D. Green, DEW, unpublished data). The report card for a particular year is based on the preceding flow year assessed through site-based condition monitoring conducted in autumn annually (e.g., the 2021 assessment is based on the flow period of winter 2020 to autumn 2021).

In summary, report carding for an individual catchment reflects the condition of identified fish-related assets, such as recruitment and survival of populations of threatened species, diverse fish communities and the presence of alien species. The assessment of individual threatened species fish-related assets (scored out of 7) is based on presence and measures of recruitment (i.e., fish spawned in that flow period) and survivorship (i.e., older fish) linked to previously developed categories (i.e. excellent, good, marginal or poor (Table 2-4): SAMDBNRM Board 2013; VanLaarhoven and van der Wielen 2009). Pre-established population models were used to define recruits and survivors for each species (see Hammer 2007b; Hammer 2009; Whiterod and Hammer 2014).

Table 3-4. Summary of report card scoring for each indicator for fish-related assets of the Marne Saunders PWRA.

Fish-related assets – species	Indicators									
	Presence (max. 1)		Recruits (0+ fish) (max. 3)				Survivors (>2+ fish) (max. 3)			
	0	1	Poor	Marginal	Good	Excellent	Poor	Marginal	Good	Excellent
			0	1	2	3	0	1	2	3
Obscure Galaxias	none	>1	0	1	2-9	>10	0	1	2-4	>5
River Blackfish			0	1	2-4	>5	0	1	2-4	>5
Carp Gudgeon			0	<5	6-24	>25	0	<5	6-19	>20

For fish community fish-related assets, assessment (again out of 7) is based on the number of freshwater specialist and diadromous species, highly threatened species (critically endangered or endangered nationally) and freshwater generalists (Table 3-5). The alien species condition score is based on discouraging the colonisation and establishment of large populations, with scores assigned (out of 2; 0: if aliens account >70% of total fish numbers; 1: aliens account 30−70% of total numbers; 2: alien numbers <30% of total numbers) at the site level (i.e., added to averaged score all fish-related assets at that site).

Site based scores were calculated using the median of all fish-related assets plus the score for alien species (maximum score 7+2=9). Where multiple sites were present in a reach the median of these sites was used to produce a reach score, which were assigned the following condition ratings: good (>7), moderate (4 to 6) and poor (<3). In turn, the median of the reach condition scores was used to provide an overall catchment score. Trends were determined by comparing the corresponding score across years of the present review period. The report carding of fish-related assets were undertaken using the R language and environment, operated in R Studio (R Studio version 1.2.5042, running R version 4.0.0: R Core Team 2014).

Table 3-5. Summary of report card scoring for each indicator for the fish-related assets relating to diverse fish communities as well as alien species and diverse fish community.

Fish-related assets	Indicators	Presence score (no of species)		
		0	**1**	**2**
Diverse fish community	Diadromous species	0	1-2	>2
	Specialist species	0	1-2	>2
	Highly threatened (Endangered, Critically Endangered nationally) species	0	-	1 or more
	Freshwater generalists	0	1 or more	-
Limited alien species	Alien species	>70% of total fish numbers	30–70% of total fish numbers	<30% of total fish numbers

4. Results

4.1 Regional climate

An overall pattern of rainfall throughout the Marne Saunders PWRA indicates that elevated areas of the region (represented by Keyneton rainfall) receive greater annual rainfall than the lowland plains areas (represented by Black Hill rainfall) (Figure 4-1). The temporal trend over 2002 to 2020, suggest that mean annual rainfall has reduced in the upper reaches of the Marne Saunders PWRA; however, there is little difference between long-term and review period mean annual rainfall for the lower reaches (Figure 4-1). Specifically, the mean annual rainfall of 483.3 mm for the upper reach over the review period was lower than the long-term (1908–2021) mean annual rainfall (of 528.8 mm). For the lowland reach, the mean annual rainfall over the review period (299.25 mm) was slightly higher than the long-term (1936–2021) mean (284.8 mm).

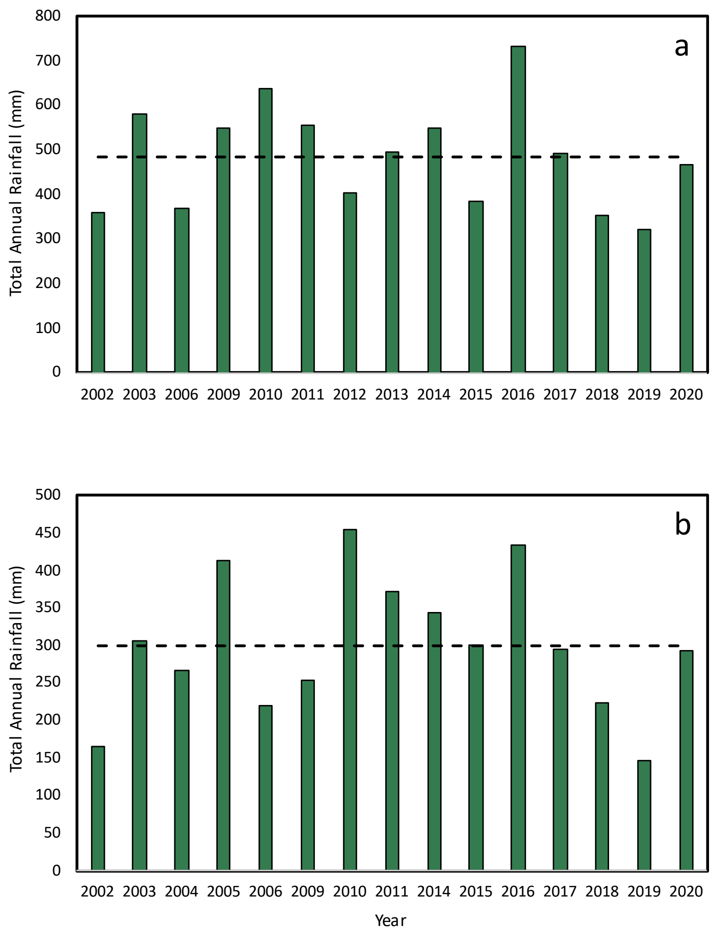

Figure 4-1. Total annual rainfall (mm) at Keyneton (a) and Black Hill (b) South Australia for years 2002–2020. Following years were not included due to insufficient data (a): 2004, 2005, 2007, 2008; (b): 2007, 2008, 2012 and 2013 (Bureau of Meteorology, unpublished data). Black dashed line indicates 20-year mean rainfall for all data included.

4.2 Groundwater

Fractured rock aquifer monitoring located within the Hills Zone of the Marne Saunders PWRA has recorded consistently reduced water levels across all monitoring wells over the last 20 years with a decline in water level ranging from 0.32 m to 3.07 m and a median water level reduction of 2.47 m (Figure 4-2; Figure 4-3: DEW 2020). Five year trends indicate the rate of water level reduction for the fractured rock aquifer recorded at monitoring wells ranged between 0.11–0.56 m year^{-1} with a median rate of water level reduction being 0.27 m year^{-1} (DEW 2020). Similarly, Murray Group Limestone aquifer monitoring wells located in the Plains Zone all illustrate a trend of reducing water level, with rates of decline are variable (e.g., 0.05–2.13 m year^{-1}) with a median rate of water level reduction being 0.23 m year^{-1} (DEW 2020). The Murray Group limestone aquifer has shown discharge rates of 250–315 ML year^{-1} at sites within the Black Hill Springs area (Harrington 2004), current rates of discharge are unknown. Groundwater salinity has shown to be variable in both the Fractured Rock and Murray Group Limestone aquifers and appears to be influenced by the sediment in which aquifers occur rather than any correlation with decreased water level.

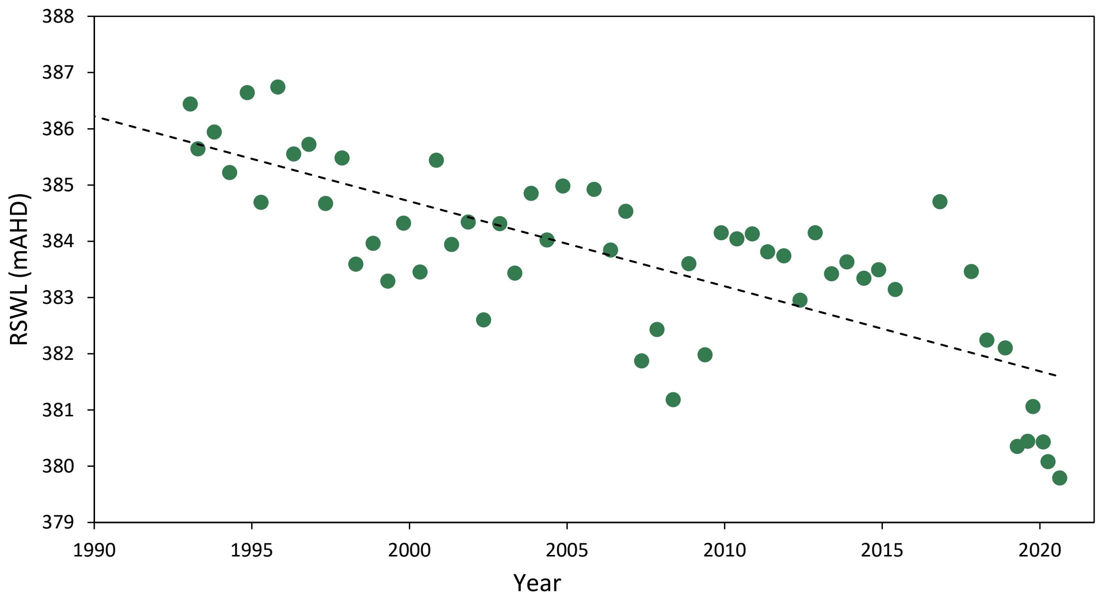

Figure 4-2. Water levels (mAHD) for Fractured Rock aquifer monitoring well near Keyneton in the Hills Zone. Data from Marne Gorge gauge (station JEL007).

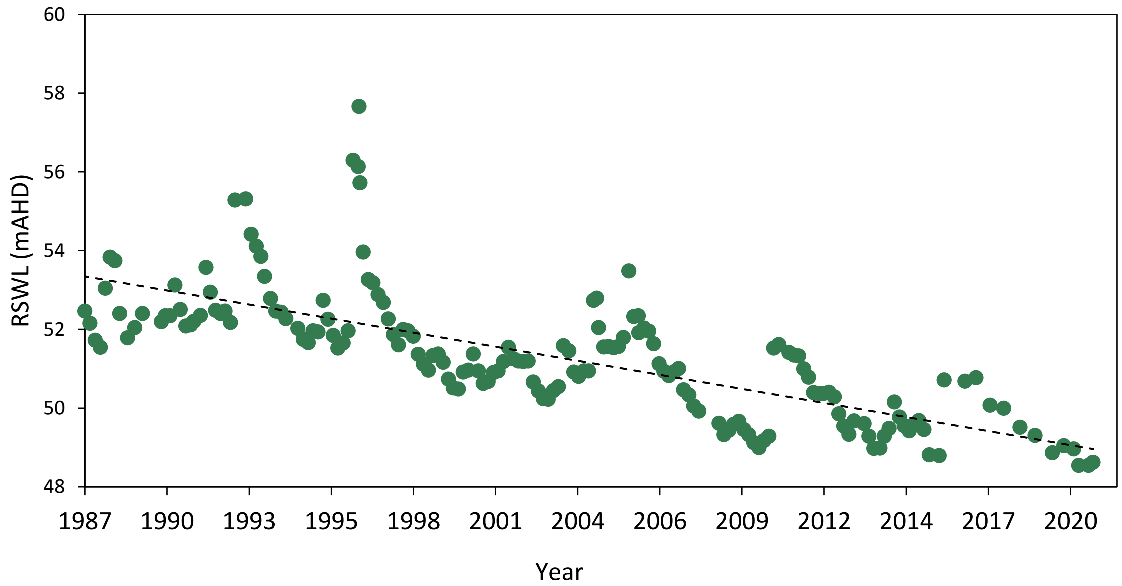

Figure 4-3. Water levels (mAHD) Murray Group Limestone aquifer monitoring located in between Cambrai and Black Hill in the Plains Zone. Data from Marne Gorge gauge (station ANG014).

4.3 Surface flow

Overall summary

Across the review period (2002–2021), the characteristic variability and episodicity of the flow in the Marne Saunders PWRA was evident (Figure 4-4 to Figure 4-6). There were long periods of zero flow at all gauging stations and when flows occurred, they were not uniform throughout the PWRA. For example, the lowest peak flow recorded in the Marne Saunders PWRA was observed in Saunders Creek Gorge reach, occurring during July 2014, whereas the greatest peak flow recorded in the Marne Saunders PWRA was observed at the upper lowland reach (Redbank Crossing) of the Marne River during July 2005. The greatest flows occurring within the upper and mid reaches of the Marne River Catchment during early spring reflects rainfall patterns of the Marne Saunders PWRA, where rainfall is greatest in elevated regions of the catchment during winter and spring seasonal periods. Flows generally increase throughout winter and spring periods as the catchment area becomes wetter and groundwater discharges into watercourses, some higher flows have been recorded into early summer which is likely to be due to saturated ground and full water storages (such as farm dams) from spring rains allowing for a maximum surface runoff. Large differences in flow can also observed between differing sites within the same reach (e.g., Vigars Road and Jutland Road). Although flow data at these sites was recorded over variable time periods, the maximum flows were recorded only one day apart (e.g., Vigars Road: 29 September 2016; Jutland Road: 30 September 2016).

Even though the magnitude of flow is variable between reaches and sites across the PWRA, the 20-year trend in flow is broadly consistent (Figures 4-4 to 4-6). Flow data throughout the years of recording shows a trend at all sites within the Marne River Catchment for peak flows to occur every 4–6 years with peak years of flow generally preceded and followed by one or two years of above average flow. The Saunders Creek Gorge reach shows a differing flow pattern to sites within the Marne River Catchment, with maximum flows throughout the Marne Catchment being largely recorded during 2016, whereas maximum flows were recorded in the Saunders Gorge during 2014. The observed differences in the maximum daily flows and their period recorded in the two catchments is likely to be due to variation in rainfall patterns within the Marne Saunders PWRA. Variation in flow within the Saunders Catchment was also evident; three gauging stations within Saunders Creek showed differing patterns and magnitude of flow indicating a lack of connectivity of flow throughout the system or variability in localised rainfall and surface runoff.

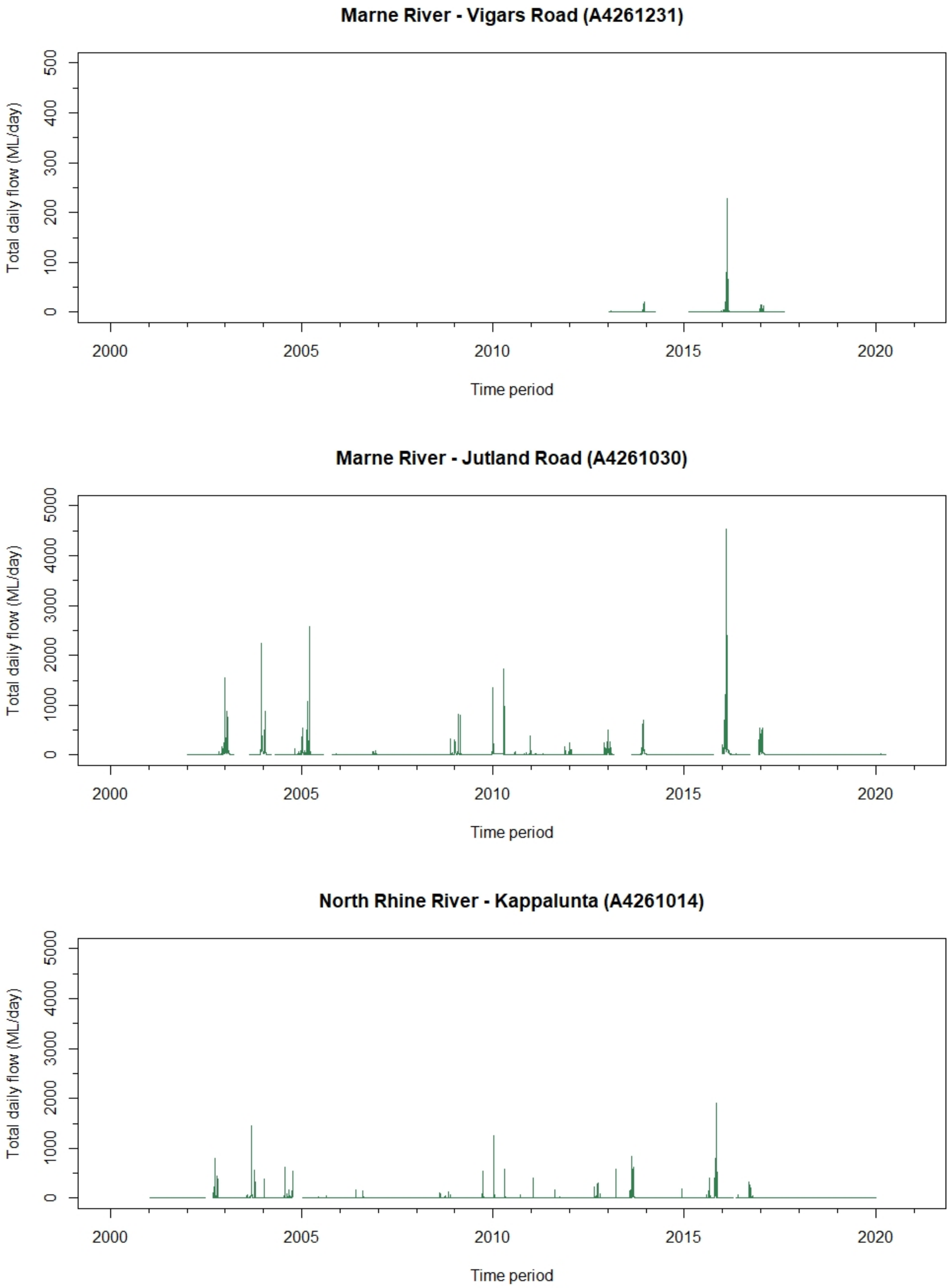

Figure 4-4. Total daily flow (ML Day^{-1}) for the Marne River UPR reach: (top) Marne River – Vigars Road (A4261231); (middle) Marne River – Jutland Road (A4261030); and (bottom) Marne River MPR reach: North Rhine River – Kappalunta (A4261014).

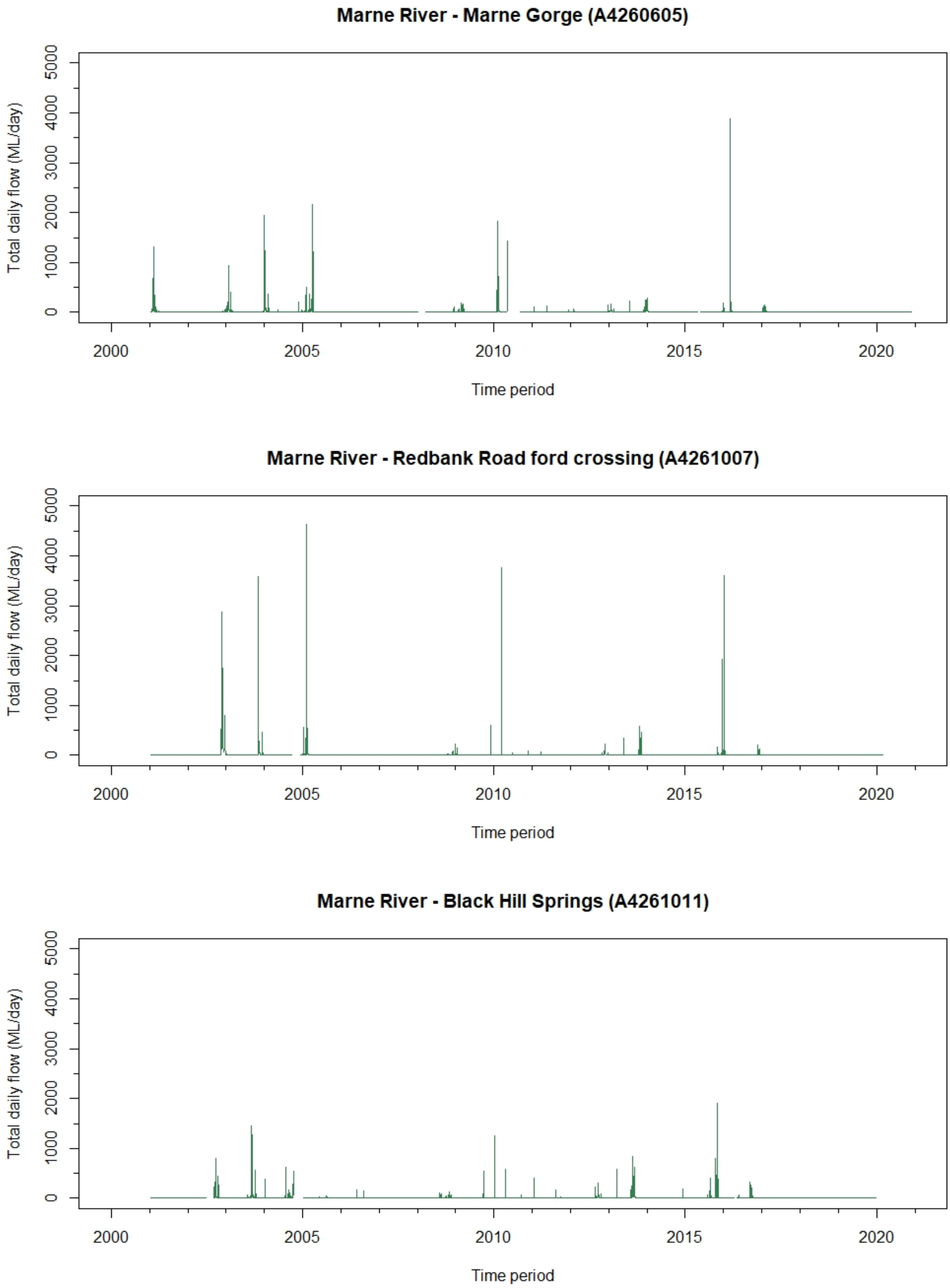

Figure 4-5. Total daily flow (ML Day^{-1}) for (top) Marne River – Marne Gorge (A4260605); (middle) Marne River – Redbank Road ford crossing (A4261007); and (bottom) Marne River – Black Hill Springs (A4261011).

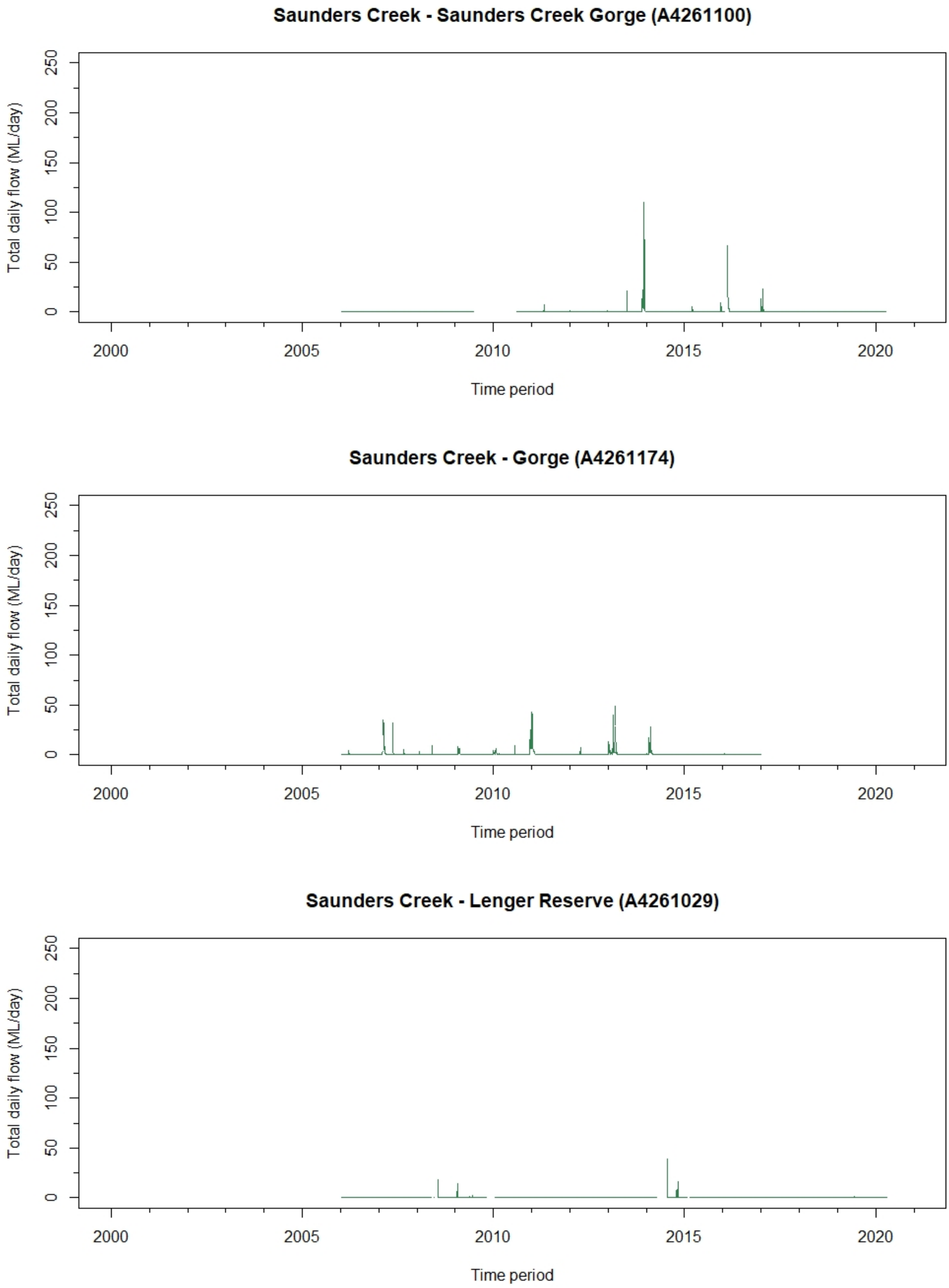

Figure 4-6. Total daily flow (ML Day^{-1}) for the Saunders Creek: (top) Saunders Creek – Saunders Creek Gorge (A4261100); (middle) Saunders Creek –Gorge (A4261174); and Saunders Creek – Lenger Reserve (A4261029).

Metrics of the flow regime

The metrics of the flow regime at sites across the Marne Saunders PWRA reinforce the overall summary provided above (Figure 4-7 to Figure 4-9; Table 4-1). Namely, it is evident there is a declining trend in the number of flow days at all sites (except for Saunders Creek – lower Saunders Creek Gorge) over the review period (Figure 4-7). For instance, the (combined) total flowing period at Marne River – Jutland Road over the period of 2018 to 2020 was just 52 days (2018: 16 days; 2019: zero days; 2020: 36 days), whereas prior to 2012, flow was experienced for more than 100 days in most years (Table 4–1). Further, some sites across MPR (North Rhine River – Kappalunta), gorge (Marne River – Gorge; Saunders Creek – Saunders Creek Gorge) and lowland (Marne River – Redbank Road ford crossing) did not flow at all during the period 2018 to 2020. Further, considerably fewer flow days are experienced under the current flow regime at all sites when compared to what is expected under the 'no dams' scenario (Figure 4-7; Table 4-1). For instance, at the Marne River – Marne Gorge, the 'no dams' scenario predicts between 136 to 228 flow days each year over 2002 to 2010 whereas there were 73 to 157 actual flow days over this period. The discrepancy even more stark over 2018 to 2020, with no flow days experienced through the Marne Gorge with the 'no dams' scenario predicting 85 (2018), 120 (2019) and 199 (2020) flow days. Despite this, flow regimes associated with both the actual and 'no dams' scenario experienced declining trend over time, with a flowing period likely to be considerably diminished over recent years regardless of dam abstraction.

The number of days of freshes in the LFS and T1 (HFS > LFS) seasons was zero at most sites over the review period and declined for the remaining sites that did experience period of freshes (Figure 4-8; Figure 4-9). Whilst under the 'no dams' scenario, the number of days of freshes in the LFS and T1 (HFS > LFS) seasons was higher at the start of the review period, these metrics declined over time (Figure 4-8; Figure 4-9).

Table 4-1. List of sites and their number of flow days sampled per year for as part condition monitoring across Marne Saunders PWRA from 2002 to 2021.

Location	Reach	Gauging station	Year																		
			2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Vigars Road	UPR	A4261232												124	271	101	266	313	87		
		Modelled 'no dams'	202	148	219	195	177	144	222	171	212	158	159	168	192	209	124	90	107	210	202
Jutland Road	UPR	A4261013	1	149				125	53	129	108	281	122			60			16	0	36
		Modelled 'no dams'	128	218	157	227	221	184	152	222	182	238	167	162	185	204	209	137	95	115	211
Kappalunta	MPR	A4261014	21				110	46	0	90	109	100	35	77	90	7	125		0	0	0
		Modelled 'no dams'	98	183	152	217	207	143	104	213	141	212	118	141	165	128	188	113	44	115	136
Marne Gorge	Gorge	Combined	104	157	126	185	73	103		145	99		121	99		10		82	0	0	0
		Modelled 'no dams'	136	221	158	228	227	182	152	221	184	250	164	157	191	203	207	138	85	120	199
Redbanks Road	Lowland	A4261007	0	66			0	0	0	40	97	26	8	35	45	0		23	0	0	0
Black Hill Springs	Lowland	A4261011	0	13	18	13	0	0	0	0	23	13	0	0	0	0		0	0	0	0
		Modelled 'no dams'	2	16	16	28	1	6	1	12	17	3	1	11	10	2	28	4	0	4	4
Saunders Creek Gorge (upper)	Gorge	A4261174								57	45	161	158	91	162	136	126	122	62	26	0
Lower Saunders Gorge	Gorge	A4261100					0	0	0	0			4	1	36	1		22	0	0	0
Lenger Reserve	Lowland	A4261029		35		19		0	0	0			0	0	0	1					

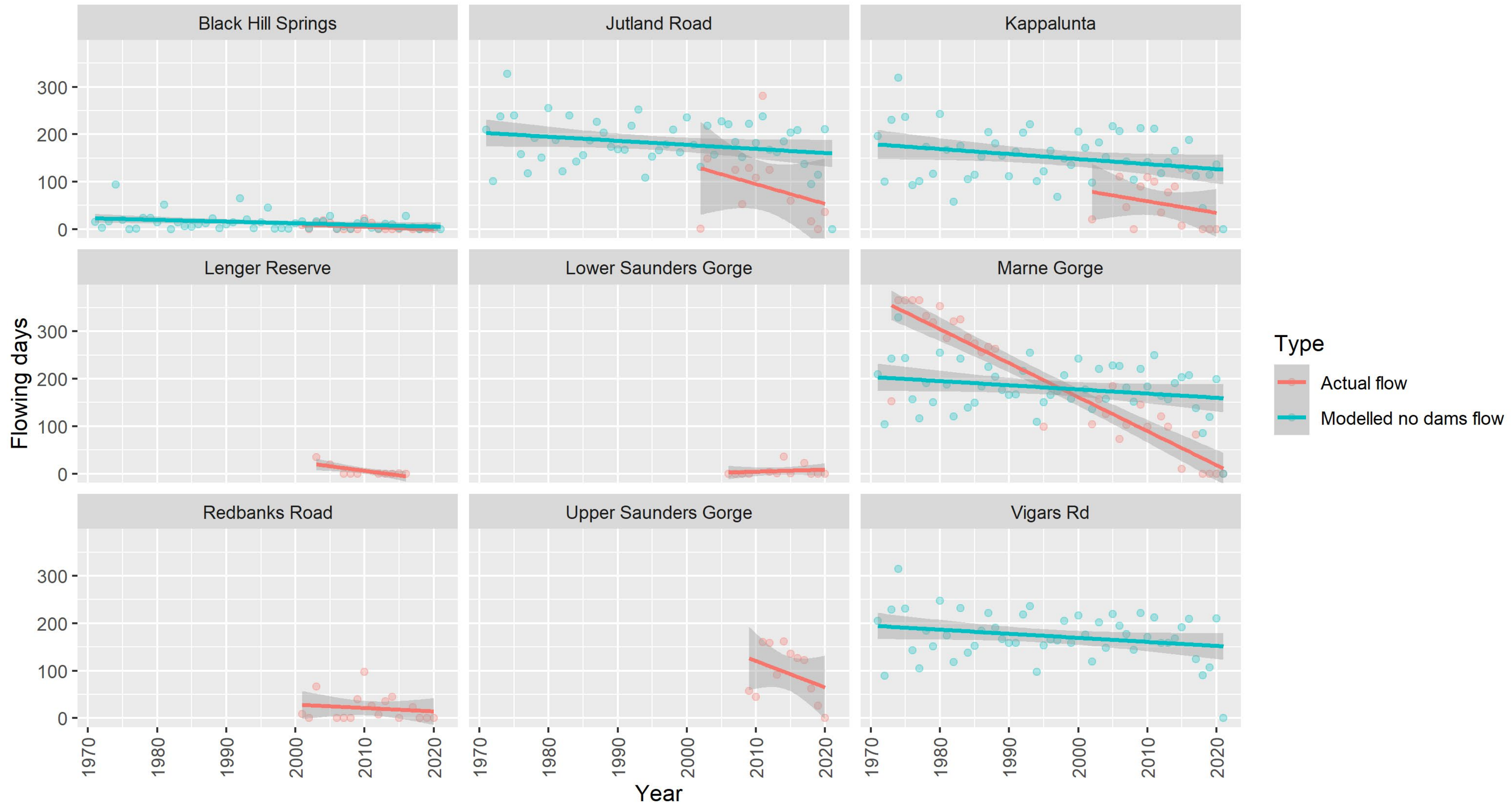

Figure 4-7. Comparison of the number of flowing days observed across the flow gauging network of the Marne Saunders PWRA compared to modelled flow data for the same sites. Some sites only have one type of data due to constraints of the data.

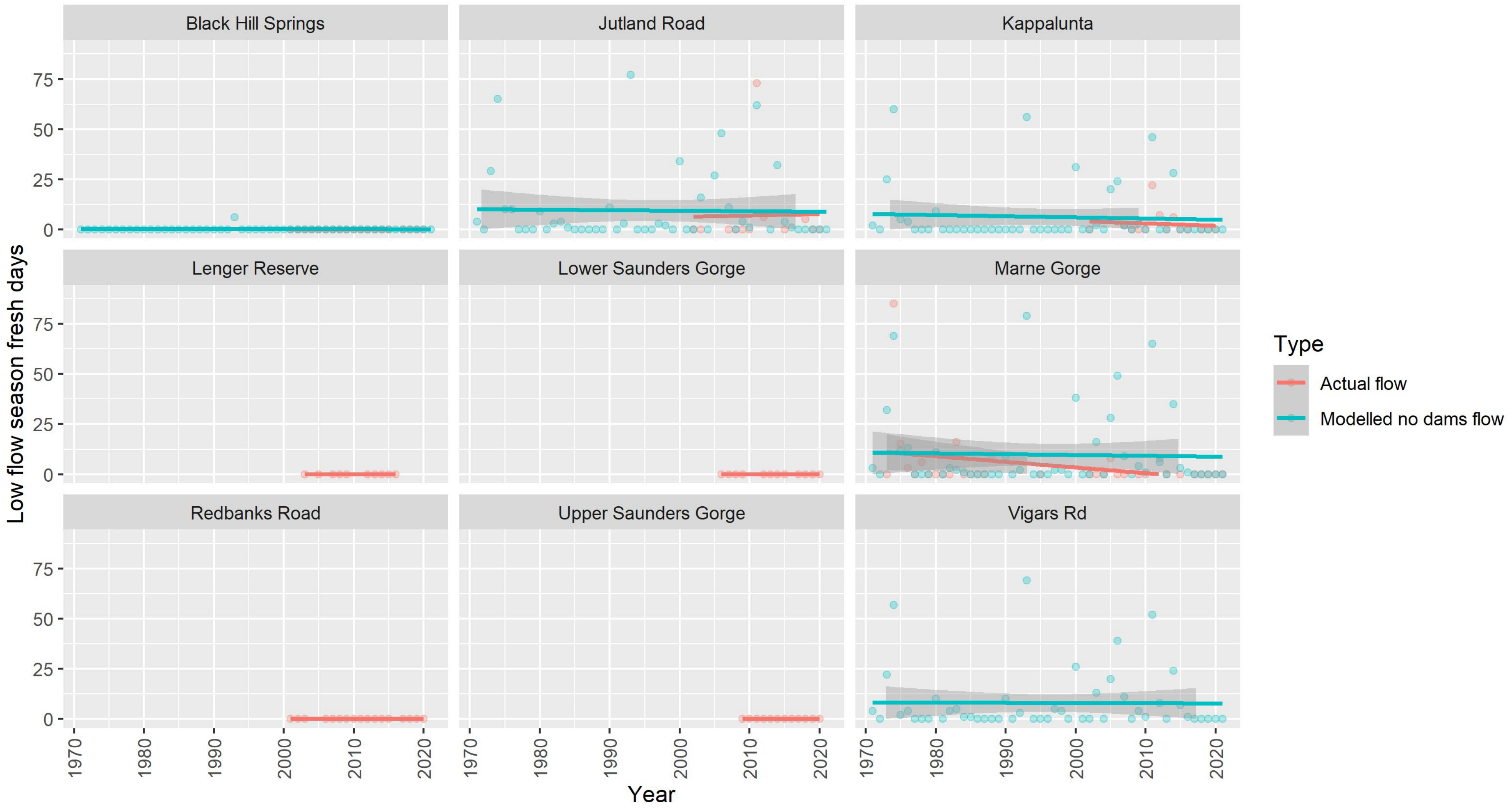

Figure 4-8. Comparison of the number of days with flow above the low flow season fresh threshold observed across the flow gauging network of the Marne Saunders PWRA compared to modelled flow data for the same sites. Some sites only have one type of data due to constraints of the data.

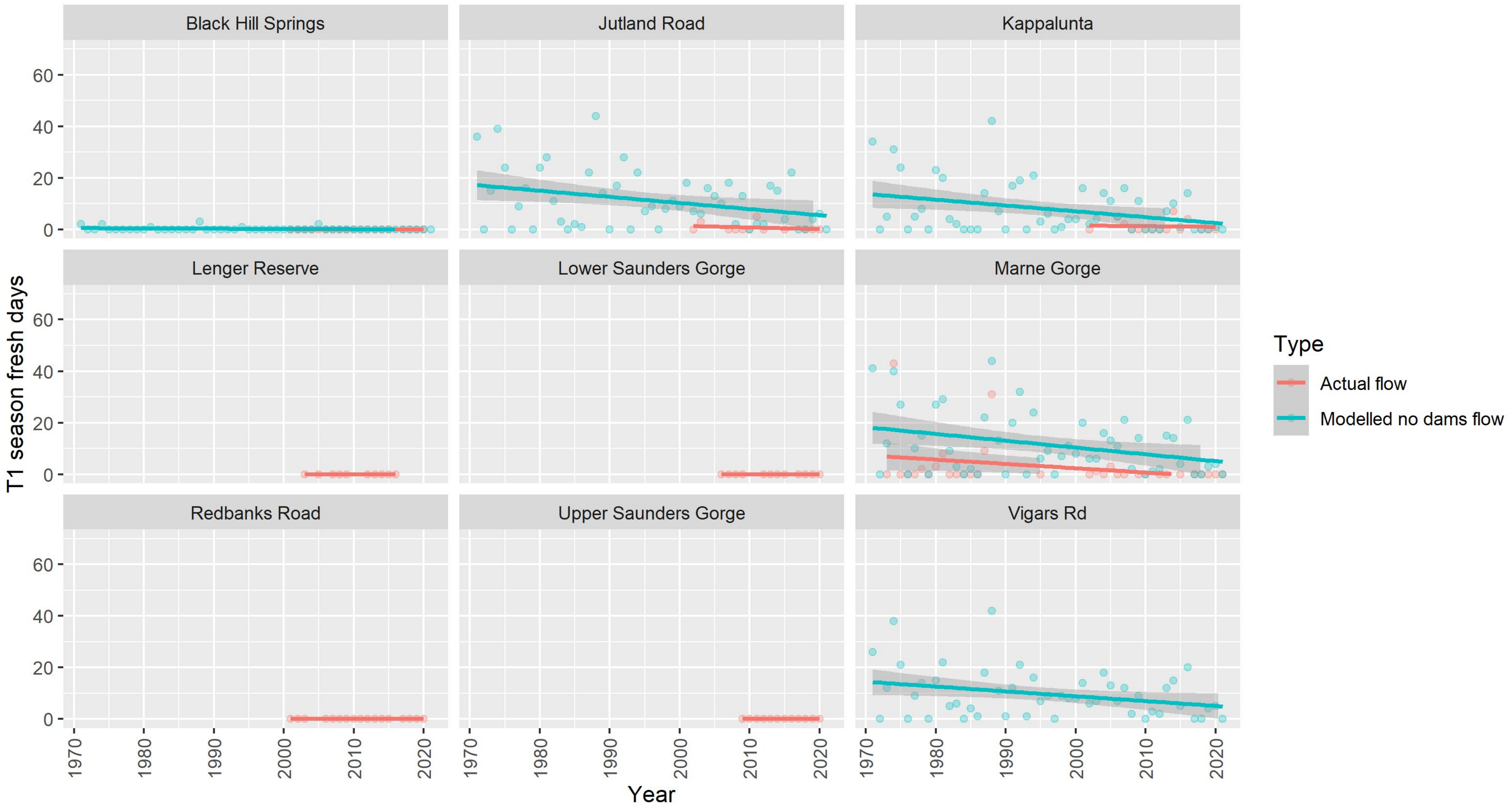

Figure 4-9. Comparison of the number of days with flow above the transition 1 season fresh threshold observed across the flow gauging network of the Marne Saunders PWRA compared to modelled flow data for the same sites. Some sites only have one type of data due to constraints of the data.

4.4 Water quality

Monitoring of hydrological parameters throughout the Marne Saunders PWRA has been carried out at a number of sites from 2002 to 2021. Throughout this 20-year period, recorded parameters show high levels of variability between sites across both catchments (Table 4-2).

Table 4-2. List of the maximum and minimum for each of the hydrological variables recorded across all sites in the Marne Saunders PWRA from 2002 to 2021

Range	Water temperature (°C)	Salinity (EC, µScm^{-1})	pH	Dissolved oxygen (mgL^{-1})
Min.	8.3°C Vigars Road, recorded 1/04/2008	207 EC Marne River-Marne Mouth, recorded 30/04/2012	6.88 (Marne River - Three Sisters Pool, recorded 27/03/2017)	0.5 mgL^{-1} (Marne River-Jutland Road, recorded 14/04/2010
Max.	21.9°C, North Rhine River-Pine Hut Road, recorded 17/11/2007	37,928 EC, Saunders Creek-Myrtle Grove, recorded 20/04/2018	10.94 (Marne Gorge, recorded 7/05/2007)	17.2 mgL^{-1} (Saunders Creek-Saunders Creek Gorge recorded 8/04/2020

The irregularity within the parameters recorded can largely be explained by both temporal and spatial variation of water quality sampling events. With the arrival of episodic seasonal surface water flow, the salinity levels within the catchment reduce significantly (Figure 4-10). Using the Marne River – Jutland Road as an example, the salinity within the Marne Saunders PWRA appears to be increasing over the relatively short period from 2005 to 2021 (Figure 4-11). Similarly, an increase in mean salinity is also evident over a broader time scale (Figure 4-12), indicating an increase in salinity throughout the Marne Saunders PWRA. The salinity levels observed across many sites throughout the Marne Saunders PWRA are beyond the limits for many of the native freshwater fish of the region, for example it has been suggested that the upper salinity limit for River Blackfish is 4000 EC (Whiterod and Hammer 2014). Dissolved oxygen largely remained within limits suitable for freshwater fish within the Marne Saunders PWRA, with most sites exhibiting concentrations greater than 2 mgL^{-1} (Figure 4-13). During the review period, pH across the catchment has largely remained stable with most sites recording neutral to alkaline pH levels (Figure 4-14). Any variation in pH levels is likely to be due to localised and aquifer differences in sediment and bedrock or levels of organic matter; the pH values recorded are largely ideal for fish communities within the Marne Saunders PWRA.

Groundwater salinity has remained relatively stable in some areas (Figure 4-15, Figure 4-16) but in others there has been an increasing trend (DEW 2020).

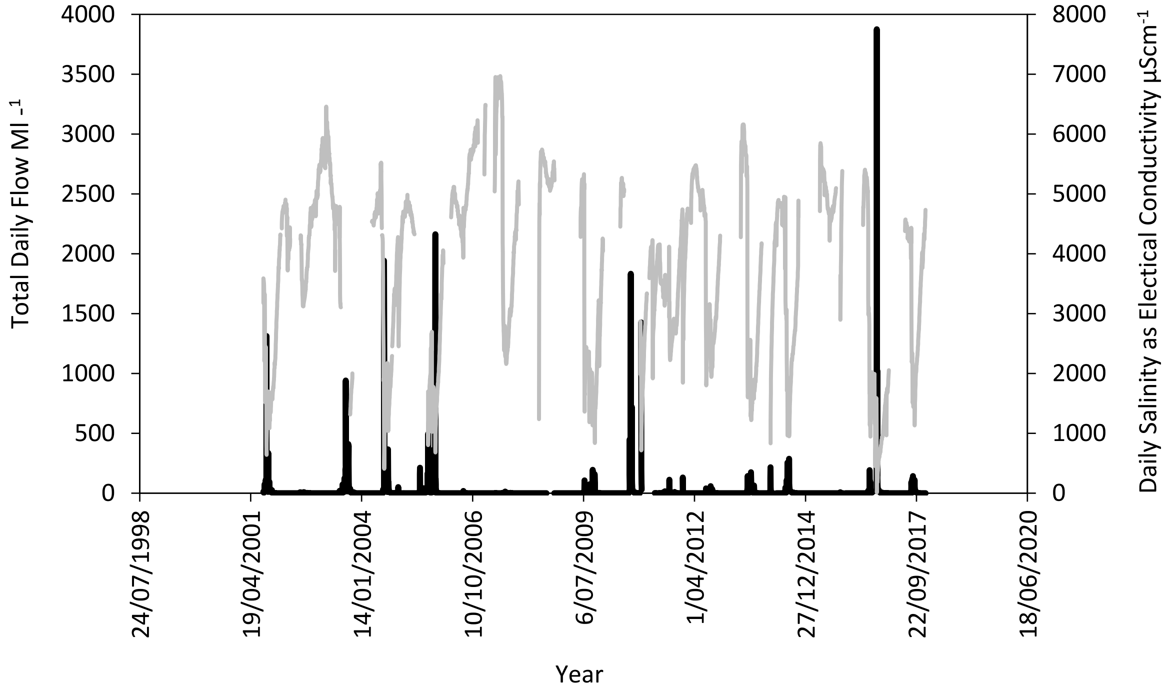

Figure 4-10. (a) Representative total daily flow (ML Day^{-1}) and mean daily Electrical Conductivity (EC) for the Marne Gorge. Data from Marne Gorge gauge (station A4260605).

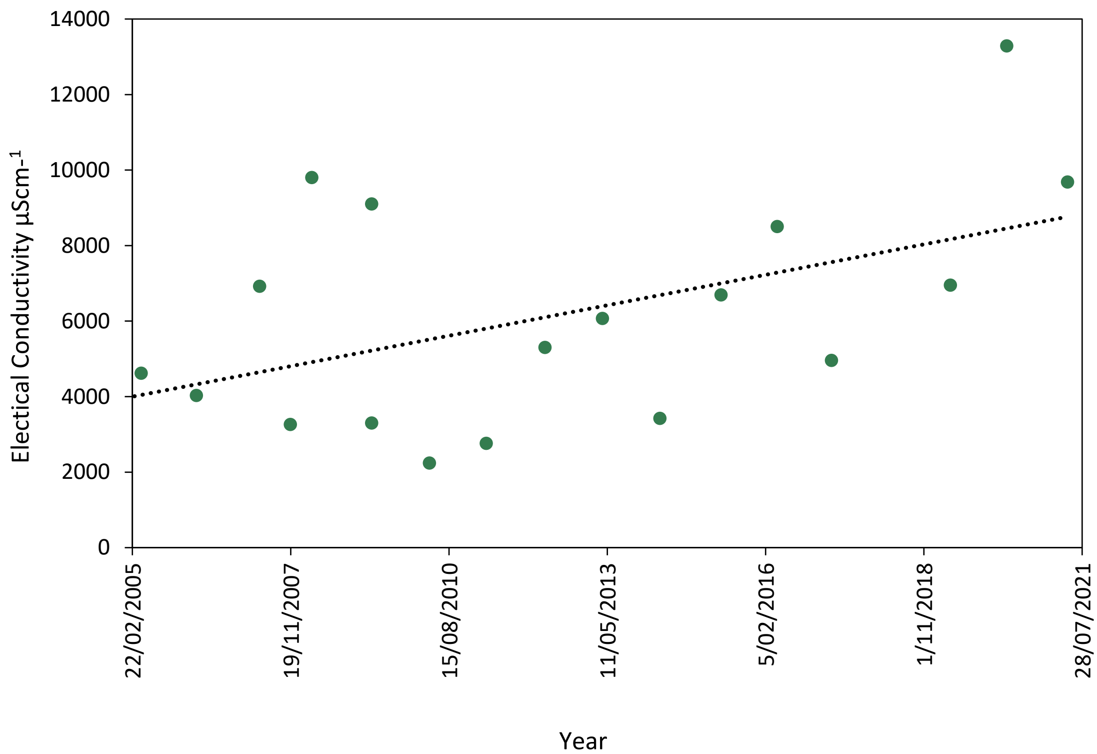

Figure 4-11. Salinity (as Electrical Conductivity EC) collected at Jutland Road during 2005–2021.

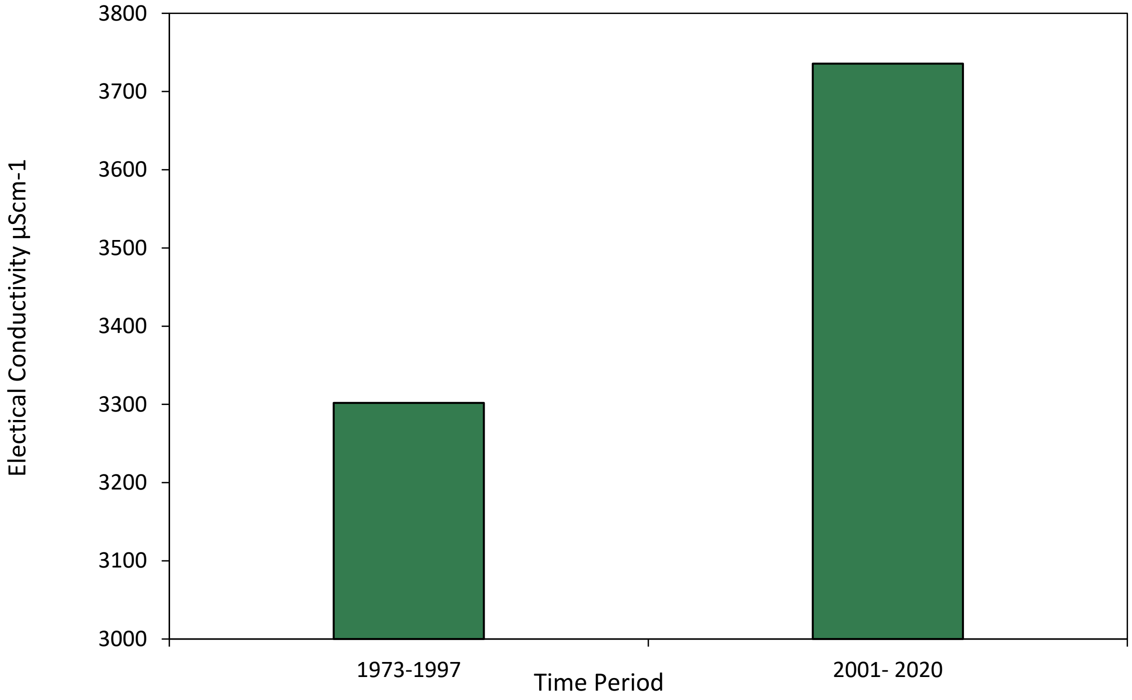

Figure 4-12. Mean annual salinity (as Electrical Conductivity EC) for years 1973-1997 (Jolly et al. 2000; Marne River at Cambrai, station A426529) and 2001–2021. Years 2019 and 2021 Marne Gorge gauge (station A4260605) omitted due to lack of data.

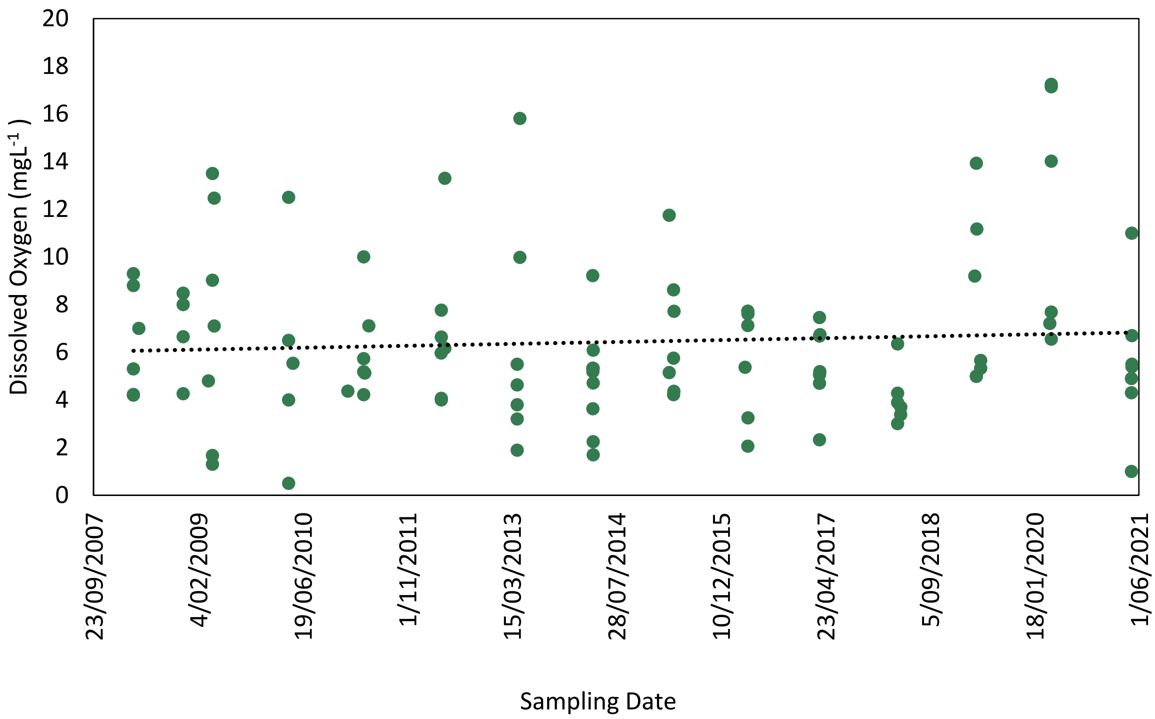

Figure 4-13. Dissolved oxygen across all sites sampled during 2008–2021.

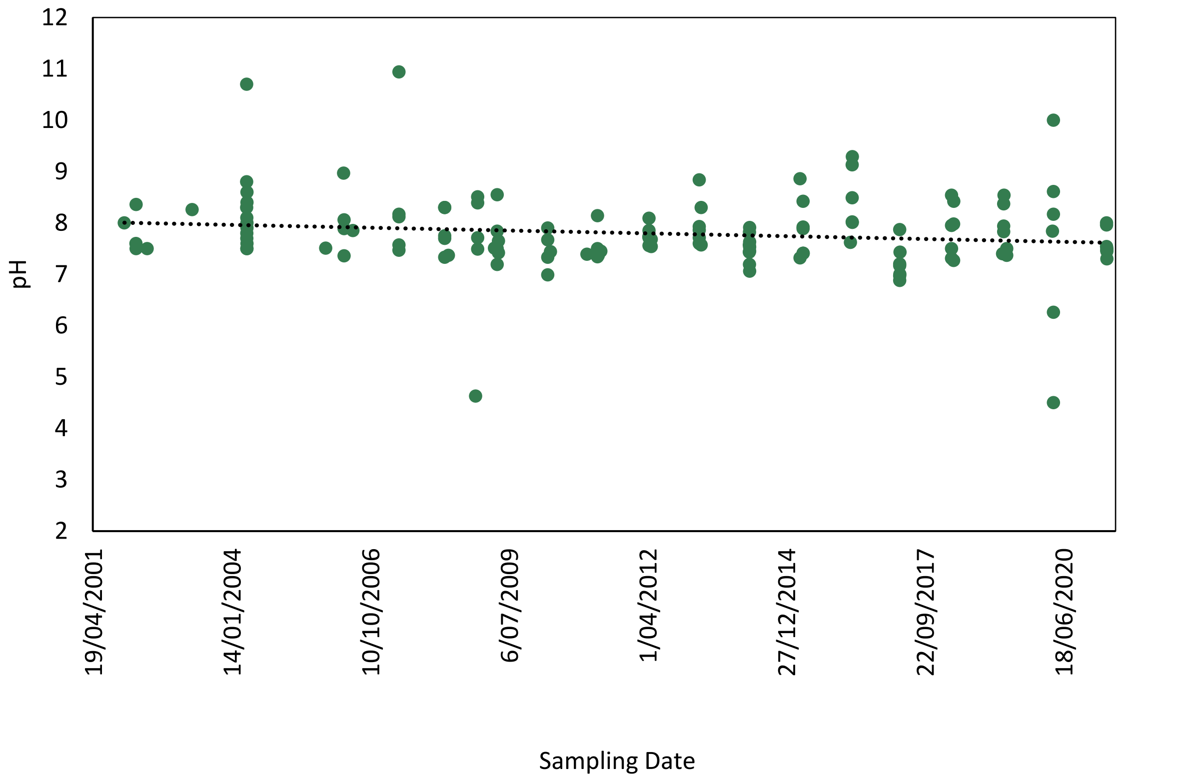

Figure 4-14. pH recorded across all sites sampled during 2001–2021.

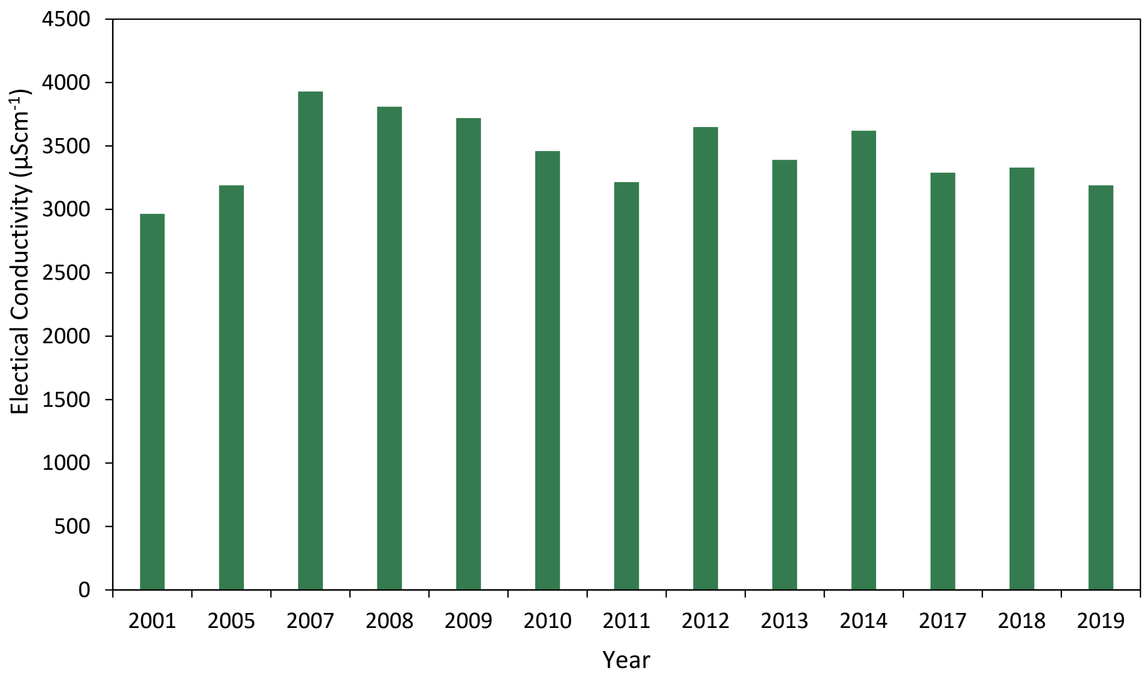

Figure 4-15. Mean annual salinity for representative Plains Zone groundwater (as Electrical Conductivity EC) over time (2001-2019; years 2002,2003,2004,2006,2015,2016 not included due to insufficient data) (station RIL015) located near Blac Hill Springs.

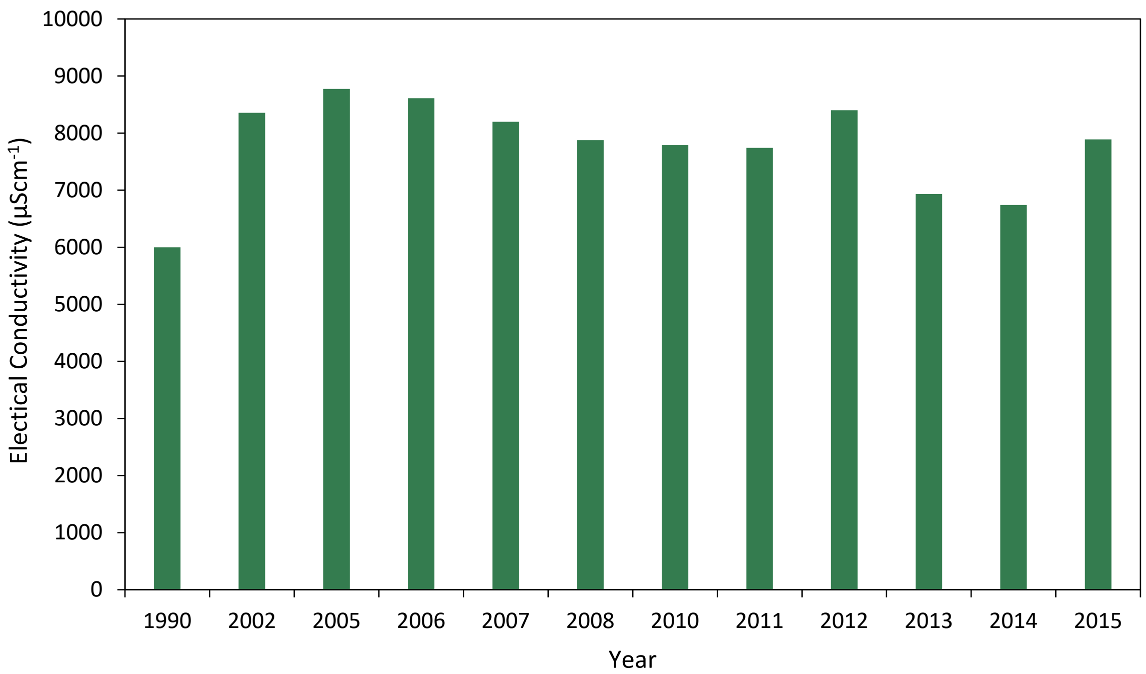

Figure 4-16. Mean annual salinity for representative Hills Zone groundwater (as Electrical Conductivity EC) for years 1990-2015 (years 1991-2001, 2003, 2004 and 2009 not included due to insufficient data) collected (station JEL028) near Keyneton.

4.5 Fish community

Overall summary

Throughout the period between 2002 and 2021, 12 freshwater fish species have been recorded within the Marne Saunders PWRA; of these species, ten were native and two introduced (Table 4-3) (Hammer et al. 2012). Native species were represented by three functional groups; namely, freshwater specialists, freshwater generalists, and a freshwater generalist which is potamodromous (Figure 4-17, Table 2-2). Considering the assemblage of fish throughout all sites sampled during the twenty-year review period in the Marne Saunders PWRA, the dominant group of fish was the alien species contributing 18,936 individuals which made up 65.4% of the total catch. Alien fishes were represented by two species, with Eastern Gambusia (18,914 fish) the most abundant followed by Common Carp (22 fish). The next most abundant group was the freshwater generalists (5928 fish and 20.5% of total catch), with Carp Gudgeon (5313 fish) being the most abundant. Freshwater specialists (4096 fish and 14.1% of total catch) were represented by two species, Obscure Galaxias (3847 fish) and River Blackfish (249 fish). Diadromous species such as Common Galaxias and Congolli were not recorded during the 2002–2021 survey period.

Figure 4-17. Freshwater fish recorded in the Marne Saunders PWRA over the review period (2002–2021): (clockwise from top left): Obscure Galaxias; River Blackfish; Carp Gudgeon; and Dwarf Flathead Gudgeon.

Table 4-3. Freshwater fish abundance and distribution throughout annual monitoring sites within the Marne Saunders PWRA between 2002 and 2021.

			Native										Alien		
Waterway	**Location**	**Reach**	**Carp Gudgeon**	**Dwarf Flathead Gudgeon**	**Golden Perch**	**Obscure Galaxias**	**River Blackfish**	**Australian Smelt**	**Murray Rainbowfish**	**Unspecked Hardyhead**	**Bony Herring**	**Flathead Gudgeon**	**Eastern Gambusia**	**Common Carp**	**Species Richness**
Marne River	Vigars Road	UPR	0	0	0	766	0	0	0	0	0	0	0	0	1
Marne River	Jutland Road	UPR	0	0	0	493	0	0	0	0	0	0	100	0	2
North Rhine River	Pine Hut Road	MPR	0	0	0	22	0	0	0	0	0	0	0	0	1
Marne River	Marne Gorge	Gorge	0	0	0	279	0	0	0	0	0	0	0	0	1
Marne River	Black Hill Springs	Lowland	222	25	0	6	9	0	0	0	0	0	37	0	5
Marne River	Black Hill Springs (b)	Lowland	113	40	0	67	81	0	0	0	0	0	140	2	6
Marne River	Three Sisters Pool	Lowland	1808	65	0	0	2	0	0	0	0	0	20	0	4
Marne River	Marne Mouth	Terminal wetland	1934	22	2	0	0	31	110	126	43	43	1600	8	10
Saunders Creek	Saunders Creek Gorge	Gorge	0	0	0	0	0	0	0	0	0	0	0	0	0
Saunders Creek	Lenger Reserve	Lowland	547	0	0	0	0	0	0	0	0	0	11817	0	2
		Total	**4624**	**152**	**2**	**374**	**92**	**31**	**110**	**126**	**43**	**43**	**13614**	**10**	**12**

Reach summaries

Marne River - UPR reach

The major fish-related ecological asset for the UPR reach of the Marne River is populations of Obscure Galaxias. Two sites are sampled for Obscure Galaxias in this reach, one in the upper reach (Vigars Road) and one in the lower reach (Jutland Road) (Figure 4-18). The species has been responding significantly to aspects of the flow regime (Whiterod et al. 2017), and long-term trends at this stage emphasise this strong link. In 2006, for instance, greater water availability resulted in increased abundance and strong recruitment (Hammer 2007a). However, reduced water availability in the subsequent three years (2007–2009) led to dramatic declines to zero in these populations, which tested the resilience of Obscure Galaxias in this reach and catchment (Figure 3-14; Figure 3-18) (Hammer 2009).

Increased water availability over the 2010–2013 period saw recolonisation of both sites by Obscure Galaxias and gradual increases in population numbers (Figure 3-15; Figure 3-19) (Whiterod and Hammer 2014). At Vigars Road, there were only four fish in autumn 2010, none in autumn 2011, but then 11 fish in 2012 and a large population increase to 109 fish in 2013. Similarly at Jutland Road, numbers were low (2010: 3 fish; 2011: 4 fish) before increasing in 2012 (32 fish), before a slight decline being observed in 2013 (16 fish). In both the peak years at each site, there was strong recruitment (0+ fish in the range 40–65 mm) and survivorship. Yet, despite these improvements, declining trends in water availability (At Vigars Road, 1 m in 2010 to 0.6 m in 2013) and water quality (At Vigars Road, EC 2320 EC in 2010 to 6130 EC in 2013) between 2010 and 2013, once again raised concern over these populations.

Figure 4-18. Sampling Vigars Road (left) and Jutland Road (right) during the autumn 2021 monitoring.

During the period from 2014 to 2021, the population of Obscure Galaxias at Vigars Road has experienced fluctuations (Figures 4-19 - Figure 4-26). The years 2014 and 2016 saw no fish recorded, whereas 2015, 2017 and 2018 showed an increase in the species abundance and the presence of multiple size classes (35–115 mm) including evidence of recent recruitment in all three years. The abundance of Obscure Galaxias sampled during 2018 was also the greatest catch (141 fish) recorded since conducting the annual monitoring. Despite this, more recently low numbers of the species have been recorded (2019: 13 fish; 2020: 3 fish; 2021: 2 fish). The Jutland Road site exhibited less variable abundance of Obscure Galaxias in recent years, with an overall decline in the abundance of the species since 2013. The small number of fish that have been recorded since 2013 have largely been small fish in the 50–60 mm size range, indicating a lack of adults persisting at the site.

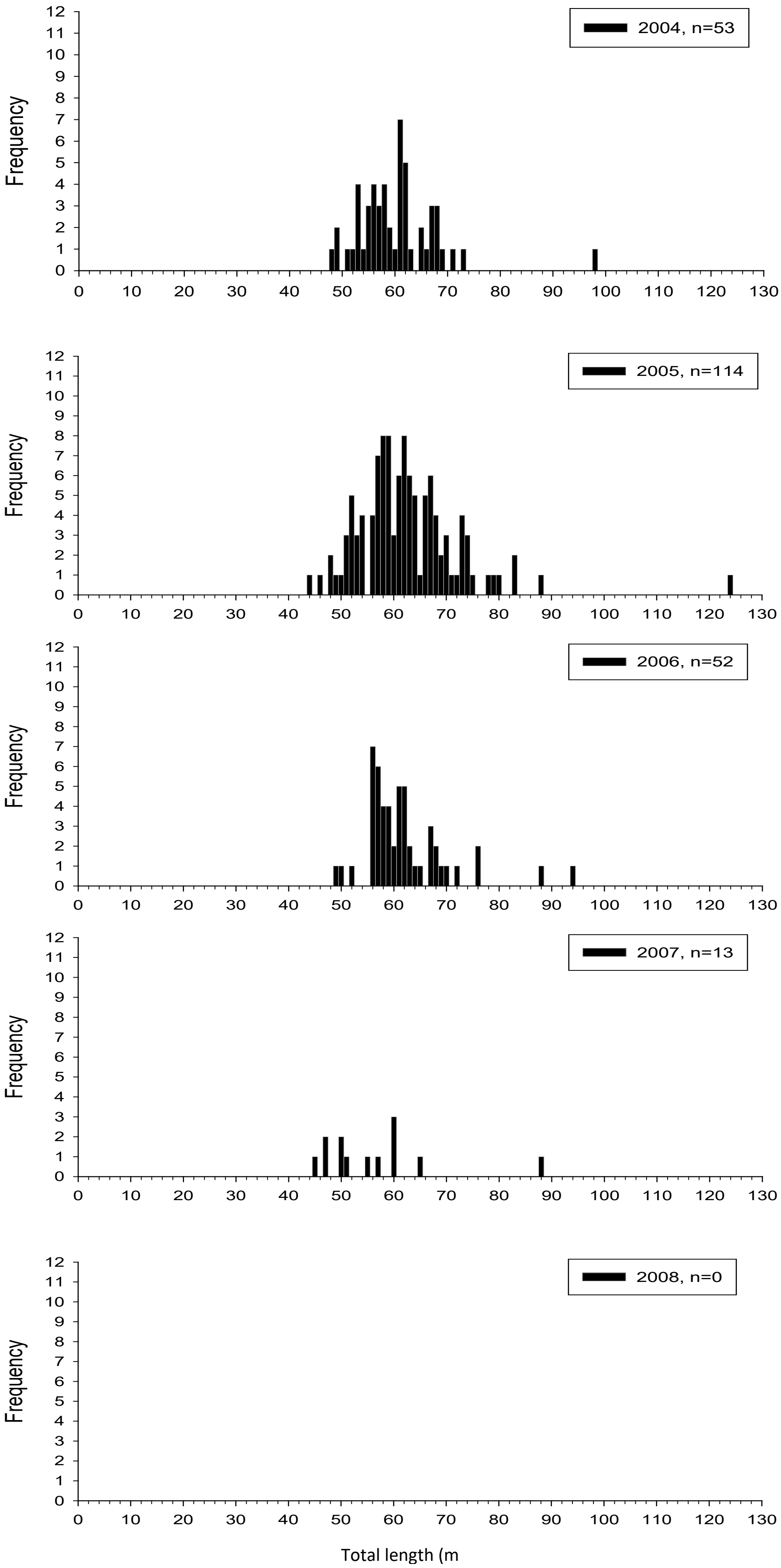

Figure 4-19. *Length structure for Obscure Galaxias at Vigars Road, Marne Catchment (UPR reach) from 2004 to 2008.*

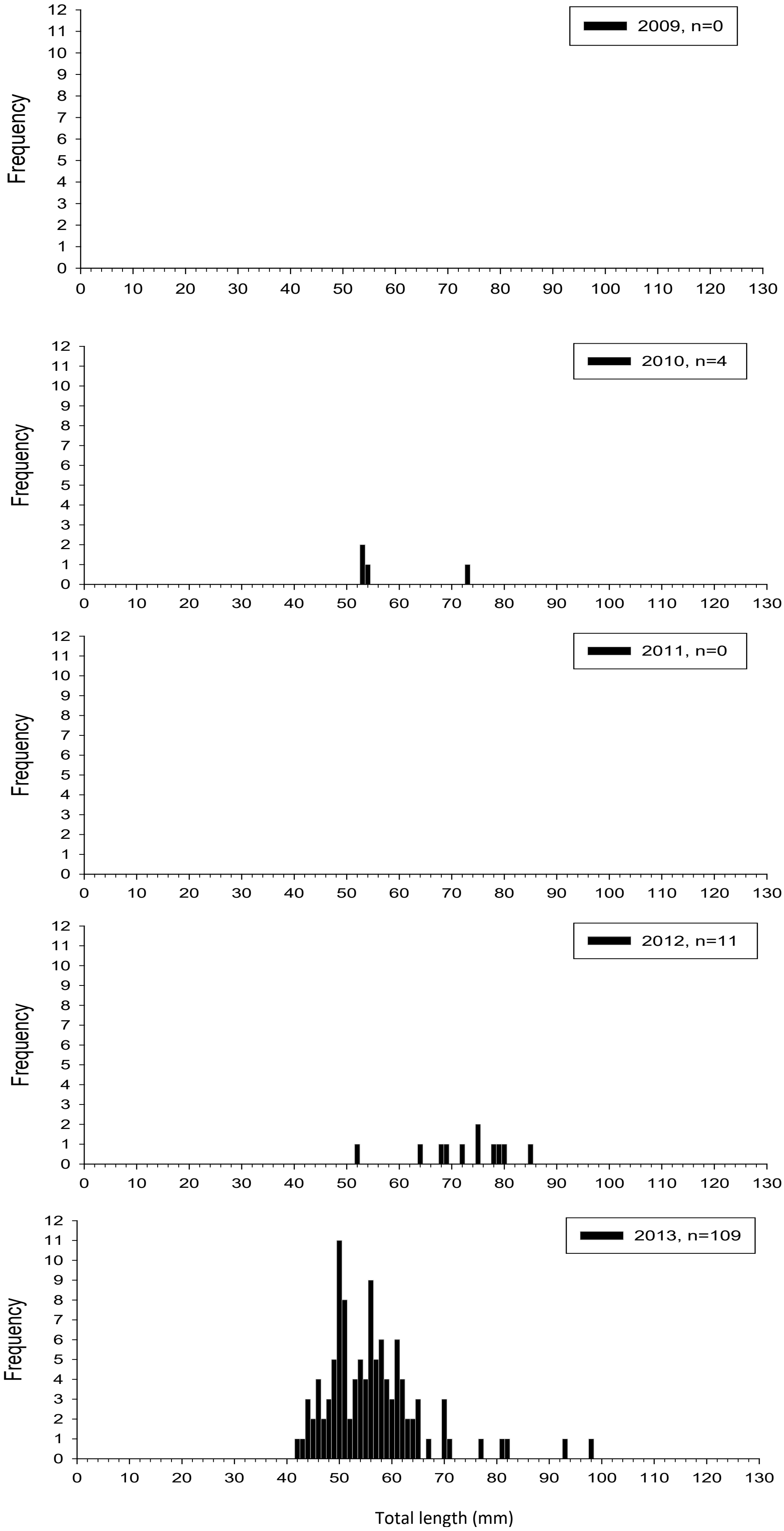

Figure 4-20. Length structure for Obscure Galaxias at Vigars Road, Marne Catchment (UPR reach) from 2009 to 2013.

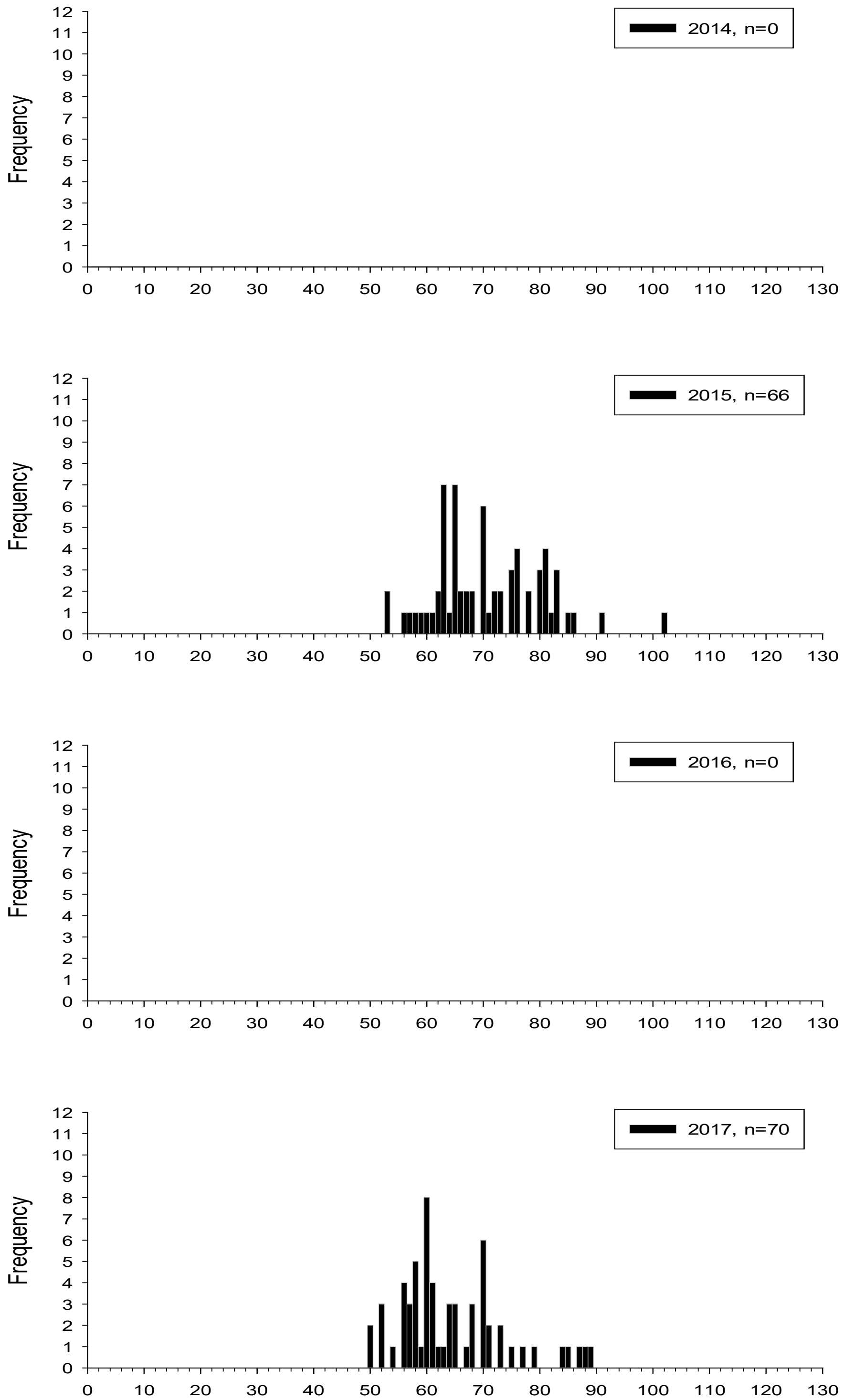

Figure 4-21. Length structure for Obscure Galaxias at Vigars Road, Marne Catchment (UPR reach) from 2014 to 2017.

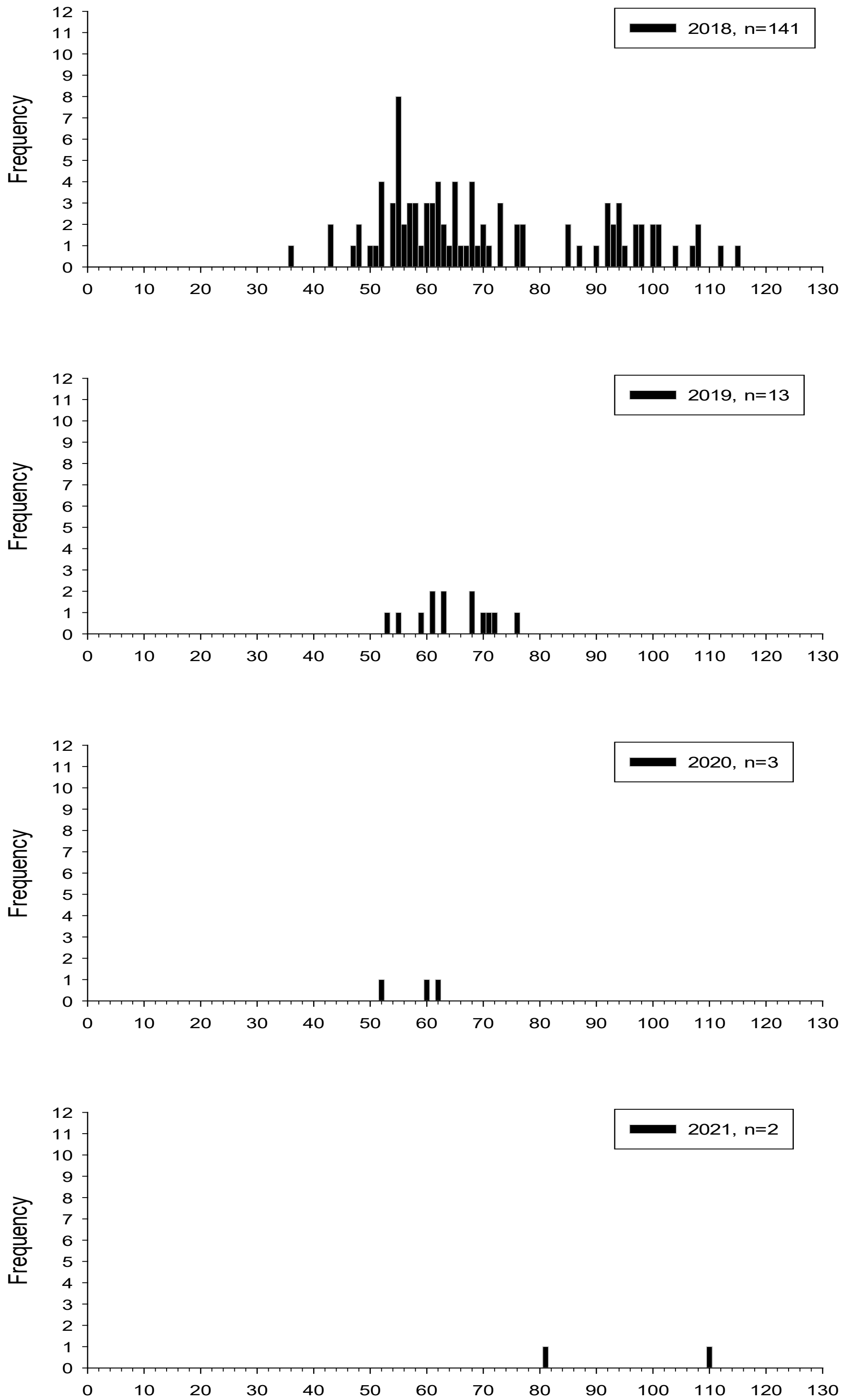

Figure 4-22. Length structure for Obscure Galaxias at Vigars Road, Marne Catchment (UPR reach) from 2018 to 2021.

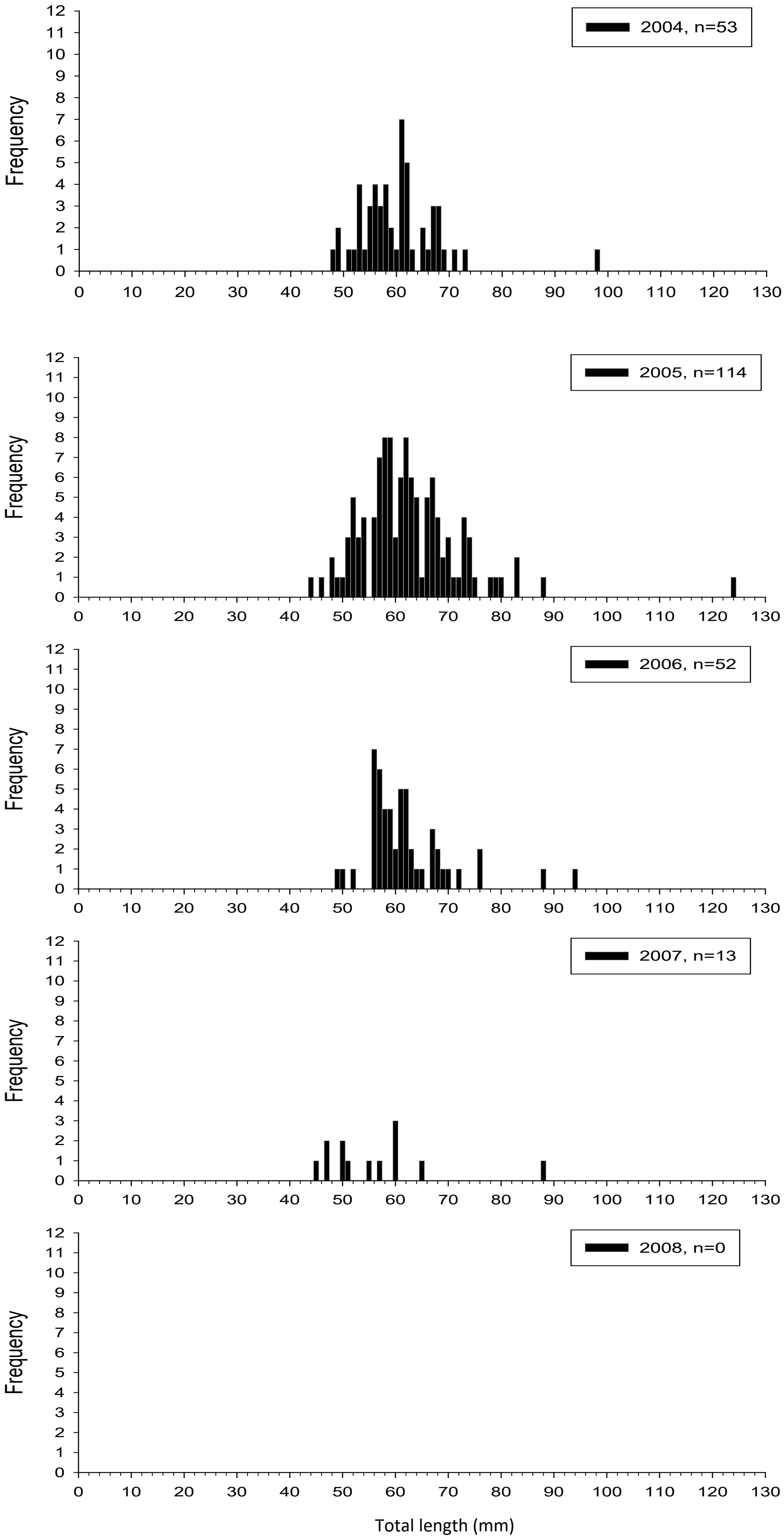

Figure 4-23. Length structure for Obscure Galaxias at Jutland Road, Marne River Catchment (UPR reach) from 2004 to 2008.

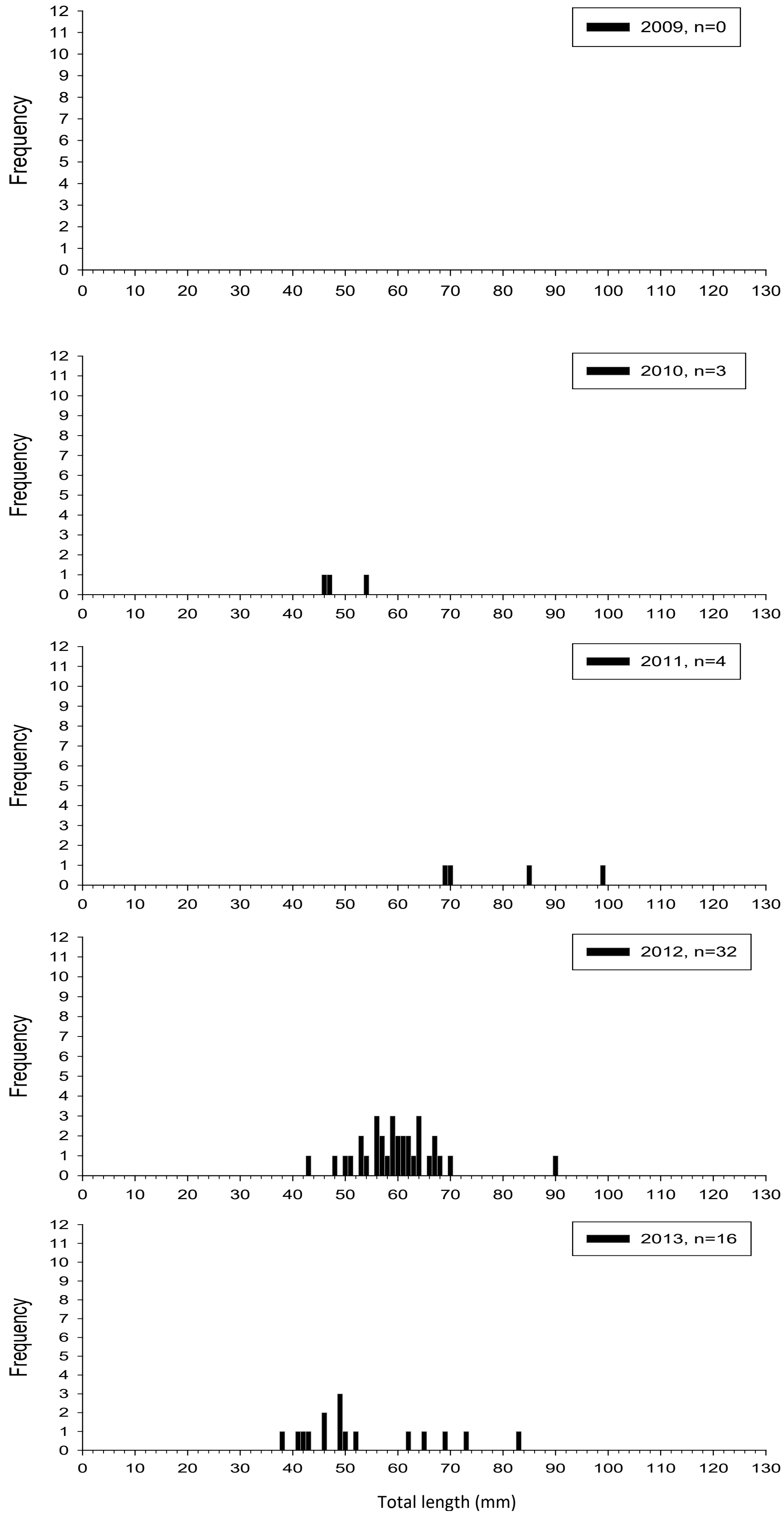

Figure 4-24. Length structure for Obscure Galaxias at Jutland Road, Marne Catchment (UPR reach) from 2009 to 2013.

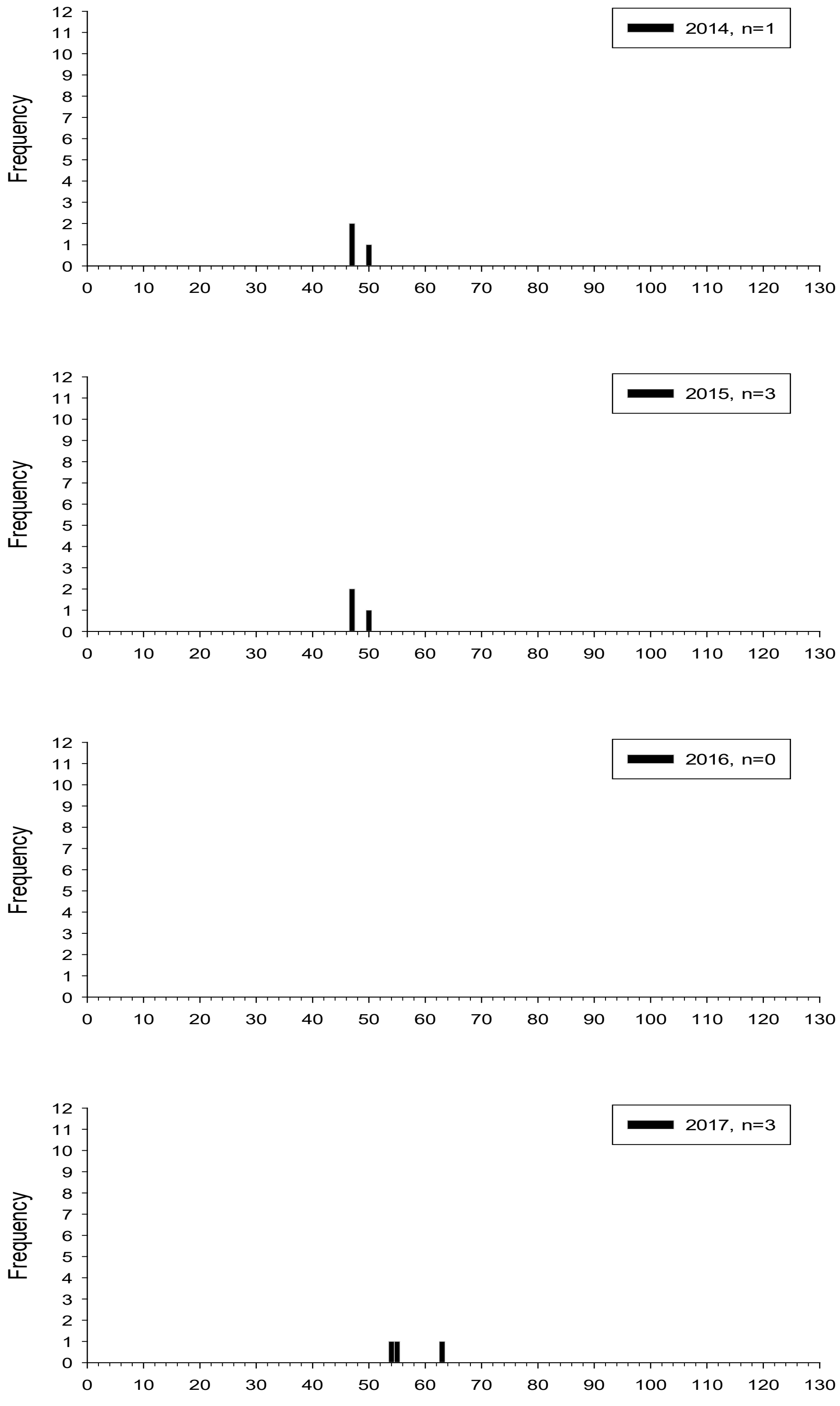

Figure 4-25. Length structure for Obscure Galaxias at Jutland Road, Marne River Catchment (UPR reach) from 2014 to 2017.

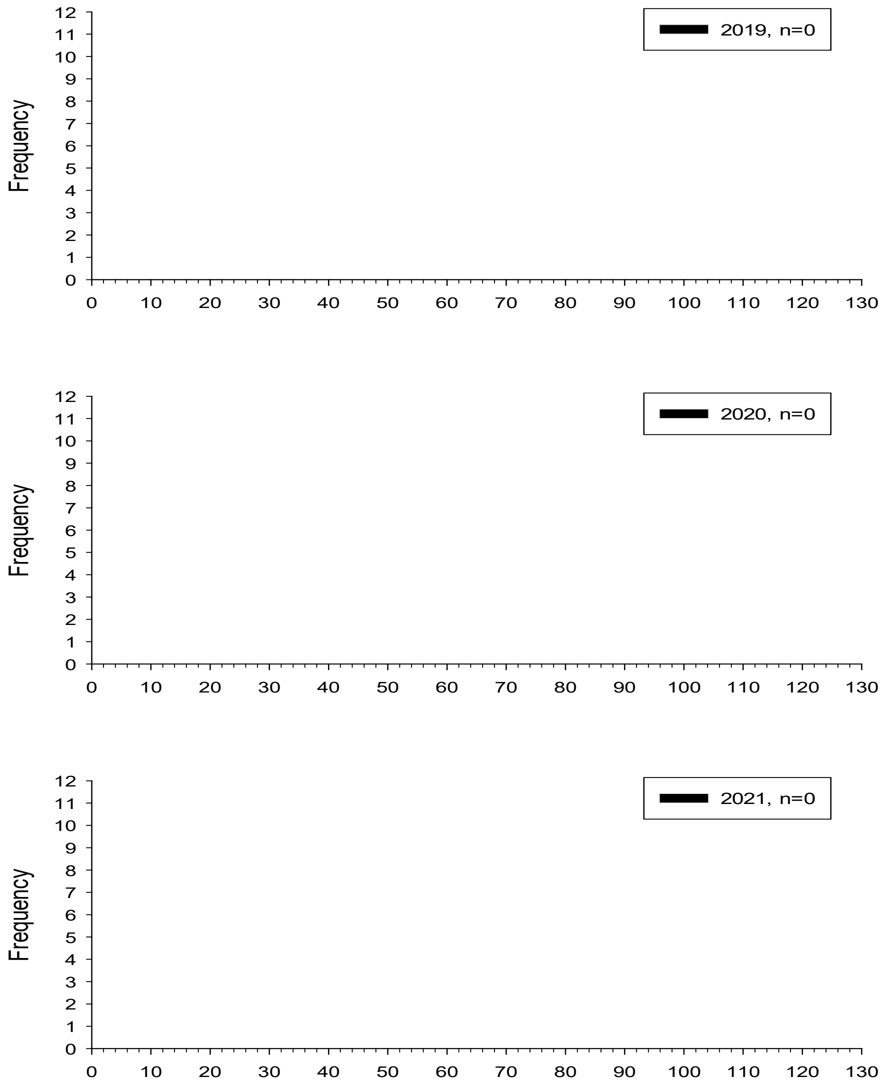

Figure 4-26. Length structure for Obscure Galaxias at Jutland Road, Marne Catchment (UPR reach) from 2019 to 2021 (note: not sampled in 2018).

Marne River - MPR reach

Obscure Galaxias are the only species of fish recorded at Pine Hut Road site on the North Rhine River and are the only fish-related ecological asset throughout the North Rhine River (Figure 4-27). The recolonisation of adult Obscure Galaxias was recorded in this reach in autumn 2006 after extended seasonal flow conditions and/or a high flow event in November 2005 (Figure 4-4). Monitoring on five occasions between 2006 and 2009, however, failed to detect the species; this result was not unexpected, given the major decline in water availability experienced over this period (i.e., in autumn 2009 only a small pool with depth 0.3 m remained and had a salinity of >10,000 EC). Despite greater water availability and improved habitat condition from 2010 to 2014, the species was not observed to have recolonised the Pine Hut Road site. Similarly, high flows were observed during the 2015–2017 period (Figure 4-4); however, no fish were recorded during or after this period. During monitoring in 2021, the Pine Hut Road site was completely dry, and fish remain absent.

Figure 4-27 North Rhine River - Pine Hut Road, with water during autumn 2013 (left) and when dry during 2021.

Marne River - gorge reach

Obscure Galaxias are the fish-related ecological asset for the Marne Gorge and this site represents a key measure of Obscure Galaxias population resilience across the Marne Saunders PWRA (as it relies on flows and fish from upstream) (Figure 4-28). It is evident that the species experiences local extirpation followed by recolonisation events when conditions are favourable. For instance, a pulse of juvenile fish (0+ age class) and potentially some 1+ age class adult fish was recorded in autumn 2008, yet a year later (autumn 2009) conditions for survival were poor (i.e., heavily concentrated shallow pool with salinity >25,000 EC) and the species was not detected (Figure 4-29; Figure 4-30). During 2010–2013, the population did not exhibit the characteristic boom and bust in numbers, but rather local extirpation in 2011 and again in 2013 was interspersed with small peaks in numbers (2010, 7 fish; 2012, 2 fish), perhaps indicating a period of sustained decline in upstream population resilience. From 2014 to 2021, the Marne Gorge population largely appears to be declining, with the species not detected in the majority of the years (i.e., not detected from 2014 to 2016 and from 2019 to 2021) (Figure 4-29; Figure 4-32). Fish were detected in low abundance (4 fish) during 2017 before a boom in being experienced in 2018 (99 fish which were predominately recruits). The observed reappearance of the species in 2017 and high catch in 2018 followed a period of high and average rainfall (2016–2017) (Figure 4-1) in the Marne Saunders PWRA, which subsequently produced relatively high flow and reduced water salinity to the Marne River (Figure 4-10).

Figure 4-28: dry times in the Marne River – Gorge: (left) 2013; and (right) 2021.

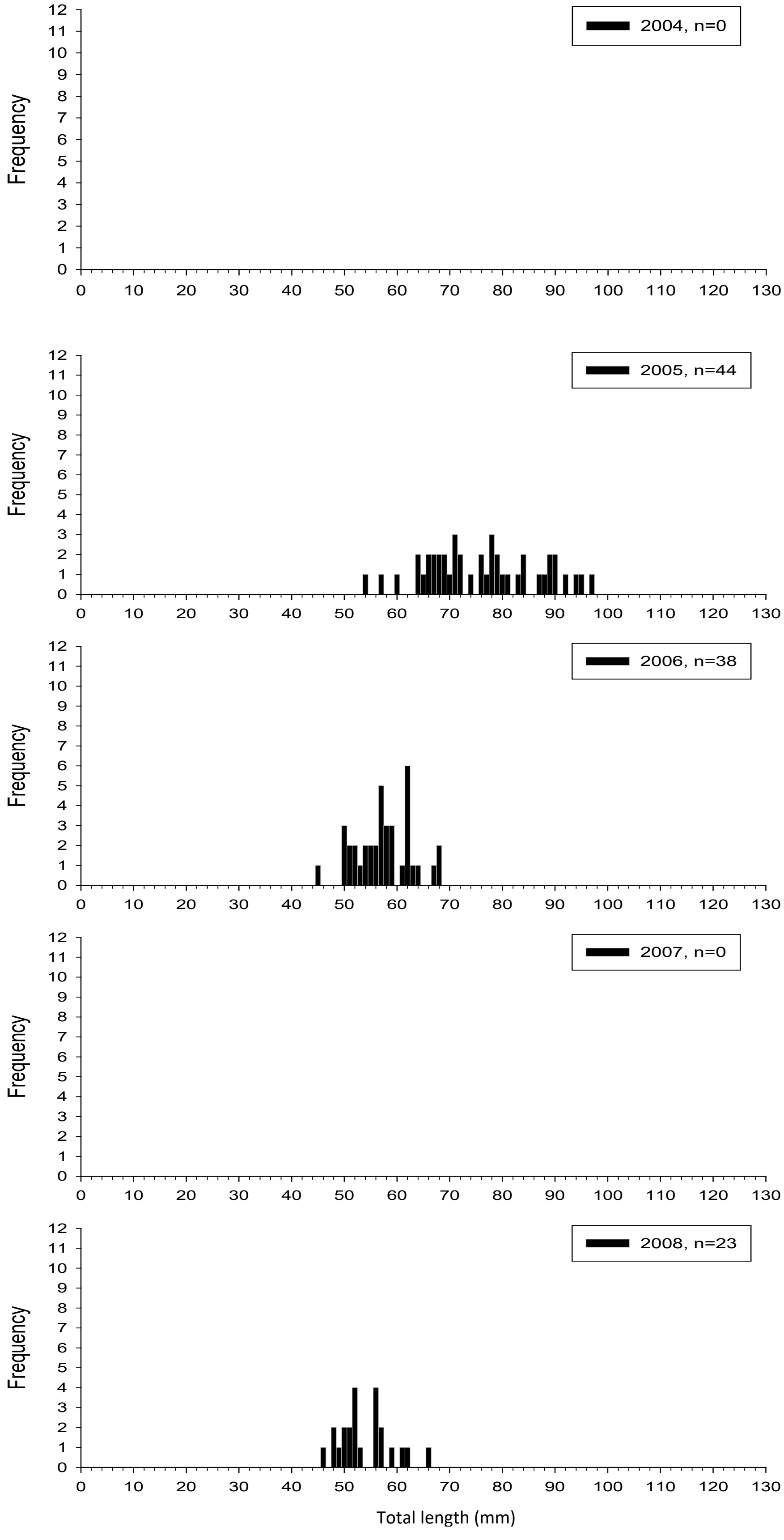

Figure 4-29. Length structure for Obscure Galaxias at Marne Gorge, Marne Catchment (gorge reach) from 2004 to 2008.

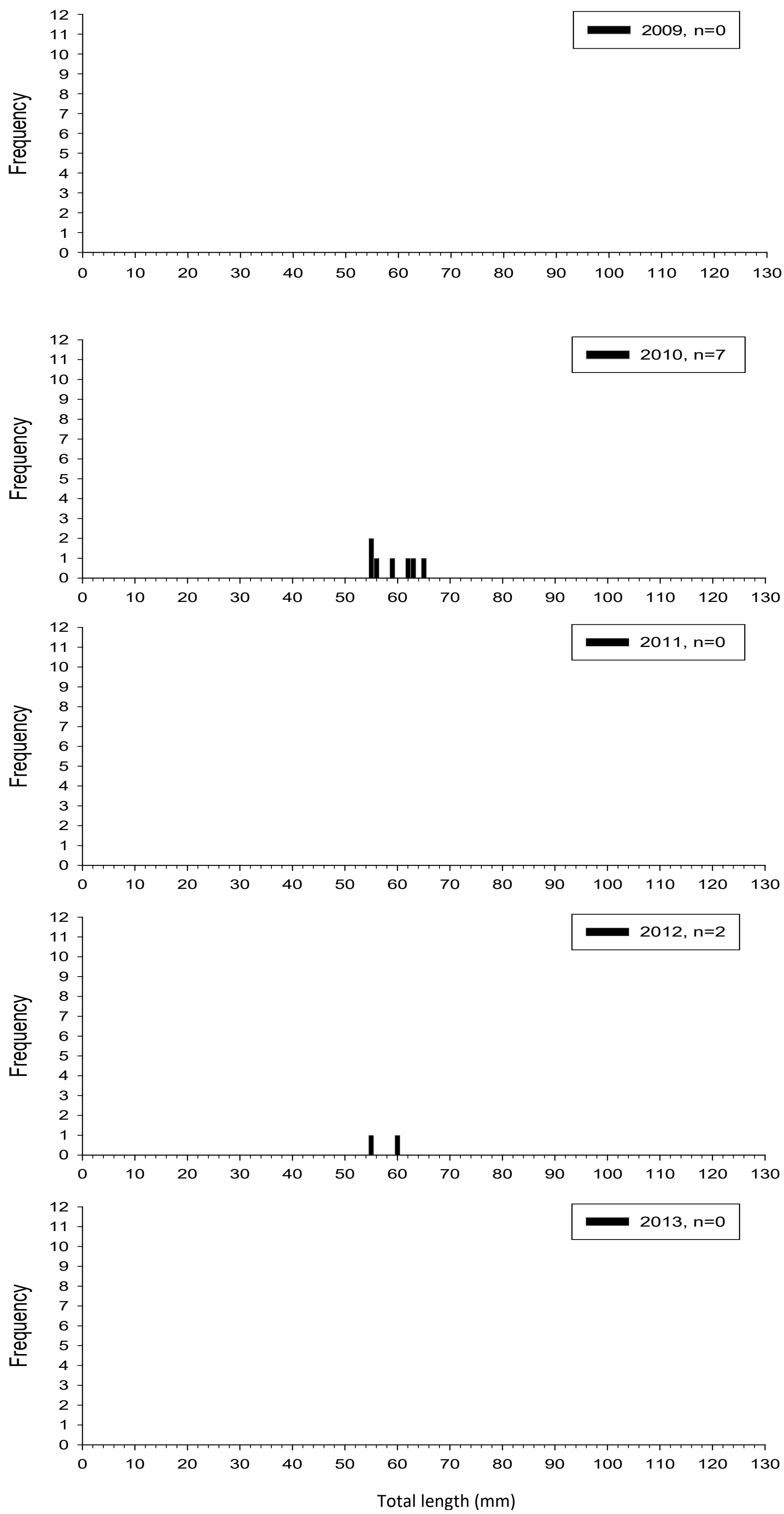

Figure 4-30. Length structure for Obscure Galaxias at Marne Gorge, Marne Catchment (gorge reach) from 2009 to 2013.

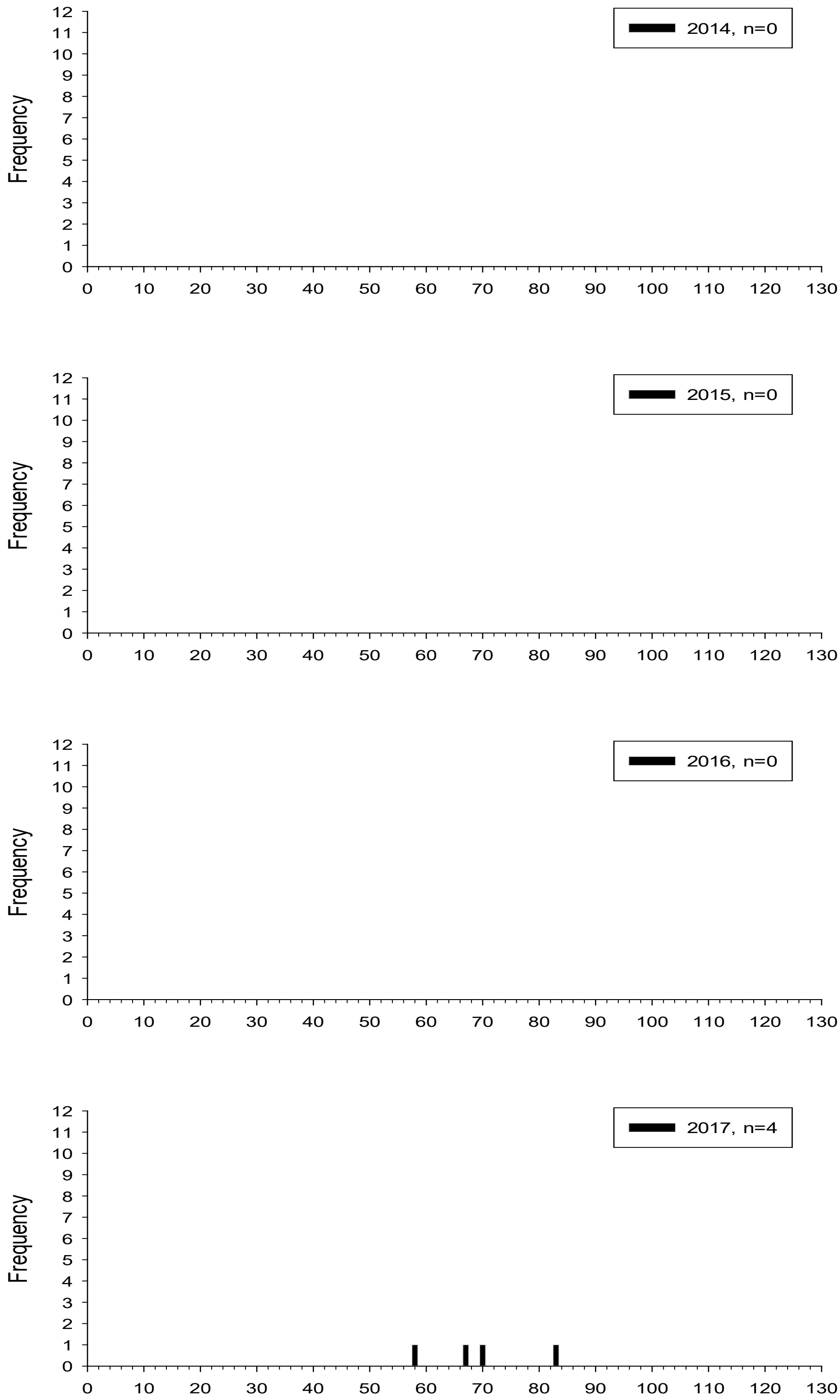

Figure 4-31. Length structure for Obscure Galaxias at Marne Gorge, Marne Catchment (gorge reach) from 2014 to 2017.

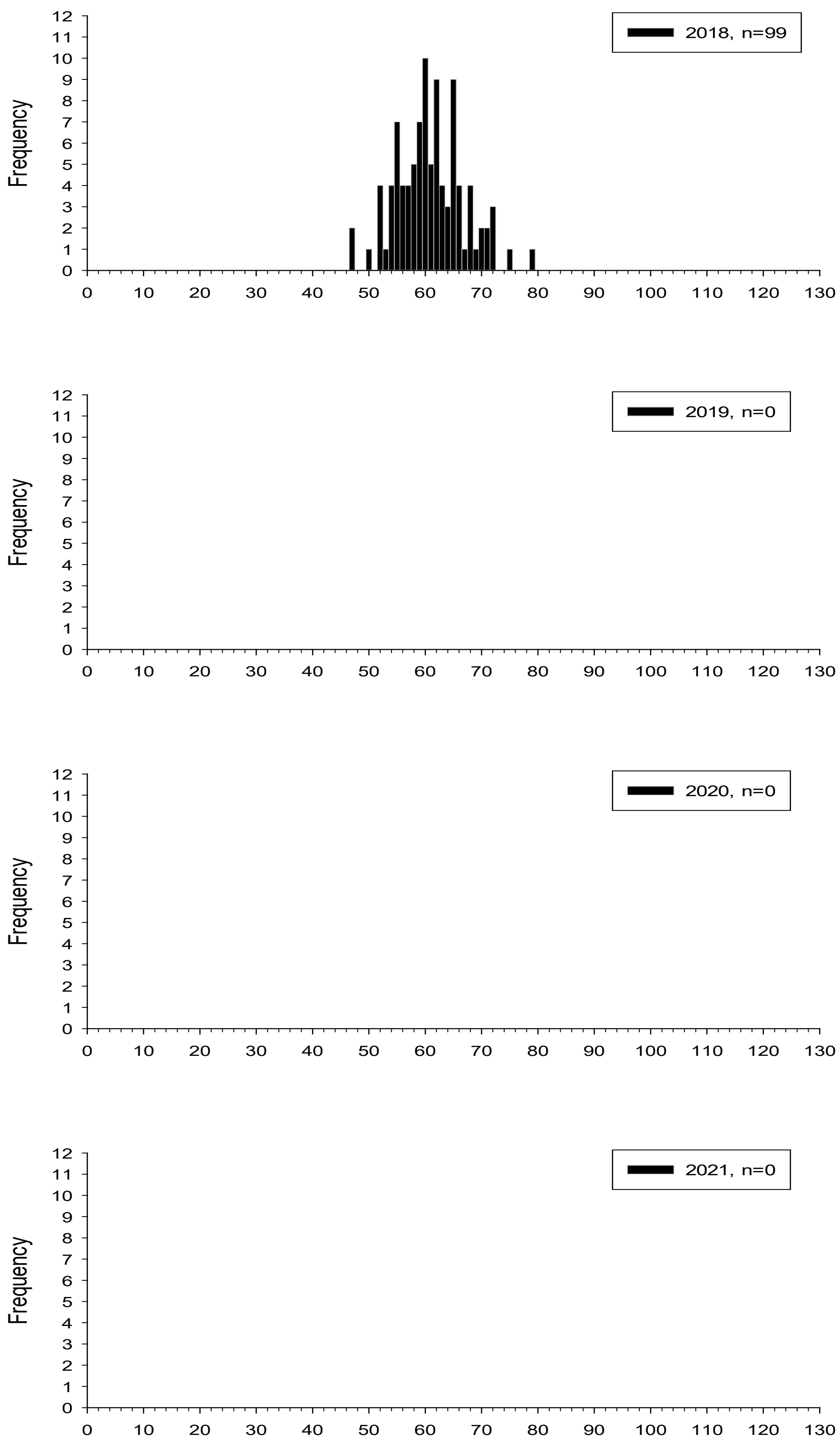

Figure 4-32. Length structure for Obscure Galaxias at Marne Gorge, Marne Catchment (gorge reach) from 2018 to 2021.

Marne River - lowland reach

The fish-related assets in the lowland reach of the Marne River are primarily the River Blackfish population (at Black Hill Springs (b) and Three Sisters Pool), as well as the general condition of a diverse groundwater dependent fish community (Figure 4-34). It is clear that the River Blackfish population is increasingly threatened, with no recruitment and the only presence of the species being large aging individuals (>200mm TL) observed during 2004–2008 (Figure 4-34) (Hammer 2009). Over the period between 2009 and 2013, the declining trend in the River Blackfish population continued, with few larger fish (<4 fish) observed up to 2012 and no fish sampled in 2013 (although one large individual was visually observed) (Figure 4-35). During the period between 2014 and 2021, three individuals of this species were recorded. A single fish was observed at the Marne River – Black Hill Springs (b) site (no other individuals of the species have been recorded at this site). In 2016, opportunistic sampling detected the species at another site, Marne River - Three Sisters Pool, which has been incorporated into the report carding since 2017; the species has only been recorded twice in recent years. All fish recorded were adults (>200 mm TL) and appeared to be in poor health. It is now evident that failed spawning or recruitment is a feature of the River Blackfish population in Marne River, which is undoubtedly on the brink of localised extirpation. Intervention measures (e.g., wild egg harvest for rearing, fish rescue and captive breeding) suggested in 2009, remain necessary (but logistically difficult) in order to secure the population; additionally, there is an urgent need to address the reduction in surface stream flow and determine to what extent the low groundwater levels are contributing to reduced water quality (in particular salinity levels) in the lower Marne River. Previous groundwater analysis indicates the groundwater discharging into the Marne River in the Black Hill Springs region is largely from the regional Murray Group limestone aquifer, with discharge rates of groundwater at two sites within the area was shown to be 250–315 ML year^{-1} (Harrington 2004)). The salinity levels of groundwater from a monitoring well near Black Hill Springs (Observation Station RIL015) indicates the EC of water discharged into the Marne River to be ~3500 EC (Figure 4.15) such salinity of ground water is already near the suggested upper limit of the species salinity tolerance, even before water extraction through evaporation and vegetation water uptake.

Figure 4-33. Marne River – Sampling Three Sisters Pool during autumn 2021 (left), the single River Blackfish recorded at the Three Sisters Pool during autumn 2021.

Other native fish found to occur at sites within the lowland reach of the Marne River are largely the native freshwater generalists Carp Gudgeon and Dwarf Flathead Gudgeon, with these two species showing an overall trend for increased abundance throughout the sites sampled. Carp Gudgeon and Dwarf Flathead Gudgeon show similar trends in catch from 2002 to 2021; the abundance of Carp Gudgeon also appears to be positively correlated with salinity within this reach. The freshwater specialist Obscure Galaxias were detected in the 2014–2021 reporting period in low abundance; this species was recorded at Black Hill Springs in 2014 (1 fish), 2018 (1 fish) and 2019 (2 fish). The alien Eastern Gambusia is also found to occur throughout the lower Marne River; this species has been detected in relatively low abundance at all sites sampled within the lowland reach.

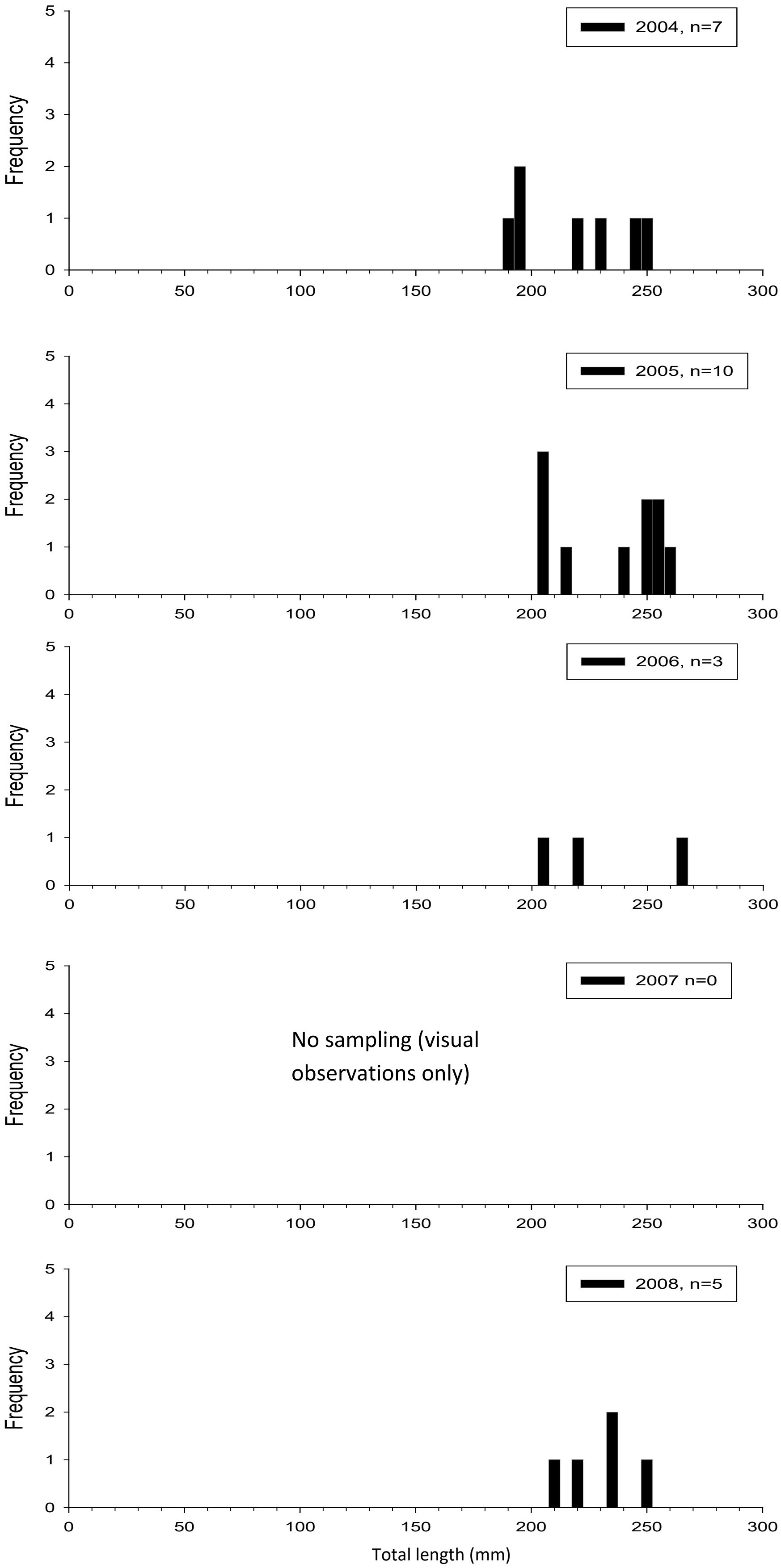

Figure 4-34. Length structure for River Blackfish at Black Hill Springs, Marne Catchment (lowland reach) from 2004 to 2008.

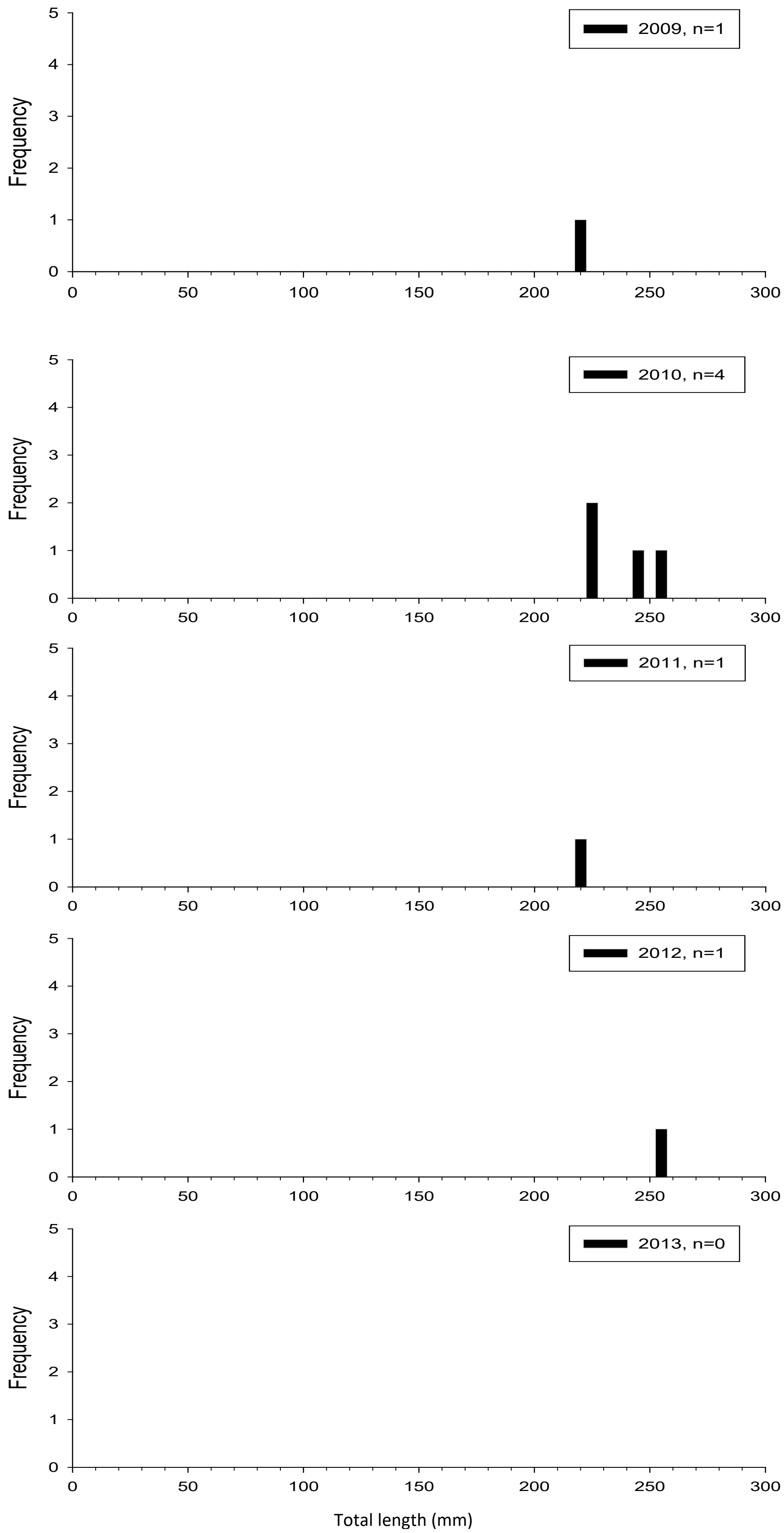

Figure 4-35. Length structure for River blackfish at Black Hill Springs, Marne Catchment (lowland reach) from 2009 to 2013.

Marne River – terminal wetland reach

The fish-related ecological asset for the terminal wetland reach is the Lower Marne/Murray backwater fish community (Figure 4-36). Historically, this community has included rare and endangered species such as Olive Perchlet (*Ambassis agassizii*) and diadromous species including Congolli (*Pseudaphritis urvillii*) and Common Galaxias (*Galaxias maculatus*); however, these species have not been recorded in recent years. The Marne River terminates at its junction with the Murray River near Wongulla. The Marne Catchment environmental objectives for fish relate to the input of water to create a variable wetland capable of supporting a diverse fish community including diadromous and rare species.

Figure 4-36. Marne River – Marne Mouth, autumn 2021.

Nowadays, flows from the Marne River only infrequently reach the terminal wetland, with Murray River flows more strongly influencing water availability at this site. Throughout the period of critical water shortage (2007−2010) in the region, the terminal wetland was disconnected from the Murray River and was subsequently dry during monitoring carried out during the late stages of the millennium drought in 2009. Since 2010, improved regional water availability has helped to reconnect the terminal wetland to the Murray River. The site was sampled in 2012 whilst the Murray River was experiencing unregulated flow and native species were in low numbers but relatively diverse (4 native species), and only one introduced species (Common Carp) was observed. Sampled every three years, the Marne Mouth has been sampled three times during the period of 2013–2021. Largely due to the influence of the connected Murray River, the fish assemblage recorded at the Marne Mouth is distinct from other sites monitored within Marne Saunders PWRA. Although the freshwater fish species richness is greater at the Marne Mouth than other sites sampled within the catchment, the freshwater specialist species River Blackfish and Obscure Galaxias have not been recorded at the site. The greater species richness (10 species recorded 2002–2021) at the Marne Mouth can largely be attributed to the inclusion of Murray River species; of the ten species that have been recorded at the site eight species were native and two were alien.

Saunders Creek – gorge reach

The fish-related asset in the gorge reach is Obscure Galaxias, with a Saunder Creek – Saunders Creek Gorge monitored for fish and water quality five times over the 2002–2021 period (Figure 4-37; Table 2-2). No fish have yet been recorded at this site, potentially due to consistently high salinity at the sampling site (ranging between 7740–26,226 EC) and low abundance of nearby aquatic habitat (and thus limiting populations that could recolonisation the site).

Figure 4-37. Saunders Creek – Saunders Creek Gorge (gorge reach), autumn 2020.

Saunders Creek – lowland reach

The fish-related asset of the lowland reach is a Carp Gudgeon population restricted to the small section of permanent pools at or above Lenger Reserve (Figure 4-38). Monitoring of Lenger Reserve in 2004 revealed a stable Carp Gudgeon population with high abundances and juveniles, and Eastern Gambusia were also present in high numbers (Hammer 2004). Yet, in autumn 2009, low numbers of Carp Gudgeon and no signs of recent recruitment (all fish >40 mm) were observed, whilst Eastern Gambusia remained very common (observations of mixed sizes including juveniles) and a single adult Common Carp (480 mm) was recorded (Hammer 2009). The Lenger Reserve site was not monitored in 2010 but was visited annually between 2011 and 2013. The decline of the Carp Gudgeon population continued with no fish recorded in 2011 and low abundance in the other years (<12 fish), whereas large fluctuations in Eastern Gambusia were realised (415−5347 fish).

Figure 4-38. Saunders Creek – Lenger Reserve (lowland reach), autumn 2021.

During the period from 2014 to 2021, the Lenger Reserve site was sampled in 2014, 2015, 2017, 2019 and 2021; only two species, Carp Gudgeon and Eastern Gambusia, were recorded throughout this sampling period. The abundance of Carp Gudgeon increased early in this period, with 30 fish recorded in 2014, followed by 99 fish in 2015 and 374 fish in 2017 before reducing in 2019 (no fish) and 2021 (1 fish). Little difference in salinity was observed during this period with electrical conductivity consistently above >10,000 EC.

Condition of fish-related assets

The report carding assessment of fish-related assets revealed the overall condition score for the Marne Saunders PWRA was poor or moderate during all of the 2002–2021 review period (noting 2005 was on the cusp of the good condition category) (Figure 4-39). Over the review period the condition of fish-related assets experienced a declining trend (Figure 4-39). Over time, fish-related assets were increasingly deemed to be in poor condition, with condition scores of one or less observed in five of the past eight years.

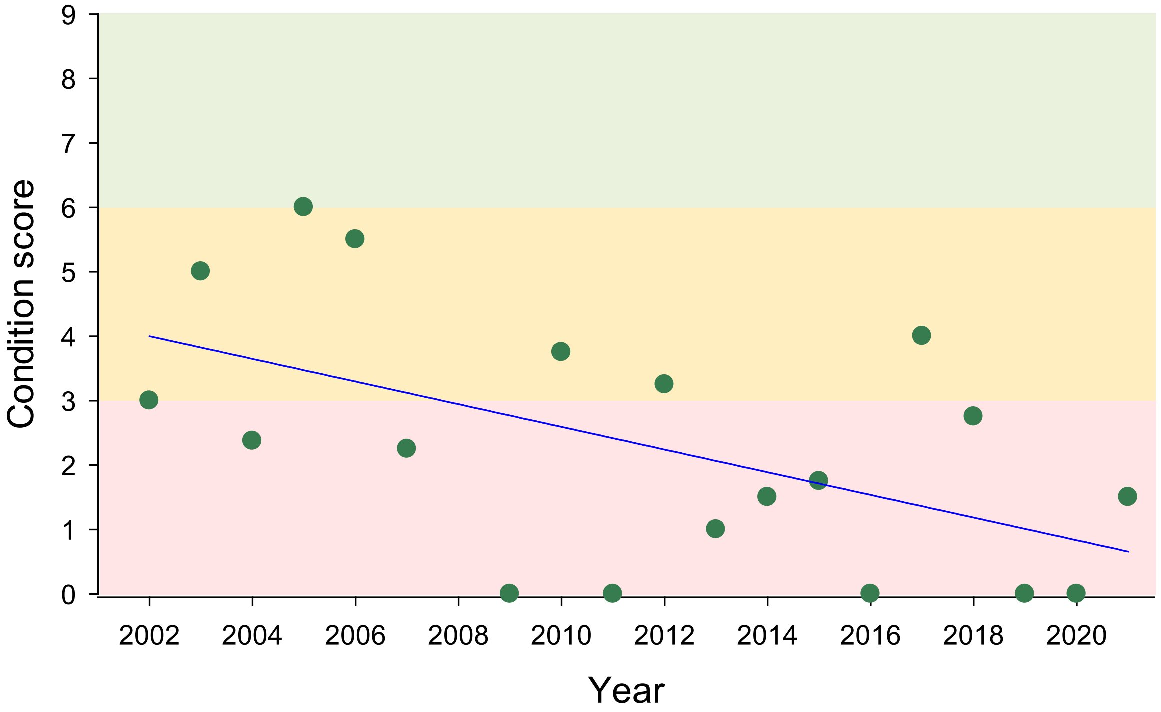

Figure 4-39. Annual condition score for the Marne Saunders PWRA over the review period (2002–2021).

As expected, the condition of individual sites across the Marne Saunders PWRA typically mirrored the overall trend across the Marne Saunders PWRA (Figure 4-40). For instance, there were sharp declines in condition at sites across the UPR (Marne River – Jutland Road), MPR (North Rhine River – Pine Hut Road), lowland (Marne River – Black Hill Springs (b)) and terminal wetland (Marne River – Marne Mouth) reaches. For some of these sites, the condition over the past three years (2019–2021), has been extremely poor with the fish-related asset not detected.

Only two sites did not decline, with these being Marne River – Vigars Road and Saunders Creek – Saunders Creek Gorge, where the trend in the condition of fish-related assets has remained stable, albeit with annual variation, over the review period. For Marne River – Vigars Road, condition fluctuated considerably but the fish-related asset (i.e., Obscure Galaxias) appears to be resilient; periods of poor condition are often followed by increases to good condition and the asset persists. For Saunders Creek – Lenger Reserve, the temporal trend indicates that the fish-related asset (i.e., Carp Gudgeon) was in poor condition during the end of the Millennium Drought before recovering between 2014 and 2017 to moderate condition with declines experienced again more recently (2019 and 2021).

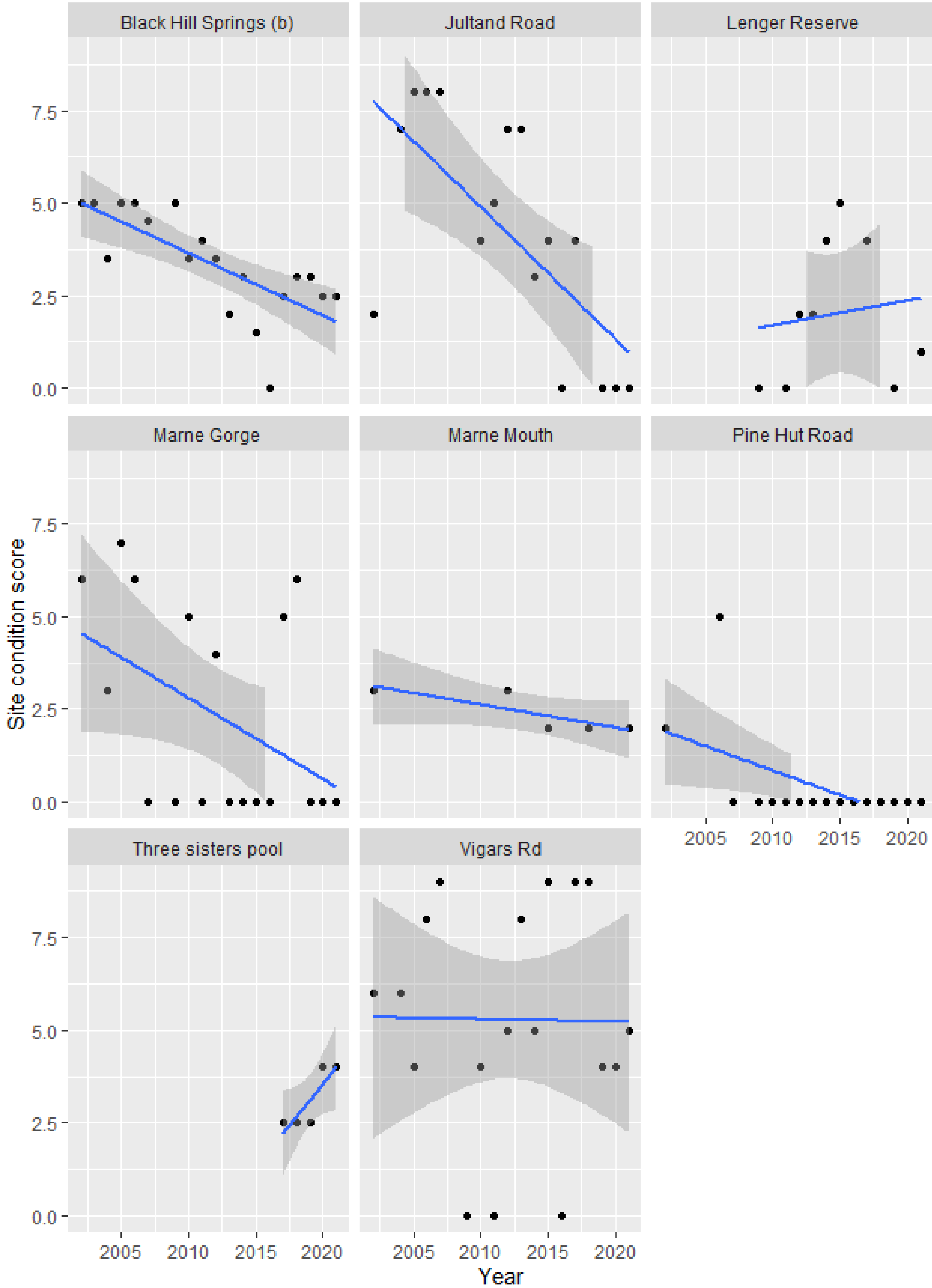

Figure 4-40. Condition score across the review period (2002–2021) for sites across the Marne Saunders PWRA.

5. Discussion

The Marne Saunders PWRA currently supports a rapidly degrading fish community characterised by the increasing dominance of freshwater generalists and alien species in its lower reaches and reduction in number and extent of fish in the upper reaches. Fish communities throughout the Marne Saunders PWRA vary between the defined reaches, with species richness lowest in the elevated sites of the mid and upper reaches, before increasing in the lowland with the highest species richness observed at the terminal wetland. With already relatively low species diversity within the upper reaches, the Marne Saunders PWRA is exhibiting declines in fish-related assets throughout the system due to species' environmental water requirements not being met. Obscure Galaxias are showing strong signs of decline throughout much of the mid, upper gorge reaches. More urgently, the River Blackfish population within the lowland reach is likely to become extirpated in the immediate future without improvements to prevailing flow and water quality. Over the review period (2002–2021), it is evident that there has been no improvement in diversity or distribution of native fish communities, which reinforces the need for improved streamflow and habitat enhancement to aid the improvement of fish communities (as well as other fish-related assets) across the Marne Saunders PWRA.

5.1 Flow regime and water quality

Exploration of trends in flow regime and water quality across the Marne Saunders PWRA reveal a substantial decline in flow volume and key metrics of the flow regime. The decrease in flow within waterways has been observed throughout much of the Marne Saunders PWRA, with a reduction in the total flowing period (e.g., number of flow days), with the exception of Saunders Creek Gorge (Figure-4.7), and fewer freshes over the LFS and T1 season for all gauging sites across the review period. In turn, fish monitoring sites are now experiencing less water in refuge pools and the quality of the water, namely salinity, is deteriorating. Taken together, the suitability of prevailing habitat is declining for fish-related assets.

One factor that has in the past been considered a major contributor to the lack of surface flows throughout the Marne Saunders PWRA is water extraction for uses such as agriculture, with farm dams the main example. When comparing current flow data with modelled 'no dams' data, it is apparent that farm dams are preventing a significant amount of surface runoff from entering waterways of the catchment. However, even in the modelled 'no dams' data, a trend indicating a significant decline in flow days and freshes is evident. Such a trend suggests that surface water usage is not the only factor contributing to reduced flow magnitude and frequency. Although the considerable reduction in flow through the Marne Saunders PWRA cannot be completely aligned with anthropogenic water uses, the problem of reduced flow can largely be attributed to reduced rainfall created runoff. This points to the impact of broader climatic change (i.e., less rainfall and increasing temperatures) over the review period; although rainfall within the lower reaches of the catchment, appears to have remained relatively stable over the past ~20-year period, rainfall within the upper reaches has reduced (Bureau of Meteorology, unpublished data). Considering the upper catchment areas of the Marne Saunders PWRA are where most of the rainfall is collected and forms surface runoff (SA MDB NRM Board 2019), the reduction of rainfall is cause for concern. Climate change is predicted to reduce annual rainfall and increase temperatures throughout southern South Australia (Suppiah et al. 2006), placing the fish assets of the Marne Saunders PWRA under further threat.

Further to the reduction of surface flows throughout the Marne Saunders PWRA is consistent with observed reductions of groundwater level across the region. Most aquifer monitoring wells within the Hills and Plains zones are recording record low water levels. Despite the reduced water levels, some aquifers in the region are exhibiting a decrease in ground water salinity levels. Despite the reduced salinity of some groundwater, the lower water levels are likely to result in a decrease of water discharged into the system and when combined with water loss through plant uptake and evaporation, this may result in an increase in salinity throughout waterways.

5.2 Fish-related assets

This review highlighted that fish-related assets in the Marne Saunders PWRA are in poor condition and experiencing a declining trend.

Obscure Galaxias

The mid, upper and gorge reaches of the Marne River are dominated by the freshwater specialist, Obscure Galaxias. Although the species persists in certain areas of the upper reaches, it has not been detected in many areas in recent years; specifically, it has been undetected in the upper reach Marne River – Jutland Road site since 2017, the mid reach since 2006, and in gorge reach since 2018. Obscure Galaxias has been persisting in a boom-and-bust cycle, surviving in low numbers in drier years before increasing in abundance during wet years. Despite the decline in flow in the upper reaches, it appears that refuge pools persist and maintain the minimum suite of EWRs for the species to persist (if not recruit). Such refuge pools are critical for the species during dry periods and those pools beyond the known pool (which are annually monitored) should be identified urgently. This will allow for adequate monitoring of the species and help with conservation planning throughout the Marne Saunders PWRA. The population within the Marne Gorge is particularly precarious and it is likely this is now a sink population, relying on individuals washed down from a source population in the upper catchment during periods of flow to repopulate the reach. Other sites appear to no longer support the species, highlighting the critical importance of refuge pools in the upper reaches. Obscure Galaxias are also found in the lower reaches of the Marne catchment (e.g., Black Hill Springs); however, the species has only been detected in lower abundance throughout these reaches and may represent vagrants washed down from the upper reaches of the catchment during periods of high flow. Overall, Obscure Galaxias are showing a declining trend throughout all the sites monitored within the various reaches with the exception of the site at Vigars Road in the upper reach, which has remained stable (Figure 4-36). Although Vigars Road has a stable reach score, Jutland Road (also in the Upper Marne reach) has declined (Figure 4-36); similarly, the Marne Gorge has recorded a declining reach score. Overall, current results suggest the population of Obscure Galaxias within the UPR will further reduce if EWR for the species are not provided in the near future.

River Blackfish

Whilst the lowland reach of the Marne River maintains some EWRs for supporting River Blackfish such as deep, permanent, cool well-oxygenated pools of water with base flow, the reduction in surface flow (and likely groundwater flow) has created unsuitable conditions. Namely, prevailing salinity is now consistently more than 5000 EC in recent years. The populations of River Blackfish monitored at Black Hill Springs and the Three Sisters Pool sites are at severe risk of extirpation. With only three larger individuals of the species observed during the 2014–2021 period and no indication of recruitment since 2002, it appears the River Blackfish are no longer able to complete their lifecycle. The detection of juvenile River Blackfish in 2002 followed above average rainfall in 2001 and the subsequent increase in flow and associated reduction of salinity within the system (Figure 4.9). Considering this, a possible explanation for the lack of recruitment of River Blackfish throughout the Marne River in recent years is the lack of regular surface water flows and likely reduced groundwater flows throughout the catchment which in turn have contributed to the increase in salinity within the Marne River. The extent that groundwater flow from aquifer discharge contributes to the surface flow within the Black Hill Springs and the Three Sisters Pool sites is likely to be significant. With the observed trend for the reduction in the water levels across most groundwater monitoring wells throughout the Marne Saunders PWRA, it is possible that reduced aquifer groundwater discharge into the lowland reaches is further contributing to the increased salinity throughout the lower Marne River. However, the salinity of groundwater (although decreasing in many areas) is relatively saline and variable between differing areas. The salinity in an aquifer near Black Hill has been recording an average salinity of ~3500 EC in recent years (Figure 4-15), it is likely that through evaporation, this will become more saline and rapidly push the salinity threshold for successful recruitment of River Blackfish, which has been suggested to be below 4000 EC (Whiterod and Hammer 2014). To achieve such a relatively low salinity within the lower Marne Saunders PWRA would require sustained heavy rainfall within the upper reaches and reduced water extraction; alternatively, the feasibility of localised freshening of refuge pools could be explored. Without immediate action, it is likely that extirpation of River Blackfish will be observed within the Marne Saunders PWRA.

Freshwater Generalists

Freshwater generalists Carp Gudgeon and Dwarf Flathead Gudgeon are restricted to the lower reaches of the Marne Saunders PWRA. Unlike the River Blackfish, these species appear to be coping well with the observed elevated salinity levels (~5000–7000 EC) in the lowland Marne River, however, their proliferation is also likely to be due to the lower flow environments present in these reaches, which favours these species. Carp Gudgeon represent the only known fish-related asset within the Saunders Creek catchment. A relatively isolated population of this species has been monitored at the Lenger Reserve site in the Lowland reach of Saunders Creek. This population has been monitored either annually or biennially since 2009. Results of recent monitoring suggest the fish-related asset is in decline within Saunders Creek. It has been suggested that the increase in salinity (>10 000 EC) within this reach of Saunders Creek may be responsible for the decline of the species (Whiterod and Hammer 2014), and Ye et al. (2010) found that Carp Gudgeon eggs failed to develop at higher salinities. Considering the salinity recorded during the most recent monitoring in autumn 2021 (10,670 EC), it is likely the Carp Gudgeon fish-related asset within the Saunders Creek catchment will continue to decline until greater surface flows are provided to increase flow velocity and freshen the system. Considering the likelihood of reduced flows throughout the Marne Saunders PWRA in future years, and Carp Gudgeon and Dwarf Flathead Gudgeon preference for low flows, it is likely these species will continue to decrease in the Saunders Creek Catchment due to salinity, whereas they may increase in abundance and become the dominant native species within the Marne River catchment until their salinity threshold is passed, should salinity continue to increase in the Marne River.

Diverse fish community

The Marne Saunders PWRA continues to maintain a relatively diverse fish community in the lowland and terminal wetland reaches. Consistent with the simplification of the fish community highlighted above, freshwater generalists make up the majority of this diversity, with more specialist species absent due to EWRs are not being met. This simplification of fish communities is a common feature of stressed river systems (Wedderburn et al. 2017; Whiterod 2020).

Diadromous and Potamodromous

Diadromous and potamodromous species were not detected in the Marne Saunders PRWA during the review period. It is evident that the EWRs of these species are not being met across the Marne Saunders PWRA. Most obviously, the Marne Saunders PWRA is lacking flows to improve connectivity and create suitable habitat across the terminal wetland.

5.3 Regional context

In order to assess if the poor and falling condition of fish assets is a localised issue or if this is a wider issue, a review of neighbouring areas was undertaken. Recent reviews demonstrate similar overall declines across the Barossa (D. Green, DEW, unpublished data; Green et al. 2014; Whiterod et al. 2018) and EMLR (DEW, unpublished data; Whiterod and Gannon 2021).

The Barossa PWRA is located due west of the Marne Saunders PWRA and has been subject to detailed fish monitoring since 2013 in order to inform the upcoming review of the WAP. Jacob Creek in the Barossa PWRA was known as a refuge for Mountain Galaxias (*Galaxias olidus*), with permanent flow and barriers to upstream dispersal of large bodied predatory exotic species. Mirroring the declines in the Marne Saunders, the population of Mountain Galaxias in Jacob Creek has declined since 2013 in line with decreasing flow duration (Figure 5.1). This decline is directly attributed to the reduction in flow duration in Jacob Creek and may represent the local extirpation of the species from the Barossa PWRA.

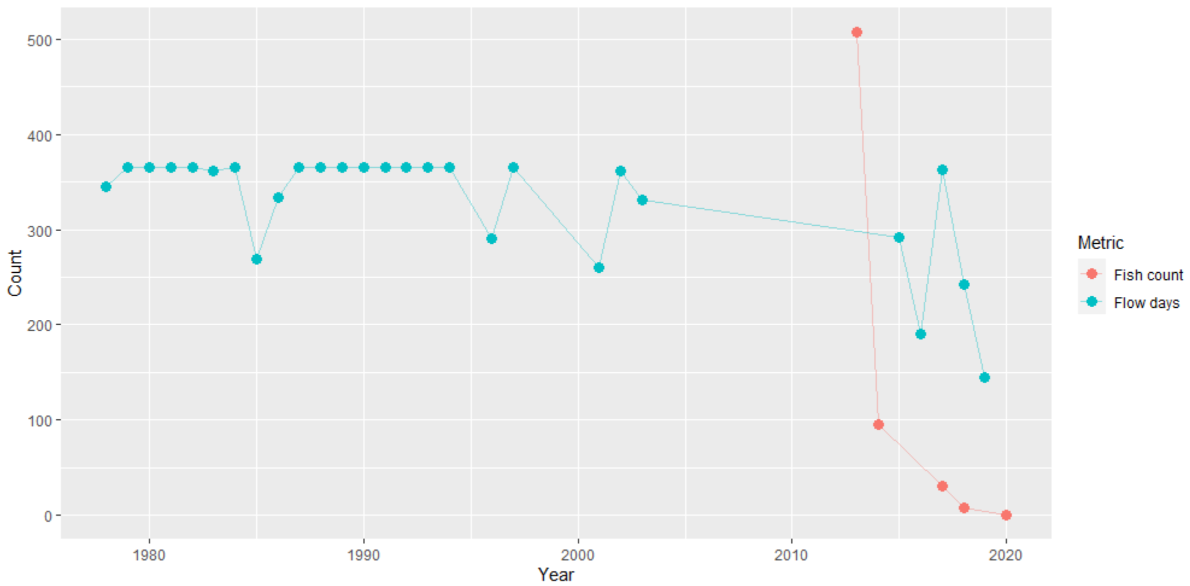

Figure 5-1. Comparison of the number of flowing days recorded at the Jacob Creek flow gauge (A5050518) and the number of Mountain Galaxias recorded at the same location (D. Green, DEW, unpublished data).

In the EMLR PWRA region, to the southern of the Marne Saunders PWRA, fish communities are also experiencing decline (DEW, unpublished data; Whiterod and Gannon 2021). Declines are most evident in the northern catchments (geographically closest to the Marne Saunders PWRA), with fish communities further south generally holding stable.

When taken in the context of the broader region, it is clear that the general loss of fish asset condition is not localised to the Marne Saunders PWRA and the drivers are generally considered to be similar.

5.4 Implications for water allocation planning

The overarching factor hindering the provision of EWRs to support the fish-related assets throughout the Marne Saunders PWRA is the lack of flow in the upper reaches. The lack of surface and ground water flows is not only responsible for the increased salinity (and deteriorating habitat) within the Marne Saunders PWRA, but also the reduction of water permanence. Indeed, the reduction of surface and ground water levels and flow is leading to the increased drying of many of the mid, upper and gorge reaches of Marne Saunders PWRA. Such drying not only directly exterminates many fish within these reaches, but also reduces the connectivity between the reaches thus reducing the ability for recolonisation to occur.

Given the current trends of flow and water quality throughout the Marne Saunders PWRA, the near-term prospects for the freshwater fish community will likely include a vast reduction in the geographic range of the freshwater specialist Obscure Galaxias, largely due to reduced connectivity between reaches and the increased drying of stream habitats in the upper reaches. Furthermore, the Obscure Galaxias will likely become extinct within the lowland reach of the Marne River or Saunders PWRA due to elevated salinity throughout this reach. The increase of freshwater generalist species favouring low flow environments is likely to continue, with Carp Gudgeon and Dwarf Flathead Gudgeon likely to increase in abundance until the salinity reaches their salinity threshold. With increasing salinity and low flows, the alien Eastern Gambusia is also likely to increase in abundance; Eastern Gambusia favour low flow environments and can tolerate poor water quality, including salinity up to 70,000 EC (Whiterod and Gannon, personal observation).

In the context of water allocation planning, the WAP details environmental water provisions (EWPs). These EWPs are the agreed water that will be provided to the environment to achieve ecological outcomes. These are based on the EWRs but take into account the needs of other users (social, cultural and economic). In the case of the Marne Saunders, the EWPs are represented by the acceptable level of deviation from the no dam scenario for each of the EWR metrics. Provision of these EWPs is not meant to put the other objectives of the WAP at unacceptable levels of risk.

It is clear that provision of adequate flows throughout the Marne Saunders PWRA to achieve the EWPs for the region's native freshwater fish communities should be given immediate consideration. Given the present risk of loss of fish assets, an assessment of the resource capacity to meet the EWRs/EWPs should be considered in line with considerations of restoring flow through the system.

5.5 Recommendations

Recommendations for the mitigation of further decline of the condition of fish-related assets within the Marne Saunders PWRA, are largely based on the requirement for increased surface flow throughout all waterways within the area. As indicated by the 'no dams' modelled data, an increase in surface flow may be achieved with a reduction in farm dams within the catchment. It is recommended that the maximum available volume of surface flow be allowed to enter waterways of the catchment to increase the frequency and magnitude of flows; such increased surface runoff is required throughout the entire catchment to prevent future increased drying and elevation of salinity. For the mitigation of further decline of fish-related assets of the Marne Saunders PWRA, it is recommended that, where possible considering climatic pressures, WAP principals are followed to ensure that the environmental water provisions are provided for each of the fish-related assets within all reaches of the Marne Saunders PWRA. Reducing the extent of water abstraction may act to increase flows throughout the Marne Saunders PWRA, however other methods may also need to be employed to increasing the flows and reduce salinity. One possible solution would be to introduce water from an external source, either to supplement current water usage (e.g., agricultural and or domestic water allocations) or to directly supply the waterways as environmental flow. If water was to be supplied as environmental flow water, the EWRs for fish-related assets within all reaches of the Marne Saunders PWRA would need to be carefully considered, as would the seasonality of the delivery of water to each reach. This review highlights the importance of monitoring continuity to develop long-term datasets to assess temporal trends – this annual monitoring must continue in the future.

Conclusion

The present review revealed stressed fish-related assets occur across the Marne Saunders PWRA. Acknowledging the current declining trend and recognising that prevailing conditions will further deteriorate in the future, dire consequences for the fish-related assets are anticipated, unless the natural flows of the Marne Saunders PWRA can be restored or replicated.

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