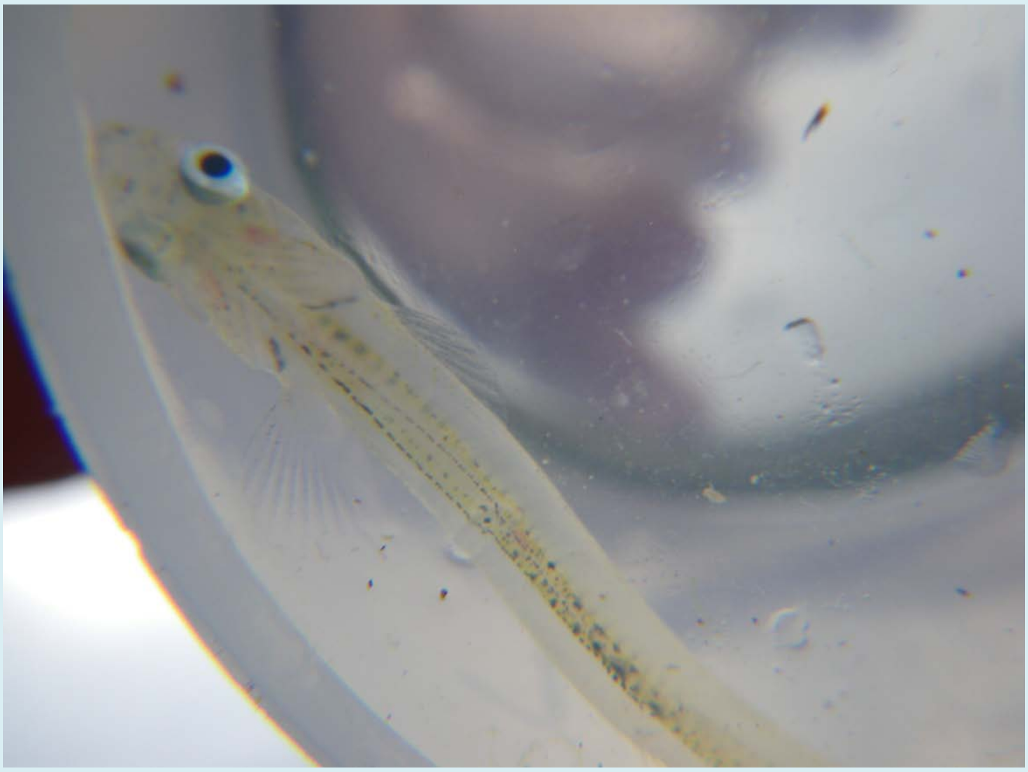
Baseline fish survey and movement study of the Drain L Catchment, South Australia



Michael Hammer, Nick Whiterod, Thomas Barnes & Melissa Tucker

Aquasave Consultants, Adelaide

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Report to Department for Water, South Australian Government

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Correspondence in relation to this report contact

Dr Nick Whiterod
Aquasave Consultants
Tel: +61 409 023 771
Email: nick.whiterod@aquasave.com.au

Cover photos

Directional fyke net near the mouth of Drain L, and whitebait Climbing Galaxias from the catchment.

Disclaimer

Executive Summary

The Drain L Catchment is an area with significant natural ecological assets persisting within a highly altered landscape, and where strong relationships now exist between aquatic fauna and the flow ecology of artificial drains. New projects investigating the potential diversion of water from upstream areas of the Drain L Catchment require clear understanding of the values that are associated with current flow conditions, to enable an objective assessment to be made of the likely risks and management implications of altered flow conditions.

This report provides the baseline information necessary to predict, assess and monitor the environmental impacts of any future changes, including: physical construction; altered hydrology (reduced magnitude and duration of certain flows); increased connectivity (and potential alien fish invasion); and, the impacts of weirs. The study had three specific aims, which were to:

- Undertake a baseline survey across the catchment to more fully document fish related ecological assets, including the establishment of specific monitoring stations at proposed water diversion points/flow nodes.
- A movement study in the lower catchment – the linkage point between the sea and freshwater for a range of migratory (diadromous) fish species – to assess the presence and timing (seasonal/and flow based) of movements for different species.
- A specific ecological investigation of Australian Mudfish to assess the life history of the species (diadromous vs. obligate freshwater) using a special chemical analysis of the otolith (fish ear bones) to determine the environment of residence over an individual's life span.

Baseline survey

The catchment wide, intensive baseline survey confirmed Drain L to be a significant and unique system with a high diversity of species, with three threatened species present and, importantly, no introduced species. In particular, Lake Hawdon South is a highly significant habitat supporting strong populations of threatened Dwarf Galaxias and Australian Mudfish. Yet, apparent declines in abundance of both these species since previous 2010 monitoring highlight their susceptibility to naturally changing catchment conditions from year to year. These species were not recorded in nearby Lake Hawdon North, however there is excellent potential for hydrological restoration works to enhance the habitat for native fish in this area. Given the widespread nature of many introduced fish species in Australia, it is noteworthy that the catchment remains free of introduced species. The findings provide a sound benchmark to guide future management and for measuring the impacts of any future changes that occur in the catchment.

Movement study

The movement study indicated that the Drain L Catchment represents a key area for the conservation of diadromous and euryhaline fishes in South Australia, with a high residency of fish species as well as migrations of diadromous species. For instance, the present study observed the second record of Climbing Galaxias, and first time as migrating whitebait, in the South East (first time from Drain L), verified the presence of Pouched Lamprey and Congolli, and resulted in the collection of six previously locally unrecorded euryhaline and diadromous species. Interestingly, the upstream movement of Australian Mudfish whitebait was not observed during the study. While artificially created, the Drain L outlet, as a relatively young estuary, appears to be an important and rare habitat type with strong connectivity. The results indicate that from a native fish perspective, the system is one of the best functioning estuaries in South Australia. These findings represent a solid foundation for further study, conservation and management of diadromous species in the region.

Otolith microchemistry

The otolith microchemistry study was unable to conclusively resolve whether diadromous movement is occurring for Australian Mudfish in the Drain L catchment. However, it is now possible to conclude that the population is not obligate diadromous with recruitment noted in Lake Hawdon South, without any signs of diadromous movement of whitebait to the marine environment. Several lines of evidence point to a wholly freshwater dependant Lake Hawdon South population, however this is not yet conclusive. For instance, the population could be facultative diadromous, functioning as wholly freshwater for the majority of the time, but occasionally undergoing diadromy (with migratory events occurring that were missed by this snapshot study). Clearly further work is necessary to investigate the specific requirements of the species including its potential for diadromous movement. Given the significance of the Australian Mudfish population in the catchment, until this question is conclusively resolved, it is recommended that the potential for diadromous migrations of the species be accounted for in all future management actions (e.g. fishway design associated with the regulators) considered for the catchment.

Recommendations

A number of recommendations emerge from the present study that relate to either management or monitoring. In terms of management of the Drain L catchment, it is recommended to:

- Maintain the catchment free of introduced fish species by preventing connectivity with pest species populations.
- Maintain sufficient diversity of drain and wetland habitats to support a diversity of fish species, particularly obligate freshwater fishes.

- Maintain sufficient flows through Drain L to ensure existing estuarine conditions are maintained at the Drain L outlet and the mouth remains open to allow continued marine/estuary connectivity.
- Ensure fish passage of diadromous species through the construction of a fishway associated with any weir structures proposed under the South East Flows Restoration Project (SEFRP), and investigate fish passage improvements at existing structures.
- Determining and providing for environmental water provisions for different functional groups of fishes in the Drain L Catchment.

Monitoring recommendations relate to the need to detect temporal changes throughout the catchment and changes associated with the proposed SEFRP. Specifically, (a) broad baseline monitoring, and (b) specific assessment of the potential impacts of SEFRP in the Drain L Catchment is recommended. Baseline monitoring is necessary to assess the broad condition of the fish community composition, in what is a highly significant catchment. Additionally, periodic movement sampling should investigate more detailed questions (e.g. fine scale timing/flow requirements) to improve understanding of the migration of threatened diadromous species (Climbing Galaxias, Congolli and potentially Australian Mudfish) but also wholly freshwater recruitment of Australian Mudfish in the Lake Hawdon South. This will assist with determining the operating guidelines for minimum flows and water levels in the system. Specific (event-based and annual) site monitoring of fish indicators in response to changes imposed by the proposed SEFRP is also recommended.

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1.0 Project background

The Drain L Catchment is an area of south east South Australia with significant natural ecological assets. Whilst extensively impacted by land reclamation and surface water drainage there is a modest amount of aquatic habitat in the catchment including a range of natural and alternate functional habitats (e.g. freshwater wetlands, a variety of permanently flowing to ephemeral drains, and a dynamic small estuary with strong connectivity to both upstream habitats and the sea). These habitats support a relatively high native fish species richness, core populations of threatened species, and no known introduced fishes (Hammer 2002; Wedderburn and Hammer 2002; Hammer and Tucker 2011).

New projects have targeted the potential diversion of water from the catchment, and thus threaten to alter the current balance. The South East Flows Restoration Project (SEFRP) specifically proposes to divert water from existing drains in the South East towards the Coorong. Potential diversion points are located on Drain M; Wilmot Drain and Drain K (both in Drain L catchment); and the Blackford Drain. Some of these potential diversion points are located upstream of important wetlands that depend upon drain inflows. Specifically, diversion points on:

a) Drain M are located upstream of Lake George; and

b) Wilmot Drain and Drain K are located upstream of Lake Hawdon North, Lake Hawdon South (indirectly) and the Robe Lakes.

Additionally, drain habitats at and downstream of all potential diversion points are known to retain important ecological assets that require a secure water supply. The present study, commissioned by the South Australian Department for Water, deals specifically with the Drain L Catchment (see (b) above). It provides information that is critical for assessing and monitoring the environmental impacts of specific hydrological changes, and follows three lines of investigation:

- **Baseline survey** across the catchment to more fully document fish related ecological assets, and establish monitoring at proposed water diversion points/key flow nodes.
- **Movement study** in the lower catchment – the linkage point between the sea and freshwater for a range of migratory (diadromous) fish species – to assess the presence and timing of movements of different species (seasonal/and flow based), and thus identify minimum environmental water requirements should future upstream diversions occur.
- **Specific ecological study of Australian Mudfish** to assess the lifecycle using a special chemical analysis of the otolith (fish ear bones) to track the environment of residence of individuals through time (i.e. wholly freshwater vs. diadromous).

1.1 Study region

The Drain L Catchment is situated within the south east of South Australia, artificially draining part of a once extensive wetland system that, prior to European settlement, occupied a significant portion (>40%) of the region. The Drain L Catchment is a discrete area (~1700km^2) extending inland from the coast at Robe and situated between the Drain M catchment to the south, and Blackford Drain catchment to the north (Figure 1.1). The region experiences a Mediterranean type climate with mild to warm and dry summers and cool wet winters (Figure 1.2 and 1.3), and overall has relatively high rainfall (e.g. average annual rainfall for Robe since 1860 is 632.6mm, Bureau of Meteorology, unpublished data).

Drain L was constructed (and is managed) to allow cross-catchment landscape drainage across the Upper South East (South Australian Department for Water 2011). Long-term average flows at Boomaroo Park, lower Drain L are ~20ML day^{-1} between January and June before increasing to a peak of ~80ML day^{-1} in July and August then gradually declining to the end of the year (Figure 1.4). Flow during 2011 (the study period) followed the long-term annual pattern but was greater than average in August (e.g. peak of 120ML day^{-1} compared to 80ML day^{-1}).

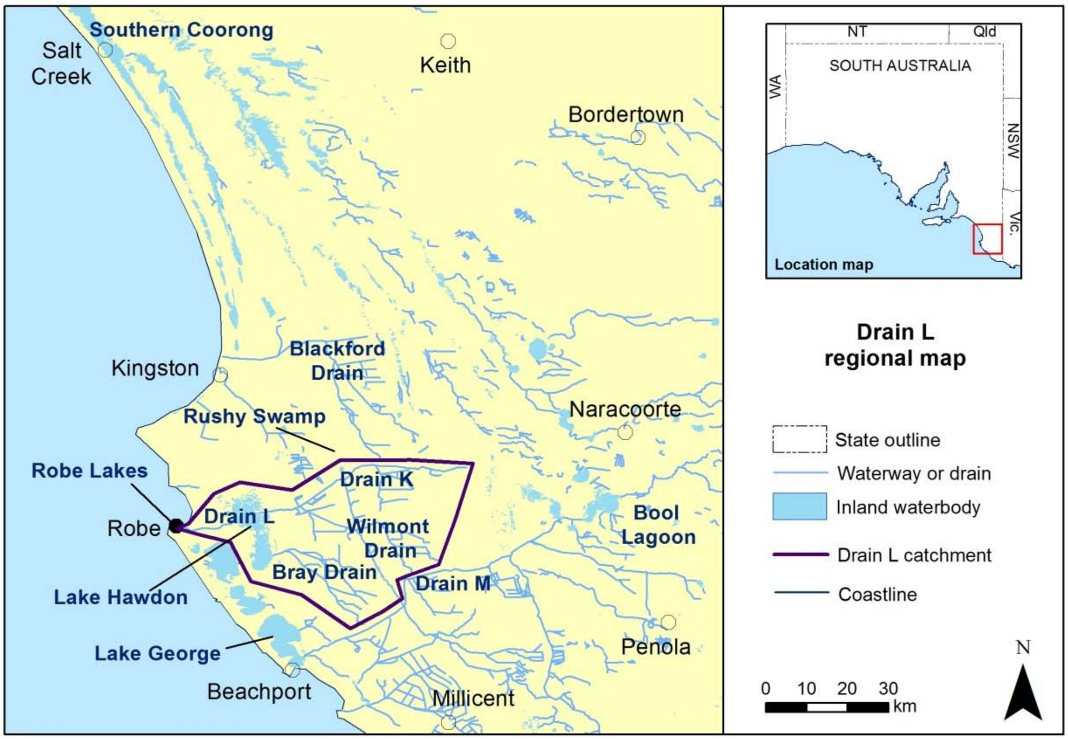


Figure 1.1 Regional map indicating major aquatic habitats within the Drain L catchment, and the broader landscape covered within the South East Flows Restoration Project.

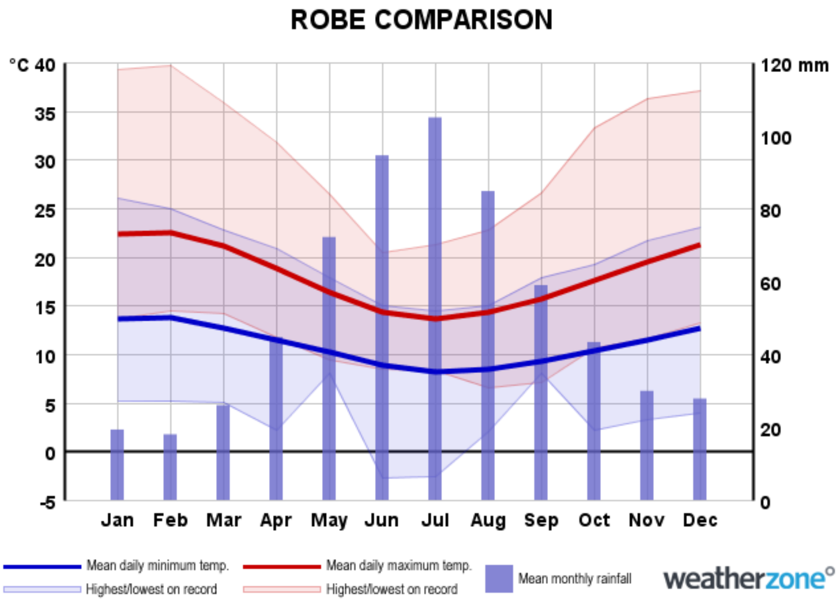


Figure 1.2 Summary of representative climate information for the study region (Weatherzone unpublished data).

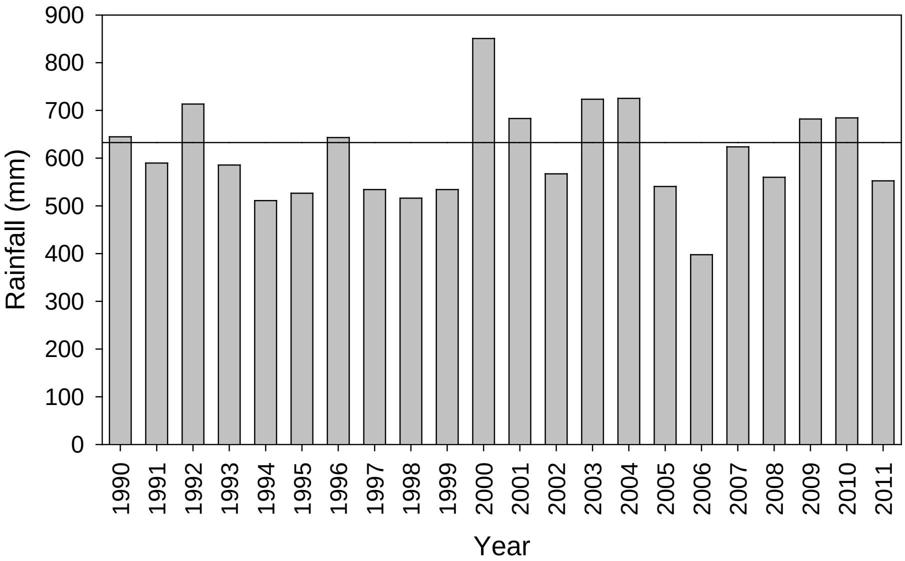
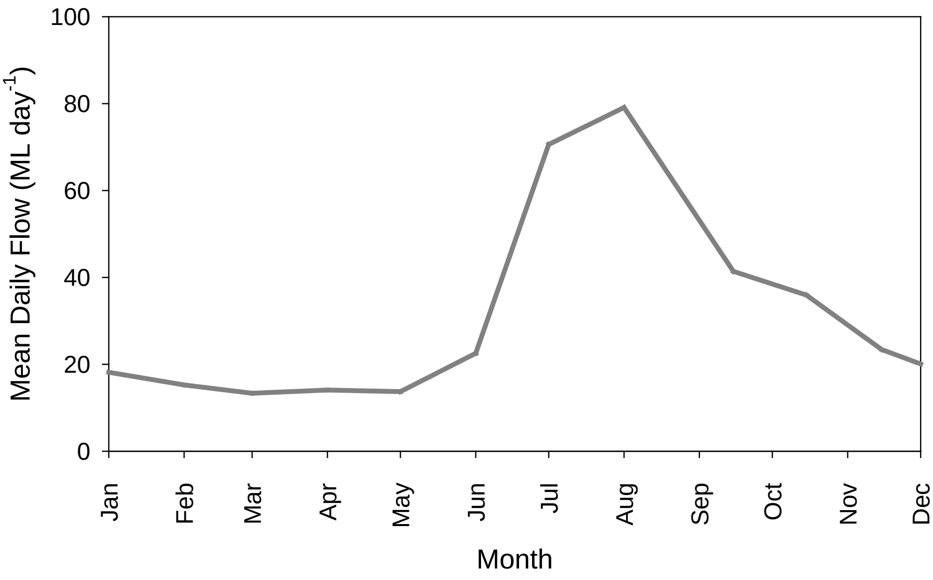


Figure 1.3 Representative rainfall data at Robe between 1990-2011 with long-term average (black line) (Bureau of Meterology, unpublished data).



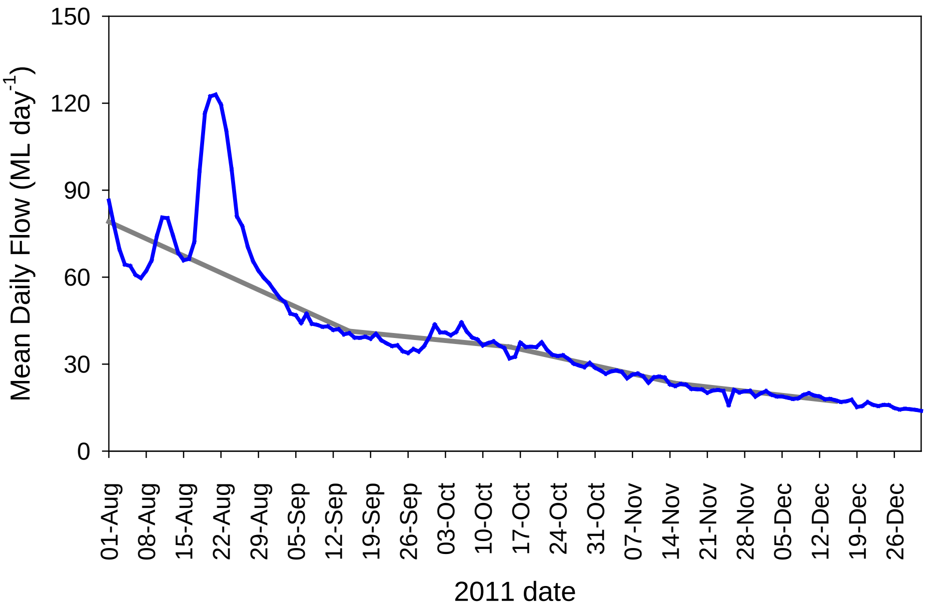


Figure 1.4 Drain L flow data including (top) representative long-term averages at Boomaroo Park and (lower) flow over winter-spring 2011 (blue) with long-term average (grey) overlayed (SA Department for Water, unpublished data).

1.2 Fish species of the South East

Twenty-one native freshwater fishes have been recorded in the South East, including eight in the Drain L Catchment (Hammer 2002; Hammer and Walker 2004) (Table 1.1). These fish can be classified according to ecological functional groups, which enables assessment of the significance of different habitats and ecological processes (e.g. presence, spawning, survivorship, movement and recolonisation), and related conceptual models (e.g. environmental water requirements, impact assessment).

Table 1. Freshwater fishes of south east South Australia, including species previously recorded in the Drain L Catchment (highlighted grey). Functional groups are diadromous, generalists (Dg); diadromous, specialists (Ds); obligate freshwater, specialised (wetland) (Fs); obligate freshwater, generalists (Fg); and Euryhaline (Eu). Conservation listings include Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Rare (R); and Protected (P) at national (Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*) and state (SA *Fisheries Management Act 2007* and Action Plan for freshwater fishes, Hammer *et al.* 2009) levels.

Common name	Scientific name	Functional group	EPBC Act	SA Fisheries	Action Plan 09
Native fishes					
Australian grayling	*Prototroctes maraena*	Ds	VU		EN
Australian mudfish	*Neochanna cleaveri*	Ds/Fs*			CR
Climbing galaxias	*Galaxias brevipinnis*	Ds			R
Common galaxias	*Galaxias maculatus*	Dg			
Congolli	*Pseudaphritis urvillii*	Dg			VU
Dwarf galaxias	*Galaxiella pusilla*	Fs	VU		VU
Estuary perch	*Macquaria colonorum*	Dg			EN
Flathead gudgeon	*Philypnodon grandiceps*	Fg			
Lagoon goby	*Tasmanogobius lasti*	Eu			
Mountain galaxias	*Galaxias olidus*	Fs			VU
Pouched lamprey	*Geotria australis*	Ds			EN
River blackfish	*Gadopsis marmoratus*	Fs		P	EN
Shortfinned eel	*Anguilla australis australis*	Dg			R
Shortheaded lamprey	*Mordacia mordax*	Ds			EN
Small-mouthed hardyhead	*Atherinosoma microstoma*	Eu			
Smelt	*Retropinna semoni*	Fg			
Southern pygmy perch	*Nannoperca australis*	Fs		P	EN
Spotted galaxias	*Galaxias truttaceus*	Ds			EN
Variegated pygmy perch	*Nannoperca variegata*	Fs	VU	P	CR
Western bluespot goby	*Pseudogobius olorum*	Eu			
Yarra pygmy perch	*Nannoperca obscura*	Fs	VU	P	CR
Introduced/translocated fishes					
Goldfish	*Carassius auratus*	Fg			
Common carp	*Cyprinus carpio*	Fg			
Tench	*Tinca tinca*	Fg			
Rainbow trout	*Oncorhynchus mykiss*	Fg			
Brown trout	*Salmo trutta*	Fg			
Eastern gambusia	*Gambusia holbrooki*	Fg			
Redfin perch	*Perca fluviatilis*	Fg			
Freshwater catfish	*Tandanus tandanus*	Fg			
Murray rainbowfish	*Melanotaenia fluviatilis*	Fg			
Murray cod	*Maccullochella peelii*	Fg			
Murray-Darling golden perch	*Macquaria ambigua ambigua*	Fg			
Silver perch	*Bidyanus bidyanus*	Fg			
Murray Darling carp gudgeon	*Hypseleotris sp. 3*	Fg			

*requirement for diadromy currently unclear for Australian Mudfish in the catchment (see sections 3 and 4).

Resident freshwater species

1) **Obligate freshwater, specialised (wetland)**, and referred to as **obligate freshwater** species herein. Species that require particular habitats or environments for survival, being restricted to specific habitats or wetland environments. Includes Dwarf Galaxias, Yarra Pygmy Perch, Southern Pygmy Perch, and nominally Australian Mudfish.
2) Obligate freshwater, specialised (stream), none occur in Drain L. Species that require permanent surface water for survival. Are often found only in restricted or specific habitats with a reliance of stream flow (i.e. Mosquito Creek, LSE rising spring habitats). Includes Mountain Galaxias, Variegated Pygmy Perch, and River Blackfish.
3) **Freshwater, generalists**. Species that require permanent surface water for survival. Mostly found in association with other species and occupy multiple habitats. Includes Flathead Gudgeon, Smelt, and **euryhaline species** (i.e. able to complete their life in either fresh or saline habitats) **-** Smallmouthed Hardyhead, Western Bluespot Goby and Lagoon Goby.

Migratory freshwater species

4) **Diadromous species (specialised freshwater habitat)**, herein **diadromous specialists.** Species that require migration to and from the sea, or estuary, but have particular habitat requirements for their occupation in freshwater (e.g. dense riparian habitat, wetland vegetation). Includes Australian Mudfish (although requirement for diadromy currently unresolved for Drain L catchment), Spotted Galaxias, Climbing Galaxias, Australian Grayling, Estuary Perch and Pouched Lamprey.
5) **Diadromous species (generalist freshwater habitat)**, herein **diadromous generalists.** Species that require migration to and from the sea or estuary, but have less specific habitat requirements for their life stage in freshwater. Includes Congolli, Shortfinned Eel and Common Galaxias.

Other species

6) **Estuarine species.** Species regularly found in estuaries, may have some requirement for freshwater or transition from marine to fresh water. Includes species such as Black Bream, Yelloweye Mullet, Jumping Mullet and Tamar Goby.
7) **Marine vagrants.** Species occasionally found in estuaries through random movement.

1.3 Possible South East Flows Restoration Project scenarios

The SEFRP has the potential to impact upon the condition of aquatic environments, predominantly drain and wetland habitats, in the Drain L catchment. The diversity and abundance of fishes provides a useful indicator of the condition of aquatic ecosystems because, unlike many other species dependant on aquatic habitat, fish cannot escape poor conditions by removing themselves from the water until favourable conditions return (Hammer 2002). Fishes are also highly reliant and responsive to flow and flow regimes, so the greatest change may be witnessed in this taxonomic group (Bunn and Arthington 2002; VanLaarhoven and van der Wielen 2009). As such, fish populations represent key targets for assessing the impact of management actions upon aquatic environments.

The first area of potential impact of the SEFRP involves the specific diversion points, currently proposed on Drain K and Wilmont Drain. Point source and diffuse (downstream) impacts of construction, changes in downstream water availability and potential hydrological connectivity with other areas could impact freshwater fish species, potentially leading to the localised loss of threatened species and the entry of introduced species to the catchment. More broadly, by diverting water from the mid Drain L Catchment the SEFRP would reduce flows across the lower reach of Drain L and ultimately outflows at the Drain L mouth. This could impact upon the general ecology of flow dependent species, in both freshwater environments and in the estuary. Specifically by reducing the magnitude and timing of certain flows the SEFRP has the potential to impact upon fish movement into and within the lower catchment. For example, reduced flows could reduce mouth ‘openness’, restricting fish passage, or be of insufficient magnitude to pass physical or behavioural barriers in peak movement periods.

A particular focus area that may be impacted by the SEFRP project is Lake Hawdon North, which is bisected by the Drain L channel that incises the lake bed. Typically, flows in Drain L are contained within this artificial channel. However, during periods of high flow, which appear to occur in most average or above average rainfall years, Drain L flows exceed capacity and water spills out of the drain, causing inundation of Lake Hawdon North. These events are likely to be very important for the ecology of this wetland, causing an increased depth and duration of inundation, key influences upon the ecological character of wetlands. By decreasing inflows from Drain L, one predicted impact (without any preventative intervention) of the SEFRP is to adversely impact Lake Hawdon North. The frequency and duration of ecologically important overbank flows, which lead to inundation of Lake Hawdon North, could be greatly reduced. This could have significant adverse impacts upon wetland biota and lead to change in the ecological character of this high value wetland. However, these potential impacts could be prevented by the construction of a regulator on Drain L at the point it exists Lake Hawdon North. A regulator could be used to control water levels within the wetland to maintain the existing water level regime (not to be confused with flow regime), or provide an improved, more ecologically appropriate water level regime, under a scenario of reduced Drain L inflows. This is possible because Drain L has a relatively large capacity and can carry significant flows without exceeding capacity and spilling into the surrounding wetland.

Yet, a regulator constructed across Drain L would impede the upstream migration of fishes. Therefore a fishway would be required in association with the regulator. The design of fishways is strongly influenced by the species anticipated to use them. The Australian Mudfish is critically endangered in South Australia and only two populations are known to exist in the state. One of these is located in Lake Hawdon South, with this site being an extremely important stronghold for the species with a high abundance recorded (Hammer and Tucker 2011). While diadromy has been documented for some Australian Mudfish populations interstate (Koehn and Raadik 1991), other populations interstate and overseas are known to exist in land locked waterbodies (McDowall 2010). It is currently unknown if the Lake Hawdon South population of Australian Mudfish migrate annually to sea, to the Drain L estuary (Robe Lakes) or complete their lifecycle entirely within the wetland. The upstream migration of Australian Mudfish from sea to inland wetlands, should it occur, would be undertaken by juveniles (‘whitebait’). However the species appears to have low vagility (i.e. poor swimming ability), with noted congregations observed below weirs (e.g. Bray Drain, Lower Drain M) and observed absence upstream of such structures. Fish passage requirements of Australian Mudfish and other species present in the catchment, are important issues to consider during the design of fishways associated with new or existing structures, in the catchment.

Further detailed assessment in project planning may reveal additional points for consideration.

1.4 Specific project objectives

Given the potential for change in the Drain L catchment, there are several clear areas of study regarding freshwater fishes. A comprehensive baseline fish survey will provide a better understanding of the diversity and abundance of fishes, including species of nationally and state conservation concern, and establish a benchmark against which to assess the impacts of future management. Establishing monitoring to assess species demographic data will provide a base to monitor trends in recruitment success as a potential indicator of response to environmental change (e.g. Hammer 2009a). The diversity, abundance and life stage of fishes and the seasonality of movement at the mouth of Drain L is a knowledge gap. Assessing fish movement at this location will contribute significantly to an understanding of the status of the catchment and provide a useful baseline against which to measure the impact of flow decline and implement an adaptive management approach in the future. Data will also directly inform fish passage requirements through any new constructed in stream barriers. Further ecological insight on Australian Mudfish is necessary to shed light on their life history and migratory movements to inform management decisions.

The objectives of this project were thus to:

- Quantitatively describe the current distribution and abundance of fishes throughout the Drain L Catchment (section 2).
- For selected significant species (e.g. threatened species, indicator species) assess population demography to provide a sensitive baseline measure to assess future population trends (sections 2 and 3).
- Improve understanding of the importance of marine connectivity to the fish fauna of the Drain L estuary (the Robe Lakes) and greater catchment (sections 3 and 4).
- Review overall data and propose a monitoring approach to assess the potential impacts of the SEFRP upon the fish fauna of the Drain L Catchment (section 5).

2.0 Baseline survey

2.1 Introduction

Baseline fish monitoring of the Drain L Catchment aimed to provide a better understanding of the diversity and abundance of fishes currently present and establish a benchmark against which to assess the impacts of future management. Whilst highly modified the system maintains fragmented habitats containing robust native fish community with relatively high native fish species richness, core populations of regionally and nationally significant species, such as Dwarf Galaxias and Australian Mudfish, and no known introduced fishes (Hammer 2002; Wedderburn and Hammer 2002; Hammer and Tucker 2011). Yet, is it acknowledged that further information on the diversity and abundance of fishes in the catchment would be valuable. For example, Lake Hawdon North, a large and important wetland (Taylor 2006) with a high potential to be impacted by the SEFRP, has never been surveyed for fish. Additionally, much of the historic fish sampling in the Drain L Catchment occurred during an extended dry period (i.e. 2002-2009) (Hammer 2002; Wedderburn and Hammer 2002; Hammer and Tucker 2011), and so baseline data under the current conditions - rainfall and runoff from the catchment closer to the long-term average in 2009 and 2010 - will ensure that data can be collected from some previously dry habitats (see Figure 1.3). Finally, the SEFRP has the potential to impact (both positively and negatively) upon the condition of drain and wetland habitats, and it is important to document fish distribution and abundance prior to any changes.

2.2 Methods

A total of 25 baseline sites were sampled across the Drain L Catchment between August and December 2011 (Figure 2.1 and Table 2.1) (PIRSA Fisheries permit, 9902425). Sites were selected to provide good representation across the catchment.

Sampling followed the inventory style methodology adopted previously (Hammer 2002), in which comprehensive field investigations were used to determine the species occurring at survey sites. Hence, sampling was designed to document fish species richness and composition and their relative abundance, with a rapid survey design. Specific sampling methods and effort matched prevailing environmental conditions at each site (see Appendix 2 for sampling effort). The primary sampling method was fyke netting as this is ideal for deeper pools with structure and varying salinity. Other techniques employed in small pools or simple habitats included bait and dip netting. Net dimensions were as follows:

- Large fyke net: single 6m wing, D shaped entrance (0.7m wide x 0.7m high), 3 compartments and 6mm half mesh.
- Small fyke net: single 3m wing, D entrance, 2 compartments and 4mm stretch mesh.
- Double wing (directional) fyke net: double 3.5m wings, D entrance, and three compartments and 4mm stretch mesh.
- Bait trap: rectangular 0.5m long x 0.25m square, 60mm entrance and 1mm mesh.
- Dip net: 0.4 square monorail frame with 4mm stretch mesh.

All sampled fish were identified to species, counted and observed to obtain general biological information (size range, reproductive condition and external disease or parasites). Length-frequency information (as Total Length, TL) was gathered for certain components of catches, namely more sensitive freshwater and diadromous species. Threatened species were photographed at each site as identification vouchers. Records of other fauna sampled opportunistically were maintained including Southern Bell Frog *Litoria raniformis* (adults and tadpoles). At each sampled site, environmental descriptors, covering differing aspects of underwater cover, edge vegetation, pool condition, flow and water quality (see full details in Appendix 1), were recorded to aid the interpretation of results and assist with broader wetland condition assessment.

Table 2.1.Summary of baseline monitoring sites across Drain L Catchment in 2011.

Site Code	Date	Waterway	Location	Easting	Northing
SE11-12	17/08/2011	Drain L	Boomaroo Park Weir	397937	5885946
SE11-19	7/09/2011	Drain L	Lake Hawdon connecting drain	405483	5884872
SE11-20	7/09/2011	Lake Hawdon North	Site 1, eastern side	404457	5887645
SE11-21	7/09/2011	Lake Hawdon North	Site 2, middle of wetland	403644	5887293
SE11-22	8/09/2011	Lake Hawdon North	Site 3, middle of lake	404062	5889455
SE11-23	8/09/2011	Lake Hawdon North	Site 4 middle of wetland	403598	5889297
SE11-26	26/09/2011	Drain L	Pub Lake at Info bay	391585	5885840
SE11-27	27/09/2011	Reedy Creek	Off Jorgensons road	431390	5872280
SE11-28	27/09/2011	Bray Drain	Robe-Naracoorte rd crossing	418733	5876966
SE11-29	27/09/2011	Lake Hawdon South	Southern wetland (Almanda)	404514	5876661
SE11-30	28/09/2011	Reedy Creek	Ledgard property	426170	5883118
SE11-31	28/09/2011	Wilmont Drain	Upstream of weirs	423478	5886087
SE11-32	28/09/2011	Wilmont Drain	Downstream of last weir	420200	5887249
SE11-33	29/09/2011	Drain K	Old SE02-58	424422	5900607
SE11-34	29/09/2011	Drain L	Conmurra property	420006	5896839
SE11-35	29/09/2011	Drain L	SE08-04, off princes highway	418310	5895331
SE11-38	11/10/2011	Drain L	Lake Battye	392781	5885284
SE11-40	12/10/2011	Wilmont Drain	At Naracoorte road crossing	430499	5886091
SE11-41	12/10/2011	Drain K	Upstream of west avenue road	425265	5901192
SE11-44	1/11/2011	Lake Hawdon South	Southern wetland (Almanda)	404551	5876672
SE11-45	2/11/2011	Reedy Creek	At Cocky's lane bridge	424090	5889197
SE11-46	2/11/2011	Drain K	Robe-Naracoorte road crossing	439816	5900546
SE11-60	15/12/2011	Bray Drain	Biscuit Flat	422671	5866369
SE11-61	15/12/2011	Trib. Bray Drain	Biscuit Flat	423345	5867240
SE11-62	15/12/2011	Drain B31	Biscuit Flat	423036	5867594

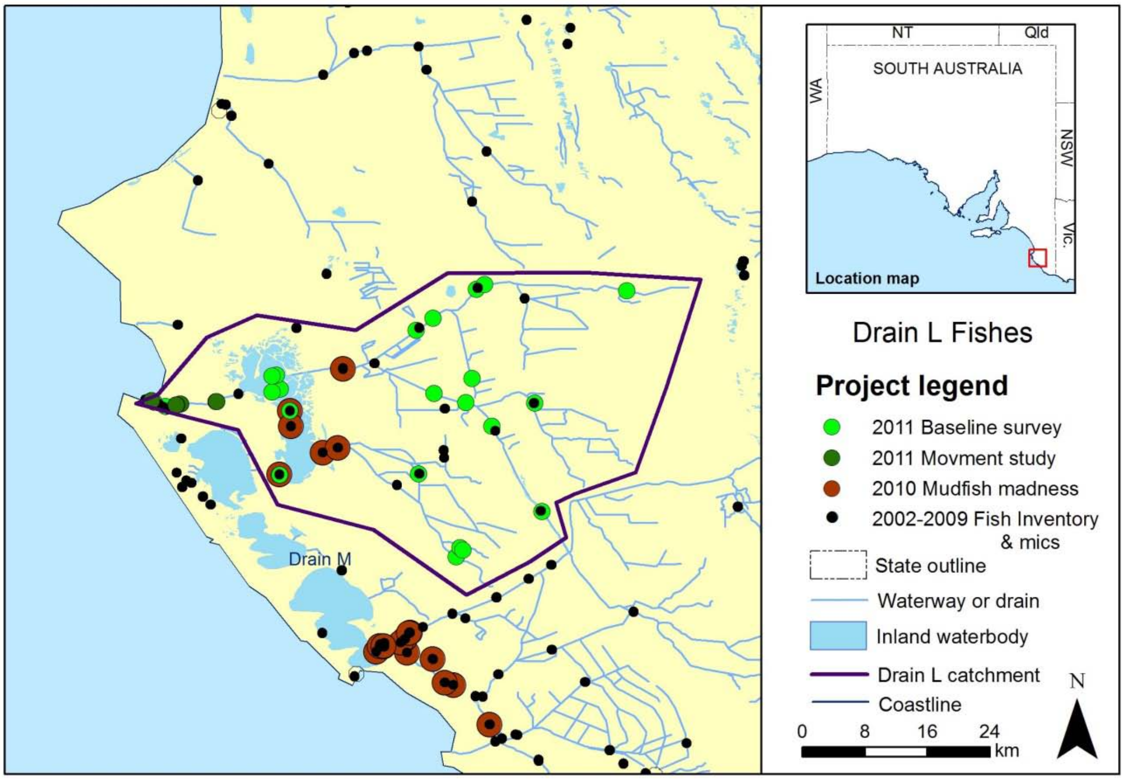


Figure 2.1 Summary of fish sampling sites in the Drain L Catchment including 2011 baseline sample, 2011 movement study, 2010 Australian Mudfish study (Hammer and Tucker 2011) and other previous data by the authors (e.g. Hammer 2002; Hammer 2009b).

Baseline survey site – Lake Hawdon North (SE11-20)

Baseline survey site – Drain L, Pub Lake at info bay (SE11-26)

Baseline survey site – Reedy Creek, Ledgard property (SE11-30)

Baseline survey site – Drain K, upstream of West Avenue Rd (SE11-41)

2.3 Results

Summary

Over 21,000 fish were sampled across the 25 baseline sites within Drain L Catchment in 2011 (Table 2.2). The catch consisted of 11 native species, including Dwarf Galaxias, Australian Mudfish and Southern Pygmy Perch that are of conservation concern, and no introduced species. The catch was numerically dominated by Smallmouthed Hardyhead (16 sites, 13,713 fish), followed by Southern Pygmy Perch (*n* = 5,875) and Common Galaxias (*n* = 1,016). Rarer species included Lagoon Goby (*n* = 39) and Australian Mudfish (*n* = 22). Importantly, no introduced species (namely Gambusia) were recorded across the baseline sites. A range of other fauna was sampled opportunistically, including Long-neck Turtle (*Chelodina longicollis*), Yabby (*Cherax albidus*), Swamp Yabby (*Geocharax* sp.) adult frogs and numerous tadpoles (Appendix 3).

Table 2.2 Catch summary across Drain L baseline sites (note: no introduced species)

Site Code	Waterway	Australian mudfish	Australian salmon	Bridled goby	Common galaxias	Dwarf galaxias	Lagoon goby	Smallmouthed hardyhead	Southern pygmy perch	Tamar River goby	Western bluespot goby	Yelloweye mullet	No fish
SE11-12	Drain L				20		4	7886	379	4	5	38	
SE11-19	Drain L	1				15		62	338				
SE11-20	Lake Hawdon North							5	12				
SE11-21	Lake Hawdon North							1	13				
SE11-22	Lake Hawdon North							27	4				
SE11-23	Lake Hawdon North							15	5				
SE11-26	Drain L		13				16	565		224	5	115	
SE11-27	Reedy Creek												x
SE11-28	Bray Drain	1				39		434	34				
SE11-29	Lake Hawdon South	2				66		1	106				
SE11-30	Reedy Creek					1			1234				
SE11-31	Wilmont Drain					2			56				
SE11-32	Wilmont Drain				91	1		96	1067				
SE11-33	Drain K							2560	246				
SE11-34	Drain L				5			758	132				
SE11-35	Drain L				815			946	198			2	
SE11-38	Drain L			1	80		19	31		48	18	44	
SE11-40	Wilmont Drain					13			509				
SE11-41	Drain K							318	1209				
SE11-44	Lake Hawdon South	18			5	202			249				
SE11-45	Reedy Creek								77				
SE11-46	Drain K								7				
SE11-60	Bray Drain												x
SE11-61	Trib. Bray Drain												x
SE11-62	Drain B31							8					

Selected fish species collected during the baseline survey: Australian Mudfish (top left); Dwarf Galaxias (top right); Southern Pygmy Perch (bottom left); and Bridled Goby (bottom right)

Opportunistic fauna sampled during the baseline survey: Striped Marsh Frog (top left); Long-necked Turtle (top right); Swamp Yabby (bottom left); and Eastern Banjo Frogs (bottom right).

Species summary – Australian Mudfish

Australian Mudfish have previously been recorded from four sites in the catchment (including Bray Drain), all in or connected to Lake Hawdon South (Hammer and Tucker 2011). In 2011, the species was collected in small numbers from Lake Hawdon South (southern wetland site, SE11-29) and further upstream in Bray Drain (Robe-Naracoorte Road, SE11-28) than previously observed. This latter observation, albeit a single large (105mm) individual, was from a site located upstream of the Bray Drain Weir, suggesting that occasional fish may be passing this structure (large congregations have previously been observed immediately downstream of the weir).

With similar sampling effort in 2011 as employed in 2010, considerably fewer individuals were recorded in the stronghold of the species, Lake Hawdon South (i.e. 117 fish in 2010, 2 fish in 2011 at the southern wetland site). This result prompted a repeat sampling strategy later in spring (SE11-44), which confirmed low abundance of adults (n= 5). This repeat sampling revealed that a recruitment of small fish to a sampleable size had occurred in the intervening period (27/9/11 - 1/11/11: Figure 2.1), an event which matched opportunistic community monitoring data from the 2010 (Hammer and Tucker 2011). Low sample sizes preclude any detailed assessment of adult growth, but there was a shift in the size of fish caught from 75-80mm to 85-95mm in essentially one month, and this might indicate rapid growth of a cohort, and help to inform a developing population model for the species (see also otolith age data in Section 4).

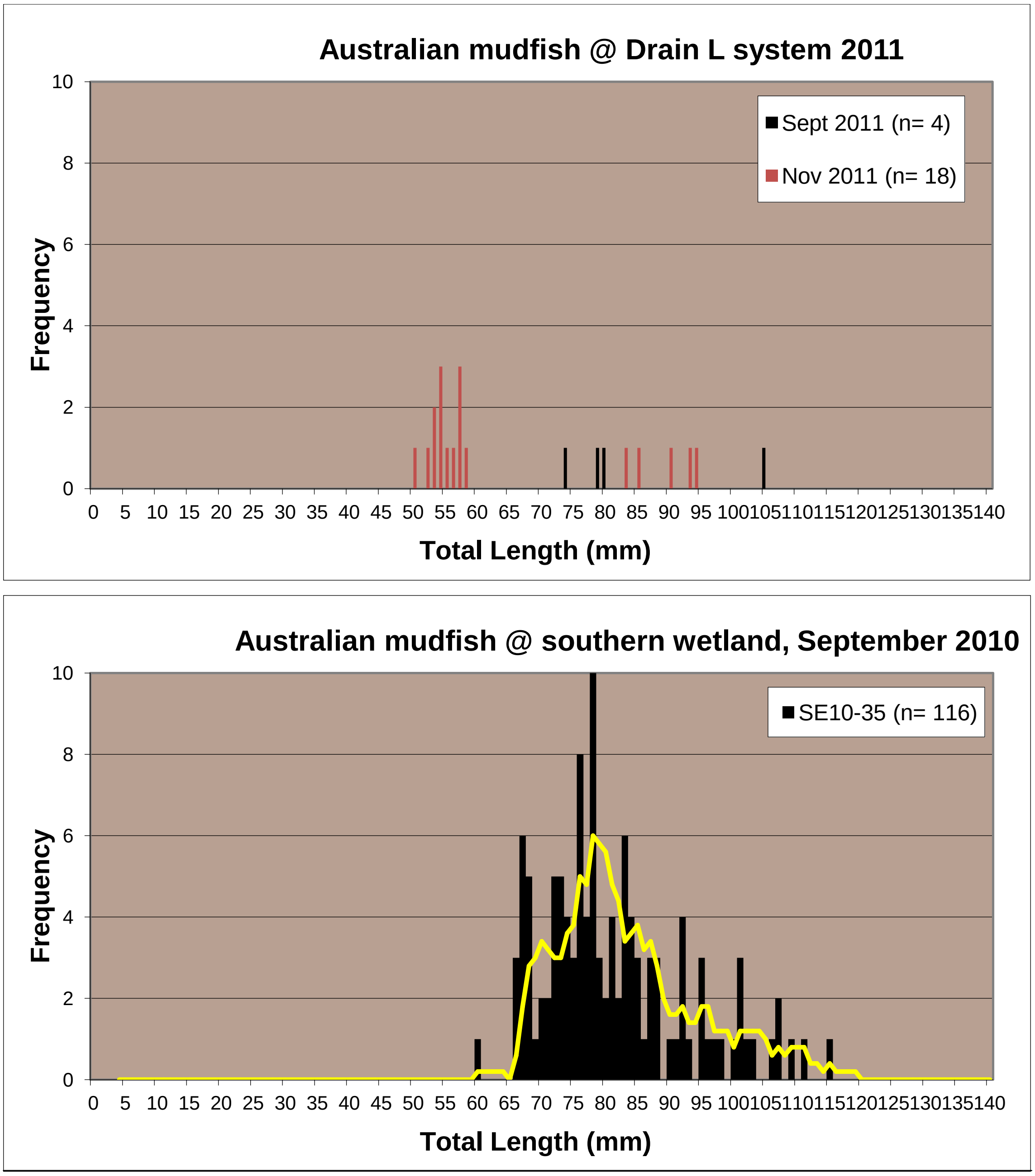


Figure 2.1 Length-frequency distribution of Australian Mudfish from the Drain L Catchment in 2011 (top) and 2010 (bottom). Data for 2010 from Hammer and Tucker (2011).

Species summary – Common Galaxias

Common Galaxias were the only diadromous species recorded across the baseline sites. The species was frequent at estuary sites (i.e. Lake Battye) and sites connected to estuary (i.e. below Boomaroo Park Weir). In addition, Common Galaxias were observed at sites upstream of Boomaroo Park Weir (i.e. Lake Hawdon South, mid-Drain L and Wilmot Drain) indicating some degree of connectivity with ocean or the existence of landlocked populations (see also Section 3).

Species summary – Dwarf Galaxias

Dwarf Galaxias were observed at eight sites within the Drain L catchment. The core habitat of the species remains centred on Lake Hawdon South (and connector drain) and low numbers were recorded mid-catchment (Reedy Creek and Wilmont and Bray drains). The species was not detected during baseline sampling of sites further upstream in the catchment (i.e. Drain K).

Environmental descriptors

Environmental descriptors for all baseline sites are provided in Appendix 4. Habitat types included drains (Drain L and K, Bray and Wilmot drains), wetlands (Lake Hawdon South and Lake Hawdon North) and lakes (Pub Lake and Lake Battye). A variety of environmental conditions were recorded across the sites. Salinity ranged between 1755-8010μScm^{-1}, the freshest being the Wilmot Drain downstream of the last weir and highest but still moderately fresh in Lake Hawdon North. Dissolved oxygen was typically high (>6ppm) at most sites, although several low or no flow upper drain sites (on Drain K, Bray Drain and Reedy Creek) exhibited low dissolved oxygen concentrations (<4ppm). Across all sites, physical habitat was generally low (1-20%) and biological (0-70%) and emergent (0-80%) habitat was variable, partially explained by flow conditions. For instance, most medium and high flow drain sites contained little habitat whereas drain sites with low or no flow contained moderate biological (typical >20%) and emergent (typically >30%) habitat (vegetation levels may shift under different flow conditions in the former). Lake Hawdon South maintained high levels of habitat, principally through dense emergent vegetation such as *Gahnia*, *Baumea*, *Triglochin* and *Villarsia* whereas Lake Hawdon North contained less overall habitat (with emergent habitat <10% at 3 of the 4 sites).

2.4 Discussion

The catchment wide, intensive baseline survey confirmed Drain L to be a significant and unique system with a diversity of species and no introduced species observed. The catchment is home to several obligate freshwater species of state and national conservation status. The Australian Mudfish population in Lake Hawdon South represents one of only two core populations of the species in South Australia, and the catchment a stronghold for Dwarf Galaxias in South Australia (Hammer 2009b; Hammer and Tucker 2011). There were apparent declines in abundance of both these species since previous 2010 monitoring suggesting that there are already population fluctuations in response to varied environmental conditions, heightening their susceptibility to catchment modifications. Dwarf Galaxias in particular appear vulnerable occurring at and below proposed diversion points (e.g. Wilmot Drain and Drain K). The absence of Australian Mudfish from Lake Hawdon North may reflect unsuitable habitat and it is evident that restoration remains necessary to improve the quality of habitat for the species (Ecological Associates 2009; Hammer and Tucker 2011).

The fact that the Drain L Catchment remains free of introduced species, in particular Gambusia, is significant. As well as a refuge from the negative effects of introduced species, the Drain L system offers rare habitat for fish in the region both in terms of summer refuge (permanency) and water quality. The absence of introduced species stems from apparent isolation from nearby source populations, but the enhanced connectivity associated with the proposed Drain K and Wilmot Drain SEFRP diversion points may result in the dispersal of Gambusia into the catchment. Once present, the establishment of Gambusia would follow as the prevailing conditions in the catchment are conducive to the broad tolerances and life strategy of the species. The expected impacts in the catchment would be considerable (Lloyd and Knight 2008) and highlight that important decisions are necessary to the proposed SEFRP.

More broadly, the findings emphasise the importance of securing core populations for freshwater species in the catchment (including Dwarf Galaxias, Australian Mudfish, and Southern Pygmy Perch), through protection and restoration of habitat and hydrology, and active management to prevent establishment of introduced species (Hammer *et al.* 2009). It is particularly important to ensure that ecological values are maintained and protected during any proposed management change. It is, therefore, recommended to maintain and enhance favourable environmental conditions for fish species in the Drain L Catchment by:

- Maintaining sufficient diversity of drain and wetland habitats to support a diversity of fish species, particularly obligate freshwater fishes.
- Specific (event-based and annual) monitoring of fish processes in response changes imposed by the proposed SEFRP.
- Determining and providing for environmental water provisions for fish.
- Preventing the introduction of introduced fish species.

3.0 Movement study

3.1 Introduction

Diadromous species are key targets of movement studies in the lower reaches of freshwater environments (e.g. Hammer 2008; Zampatti *et al.* 2010). They complete one or more parts of their lifecycle in freshwater and others in marine environments with determined movement at specific parts of their lifecycle (McDowall 1988). Different forms of diadromy exist, depending on the particular lifecycle stage at which migration occurs, the direction of migration and spawning patterns (Figure 3.1). Euryhaline or estuarine species may also be encountered as they make facultative movements in response to particular conditions (e.g. tracking salinity, opportunities to move into new habitat). Additionally, marine variants are sometimes found within estuarine environments through random movement.

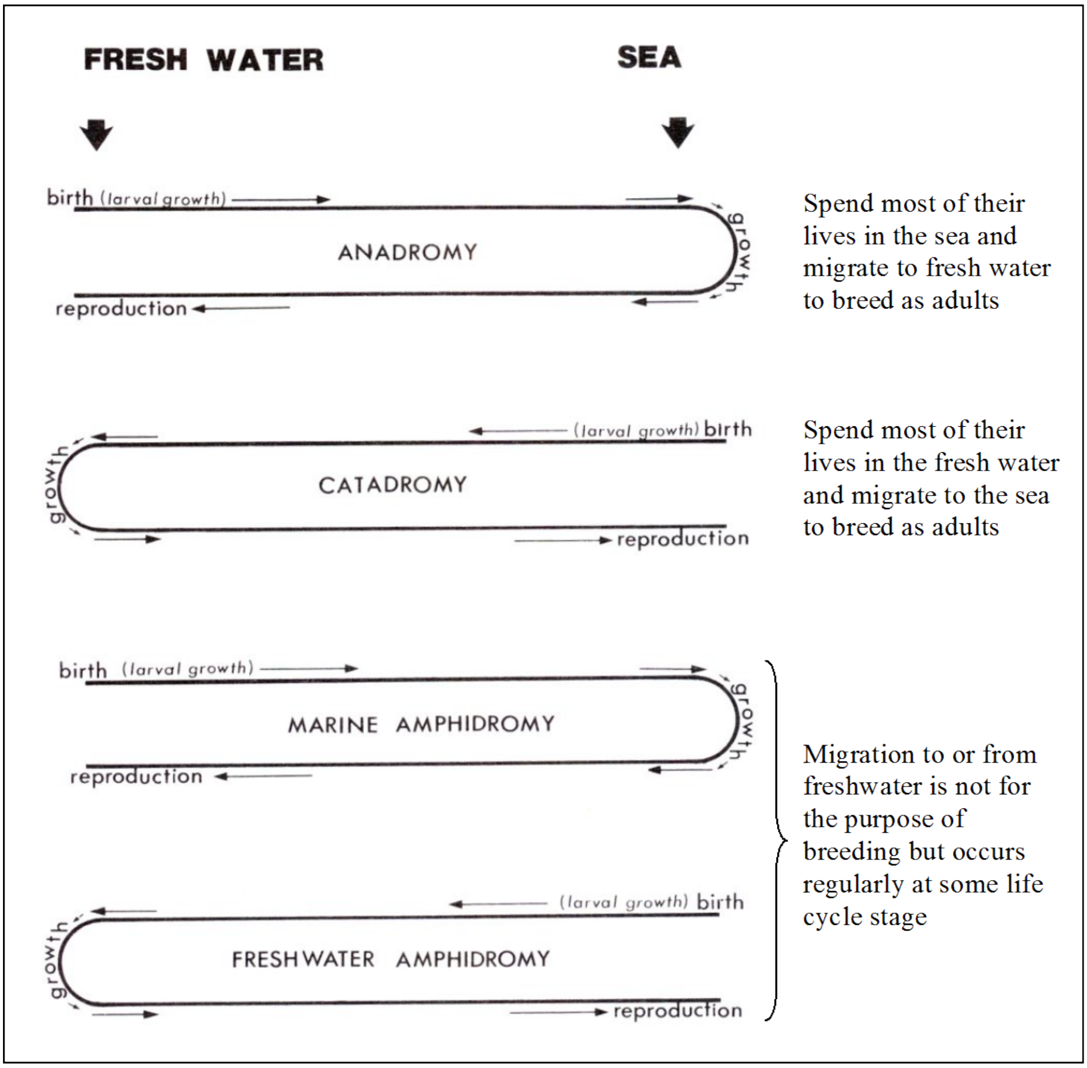


Figure 3.1 Schematic lifecycle diagram for diadromous species. Figure and text adapted from McDowall (1988).

3.2 Methods

The movement study followed the methodology adopted by Hammer (2008), which included periodic sampling events during the peak period of migration activity for diadromous species in the region (i.e. winter through spring) using directional netting (PIRSA Fisheries permit, 9902425). The specific timing of sampling events was spread across different lunar cycles, especially larger tides relating to full and new moons and variation in climatic conditions (i.e. sunny periods and storms). Six temporal sampling events of two sites (at the mouth and ~5km upstream) in the lower Drain L Catchment occurred between August and December 2011 (Figure 1.1, Figure 3.2 and Table 3.1). An additional site above Boomaroo Park Weir (~10km upstream of mouth), the first regulatory structure on Drain L, was sampled on the first two monitoring events, but later abandoned as nets were stolen. The Sandy Lane site originally located at the road crossing was moved downstream to private property on trip 3 due to nets being stolen here also.

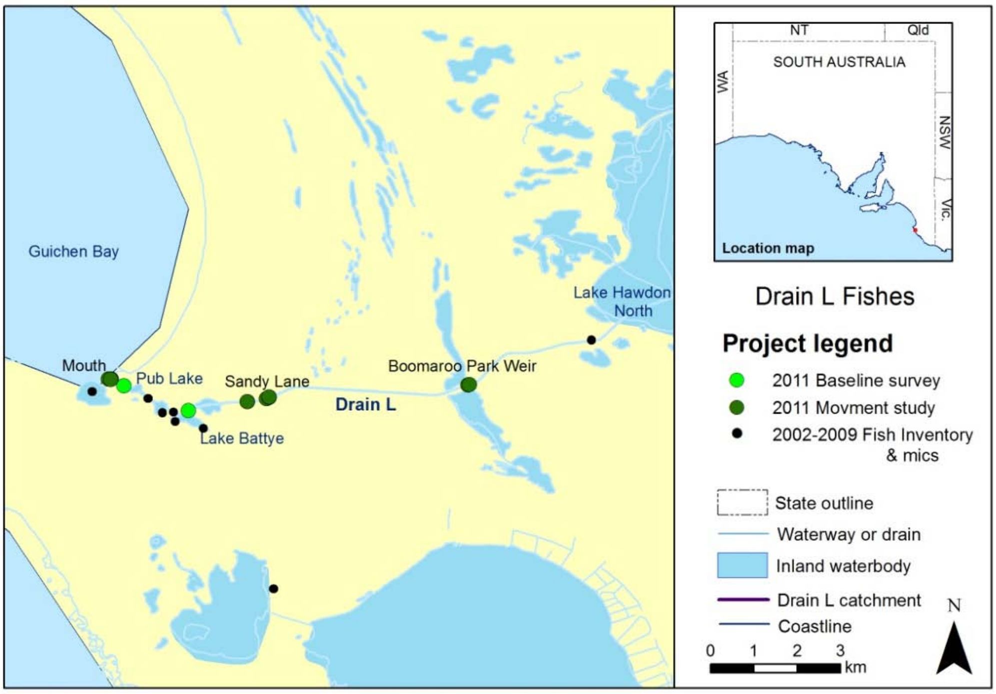


Figure 3.2 Location of movement study sites in the Drain L catchment.

In the present study, larval (3.5m wings with doubled 4mm stretch mesh, D entrance, and three compartments with 2mm stretch mesh funnels) and standard (3.5m wings, D entrance, and three compartments, all 4mm stretch mesh) double wing fyke nets were set directionally downstream with strong stakes and additional wing weights to counter high velocity and compounded drag from accumulated debris. Floats to provide an air pocket for air breathing fauna, and PVC tubes to provide separation between smaller animals and larger fish, were also provided in the final compartment. Each sampling events at each site comprised nets set for a minimum of 24 hours, but most often 36-60 hours, being checked and cleared in the morning (covering the nocturnal period) and afternoon (diurnal).

Table 3.1. Summary of (a) movement monitoring sites across Drain L Catchment and (b) sampling event details.

(a)

Waterway	Location	Easting	Northing
Drain L	Mouth, us of footbridge	391304	5885996
Drain L	Sandy Lane	393864	5885505
Drain L	above Boomaroo Park	397937	5885946

(b)

Trip no	Date	Site Code	Location	Duration (days (nights))	Nets
1	17/08/2011	SE11-13	Boomaroo Park Weir	3(2)	5
		SE11-14	Sandy Lane	3(2)	2
		SE11-15	Mouth, us of footbridge	2(2)	2
2	5/09/2011	SE11-16	Boomaroo Park Weir	1(0)	4
		SE11-17	Sandy Lane	3(2)	3
		SE11-18	Mouth, us of footbridge	3(2)	3
3	26/09/2011	SE11-24	Mouth, us of footbridge	3(2)	2
		SE11-25/36	Sandy Lane	0(3)	5
4	11/10/2011	SE11-37	Mouth, us of footbridge	3(2)	2
		SE11-39	Sandy Lane	3(2)	3
5	1/11/2011	SE11-42	Mouth, us of footbridge	3(2)	2
		SE11-43	Sandy Lane	3(2)	2
6	14/12/2011	SE11-47	Mouth, us of footbridge	3(2)	2
		SE11-48	Sandy Lane	3(2)	2

All sampled fish were identified to species, counted and observed to obtain general biological information (size range, reproductive condition and external disease or parasites). Length-frequency information (as Total Length, TL) was gathered for certain components of catches, and all species at each site were photographed as identification vouchers. Records of other fauna sampled opportunistically were maintained. At each sampled site, environmental descriptors, covering differing aspects of underwater cover, edge vegetation, pool condition, flow and water quality (see full details in Appendix 1), were recorded to aid the interpretation of results and assist with broader wetland condition assessment. Specific lunar and tidal information was supplied by the Australian Bureau of Meteorology, National Tide Centre.

Larval (green) and standard (white) directional fyke nets (top) and close up of larval net showing finer stretch mesh on funnel (bottom left and right)

Movement study site - Mouth, us of footbridge on Drain L (SE11-15)

Movement study site – Sandy Lane on Drain L (SE11-43)

Movement study site – above Boomaroo Park Weir on Drain L (SE11-13)

3.3 Results

Summary

Overall catch in the fish movement study included 21,992 fish from 15 species, of which four have conservation listings at state or national level (Table 3.2). The diadromous Common Galaxias comprised the majority of the catch (13,061 fish) being collected, predominately as juveniles (12,551 whitebait). The next most common species were Yelloweye Mullet (3,514 fish) and Southern Pygmy Perch (2,123 fish). Rarer components of the catch included diadromous (Congolli and Pouched Lamprey) euryhaline (Black Bream, Jumping Mullet, Sea Mullet) species as well as a single marine vagrant Weedfish (*Heteroclinus flavescens*). Interestingly, six of the recorded species have not previously been recorded in the Drain L catchment, the most notable being the diadromous Climbing Galaxias. A range of other fauna sampled opportunistically including Yabby (*Cherax albidus*) and tadpoles/frogs (Appendix 3).

Table 3.2.Summary of catch across movement study sites. Colour denotes functional group: green - obligate freshwater, specialised (wetland) (Fs); blue - diadromous (D); purple - estuarine (E); and marine variants (Mv). * Species of conservation concern.

		Fs	Diadromous				Euryhaline			Estuarine						Mv
Trip no.	Location	Southern pygmy perch*	Climbing galaxias*	Common galaxias	Congolli*	Pouched lamprey*	Lagoon Goby	Smallmouthedhardyhead	Western bluespot goby	Australian salmon	Black bream	Jumping mullet	Sea mullet	Tamar River goby	Yelloweye mullet	Weedfish
1	Boomaroo Park Weir	1		51	1			75	1						40	
	Sandy Lane	71		60			253	651	21	2				40	35	
	Mouth			78				17	3					63	53	
2	Boomaroo Park Weir	3	3	503				3			2		1		46	
	Sandy Lane	7	16	4716		2	30	51	11	484	1	1	1	46	1474	
	Mouth			14		1		6	4				3	134	507	1
3	Mouth		3	33			8	463	5	4				170	860	
	Sandy Lane	6	1	67	1		11	20	2	45	7			46	15	
4	Mouth			898			24	239	4	6				109	180	
	Sandy Lane	1		466			43	12	2	9	1			39	7	
5	Mouth			5695		1	10	134	4	150				36	254	
	Sandy Lane			357			74	19		1				13	8	
6	Mouth			45			8	115	3					22	18	
	Sandy Lane			78	21		172	318	13	2				10		17

Movement patterns

Biological data for diadromous species of the Drain L Catchment gathered during the fish movement study appears in Figure 3.3 and is discussed by species below.

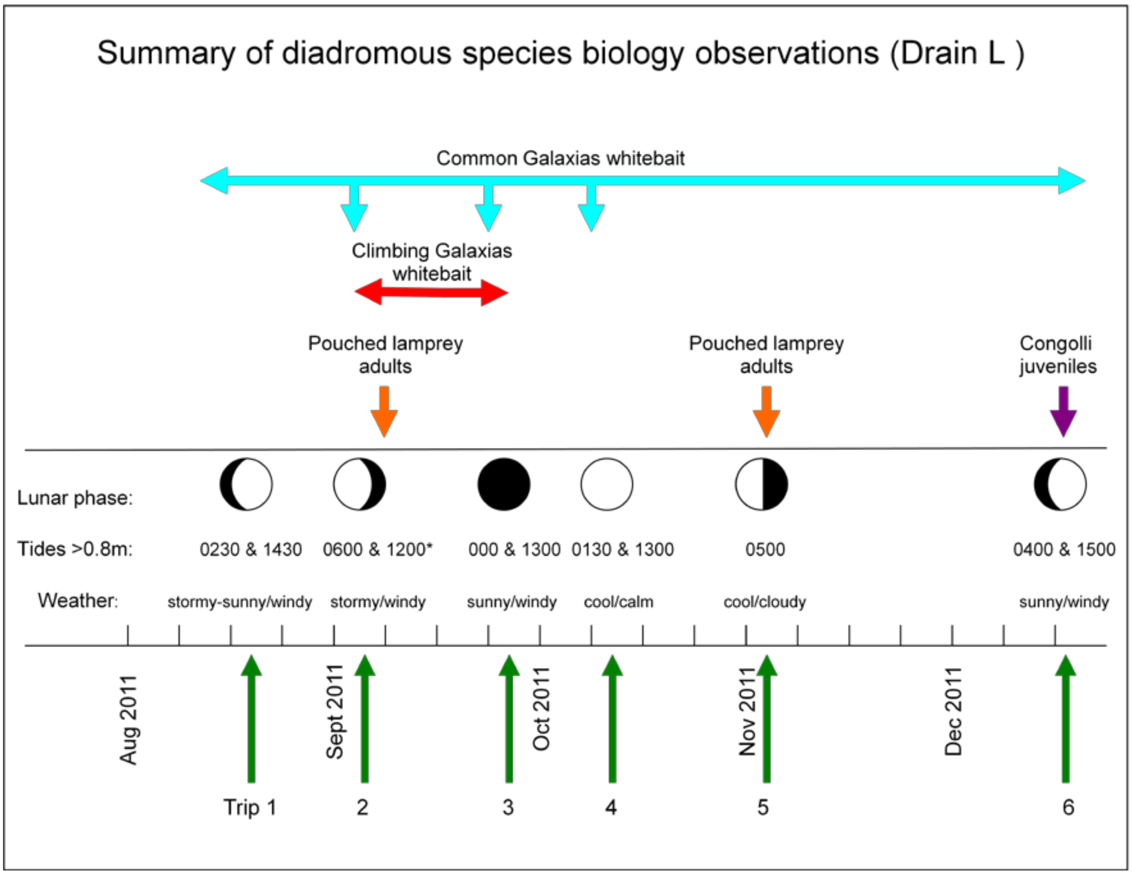


Figure 3.3 Summary of recordings of diadromous fish life history stages mapped on a calendar of sampling events and lunar, tidal and weather information. Lunar and tidal information supplied by the Australian Bureau of Meteorology, National Tide Centre.

Climbing Galaxias

Small numbers of juvenile Climbing Galaxias (37-47mm) were sampled at all three movement study sites, the first such records for the Drain L Catchment (Figure 3.4). Most of these fish were collected during a distinct period (5-7th September, 16 fish) at the Sandy Lane site, although some fish (3) were observed further upstream above Boomaroo Park Weir during this period or later in September (26th, 3 fish) (Figure 3.3). Sampling time (14 fish during the morning, 9 during the afternoon) was variable during collection of the species, as were localised weather conditions, although the majority of fish were sampled during one dodge tide event (with waning moon).

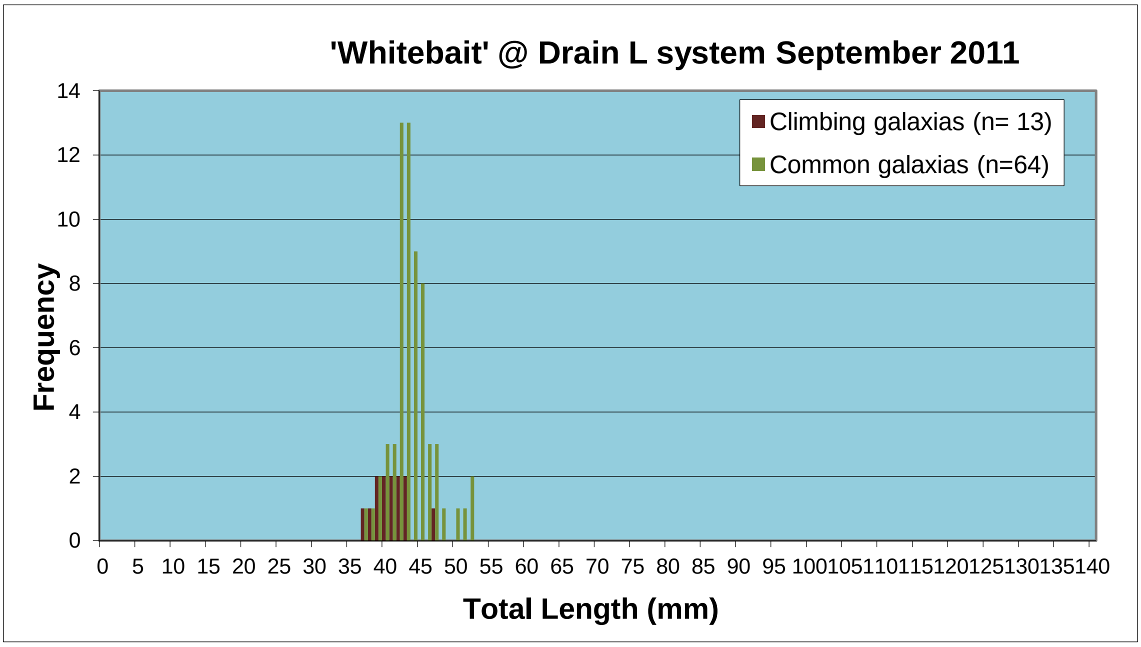


Figure 3.4 Length-frequency distribution for (a) Climbing Galaxias, and (b) sample of Common Galaxias observed during the movement study.

Whitebait Climbing Galaxias sampled from Drain L Catchment

Common Galaxias

Common Galaxias were routinely collected (71 of the 93 net checks) as juvenile whitebait (12,551 fish) as well as adults and sub-adults (510 fish) at all three sites during the movement study (Figure 3.3, 3.4 and 3.5). Juvenile whitebait (40-52mm) had an extended period of presence in catches (i.e. whole sampling period from late winter to early summer), but with an obvious peaks in spring (during early September, smaller peaks occurred in early November and mid-October) and coinciding with high tides (either during morning or night). Adults and sub-adults were consistently collected across the study period, predominately at the Sandy Lane site, but were present at all sites.

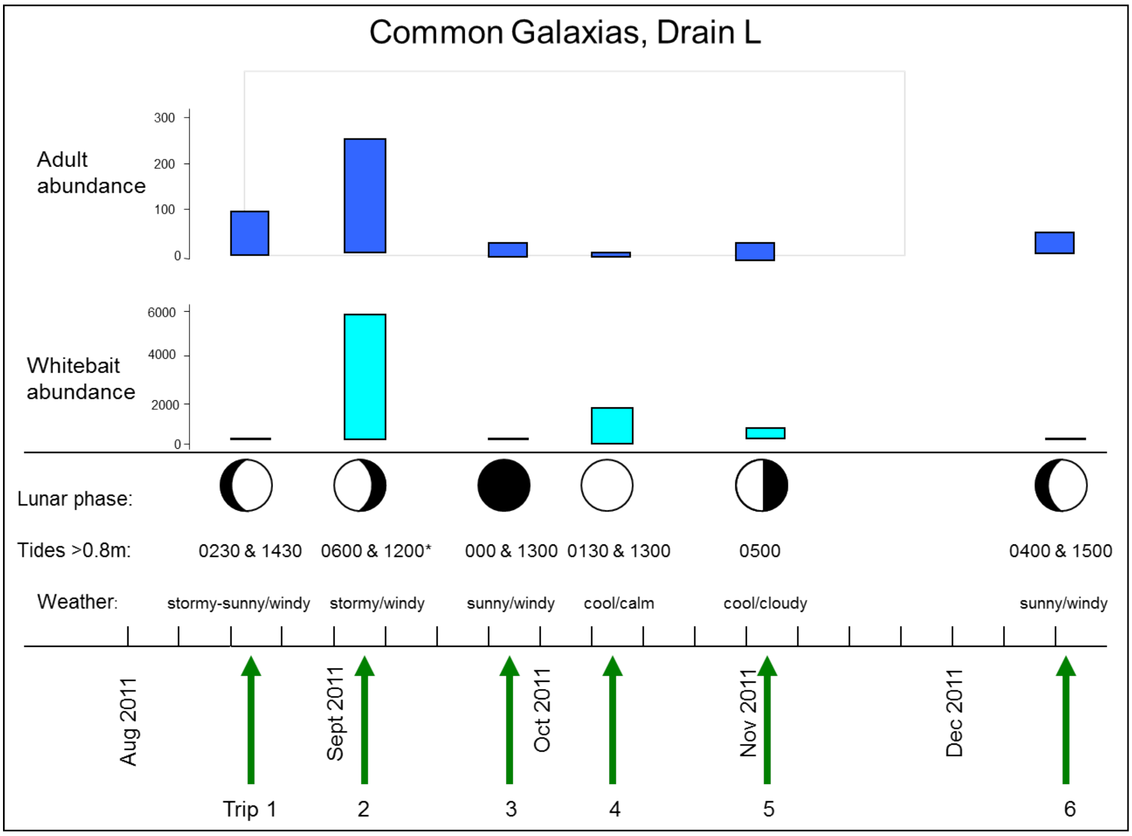


Figure 3.5. Summary of Common Galaxias collected in Drain L Catchment mapped on a calendar of sampling events and lunar, tidal and weather information.

Whitebait Common Galaxias sampled from Drain L catchment

Congolli

There were 23 Congolli (44-246mm) recorded during the movement sampling. Records were sparse (i.e. two adults >200mm were observed in August and September) until 21 fish were recorded at the Sandy Lane site during trip 6 (14-17th December), the majority were YOY (<70mm). All Congolli were collected during clear and sunny conditions, and all but four fish were sampled in the morning net check (night high tide) (Figure 3.6).

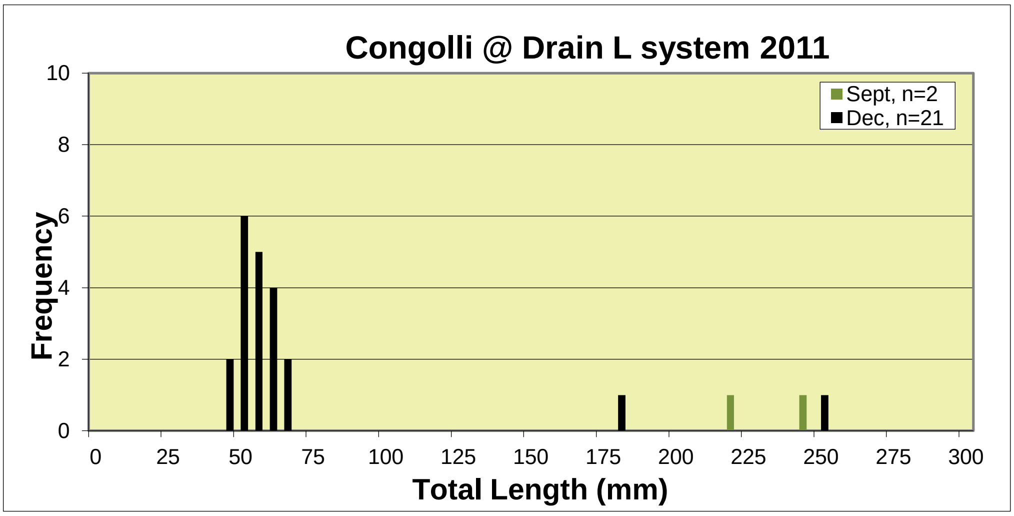


Figure 3.6 Length-frequency distribution for Congolli sampled during the movement study.

Juvenile (left) and adult (right) Congolli sampled from Drain L catchment

Pouched Lamprey

Four adult Pouched Lamprey (400-570mm) were recorded (two at mouth site, two at Sandy Lane) during early spring (7th September, 3 fish) and late spring (3th November, 1 fish). All fish were caught in a morning net check suggesting nocturnal or crepuscular movement. Conditions at the time included heavy local showers and storms during a waning moon and overnight high tides (Figure 3.3).

Adult Pouched Lamprey sampled from Drain L catchment.

Euryhaline species

Three euryhaline species were recorded and represented regular catches (Smallmouthed Hardyhead, Western Bluespot Goby and Lagoon Goby) with Smallmouthed Hardyhead collected at all three sites, whilst the two goby species were observed at only the two downstream sites. All three species were collected during each sampling trip, with peaks in Lagoon Goby abundance observed during August and December trips.

Smallmouthed Hardyhead (left), Lagoon Goby (top right) and Western Bluespot Goby (lower right) sampled from Drain L.

Estuarine and marine variant species

Six estuarine and one marine variant species were collected, accounting for just under a quarter of the Drain L movement study catch. Several of these species were regularly collected across the study period (Australian Salmon, Yelloweye Mullet and to a lesser extent Western Bluespot Goby), while opportunistic catches of Black Bream, Jumping and Sea Mullet and marine variant Weedfish were observed during late winter and early to mid spring. There was no consistent weather, tidal or lunar patterns explaining the presence of marine migrants, although Yelloweye Mullet numbers peaked in morning net checks during a dodge tide event with stormy overnight conditions during early September (Figure 3.7).

Juvenile Yelloweye Mullet (left) and juvenile Australian Salmon (right).

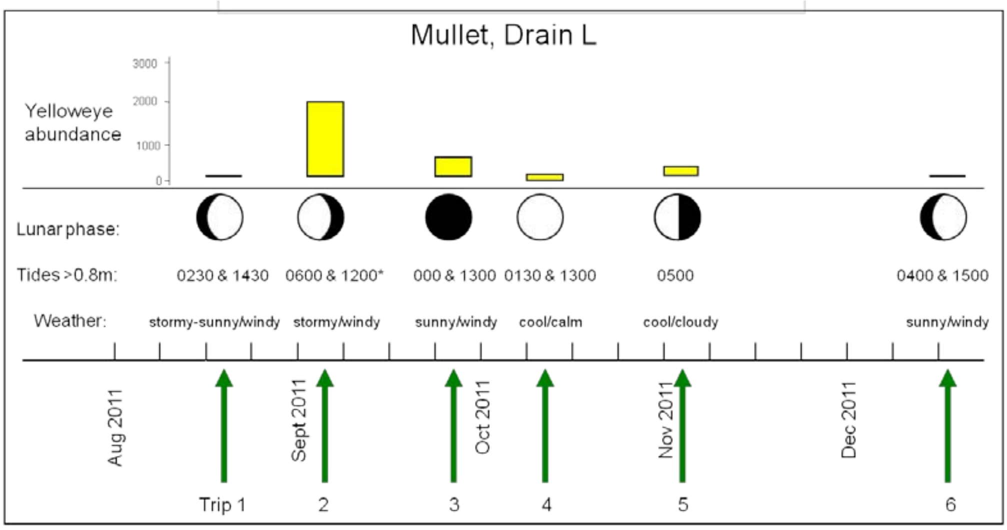


Figure 3.7. Summary of Yelloweye Mullet collected in Drain L Catchment mapped on a calendar of sampling events and lunar, tidal and weather information.

Obligate freshwater species

Southern Pygmy Perch were the only obligate freshwater species recorded during the movement study. There was no particular pattern for the species, low numbers were occasionally observed at Sandy Lane and above Boomaroo Park Weir during spring, generally coinciding with fresher conditions (<4490µScm^{-1}) compared to other sampling events.

Accumulation below weirs

Opportunistic observations at the Boomaroo Park Weir on trip 1 highlighted a significant concentration of fishes below the weir, some 8000 fish from seven species (see baseline site data SE11-12, section 2). Compared to catches in directional nets set upstream, the weir seemed to provide an instream barrier and significant fish accumulation point for Southern Pygmy Perch and Small Mouthed Hardyhead, with similar numbers of Common Galaxias and Yelloweye Mullet in both net sets indicating a lesser barrier to these species.

Environmental descriptors

The environmental descriptors for each of the movement study sites are detailed in Appendix 4. The site located at the mouth of Drain L (us of footbridge) was highly tidal and some aspects of water quality (EC, 3990-8160µScm^{-1} and pH, 7.0-9.4) were variable. The Sandy Lane site was still under the influence of the estuary, but acted as a 'freshwater' site for the majority of the sampling period, with ECs ranging between 2740-4490µScm^{-1}. The site upstream of Boomaroo Park Weir was also fresh (2650 and 3190µScm^{-1}). Levels of aquatic habitat increased from the mouth (< 20% overall habitat on all trips) to the sites further upstream (Sandy Lane, ~35% and above Boomaroo Park Weir, ~45%). At the mouth, rocks and debris made up much of the aquatic habitat, whereas filamentous algae and *Potamogeton pectinatus* contributed to biological cover and *Juncus* sp., *Schoeoplectus* sp, *Triglogchin* and *Typha* accounting for the emergent cover at the two upstream sites.

3.4 Discussion

Recent studies have provided information on the biology of diadromous species for several coastal systems in South Australia, including in the Coorong (Zampatti *et al.* 2010), western Mount Lofty Ranges (McNeil and Hammer 2007), lower Eyre Peninsula (Hammer and Whiterod 2012) and those of the lower south east (Hammer 2008). Key findings from the present study include: the second record of Climbing Galaxias in the South East, and first time migrating whitebait have been recorded; the verified presence of Pouched Lamprey and Congolli; and the collection of six previously unrecorded euryhaline and diadromous species in the Drain L catchment. Interestingly, the upstream movement of Australian Mudfish whitebait was not observed during the study. These findings represent a foundation for further study, conservation and management of diadromous species in the region.

Migratory life stages were recorded for a range of diadromous species, with abundant catches of Common Galaxias whitebait and more opportunistic data points of several other diadromous species (e.g. Climbing Galaxias, Congolli and Pouched Lamprey). Common Galaxias whitebait undertook obligate upstream migratory movements regularly across the entire study period (August to December) with peaks during spring, consistent with movement patterns in other systems (Hammer 2008; Zampatti *et al.* 2010). In the Coorong estuary, marine-freshwater connectivity strongly linked to freshwater inflows was a key determinate of Common Galaxias whitebait abundance (Zampatti *et al.* 2010). Broad connectivity clearly plays an important role in the movement patterns in the Drain L catchment, with peak abundances generally linked to high tides (and increased connectivity). The absence of large spawning aggregations (i.e. 1000s) as seen in the lower Eight Mile Creek during winter months (Hammer 2008), may simply reflect the timing of sampling (late winter to early summer) or more localised spawning in habitats where Drain L enters Lake Battye.

The upstream movement of other diadromous species (Congolli, Pouched Lamprey, Climbing Galaxias) was infrequently detected, supporting a general rarity of these species in the region at present (see Hammer 2008). As Hammer (2008) suggest this may reflect limited overall habitat of the few estuaries in the region, compared to areas such as the Coorong estuary, where juvenile Congolli in particular are common (Zampatti *et al.* 2010). The presence of Climbing Galaxias whitebait was encouraging, although juvenile and adults were not detected, and extends the known distribution of the species in the region (Hammer 2008). In contrast, no Australian Mudfish whitebait was observed in the movement study. This suggests that rather diadromous migrants are either very low in number, periodic or absent, with the possibility that the Lake Hawdon South population is confined entirely to freshwater environments. The following section (otolith microchemistry) investigates this point further.

The estuary of the Drain L Catchment maintains a diverse and mobile euryhaline fish fauna. Strong connectivity facilitated movement of many species between the sea and estuary, and the estuary and fresher lower Drain L environments (to Boomaroo Park Weir). The dominant euryhaline species was Yelloweye Mullet, which is known to occupy estuarine environments (Hammer 2008; Zampatti *et al.* 2010), but other species were rare (e.g. Tamar River Goby). While arguably artificial, the Drain L estuary appears to be an important and rare habitat type with strong connectivity, functioning perhaps as one of the healthier estuaries in the state from a fish point of view. The status of the euryhaline fish fauna further emphasises the importance of the protection of the estuary environment.

The Drain L Catchment is a key area for the conservation of diadromous and euryhaline fishes in South Australia, harbouring a high diversity and important species composition (including several species added to the known list during this survey). Facilitating different aspects of the biology of these species requires maintenance of connectivity primarily between the sea and freshwater (large migrations) but also within different areas of freshwater to allow access to preferred rearing and adult habitat and spawning grounds. Potential impacts of the SEFRP could be to reduce inflows into Drain L estuary, thus limiting marine/estuarine/freshwater connectivity and fish movement. In light of the findings of the movement study, careful consideration of any proposed management changes is necessary. It is recommended to maintain and enhance favourable environmental conditions for diadromous fishes in the Drain L Catchment by:

- Maintain sufficient flows through Drain L to ensure existing estuarine conditions are maintained at the Drain L outlet and the mouth remains open to allow continued marine/estuary connectivity.
- Ensure fish passage of diadromous species past any new weir (and investigate fish passage improvements at existing structures).
- Monitoring to assess the fine scale timing/flow requirements for migration of threatened diadromous species (Climbing Galaxias and Congolli and potentially Australian Mudfish).
- Monitoring to detect temporal changes associated with the proposed SEFRP.

4.0 Mudfish otolith microchemistry

4.1 Introduction

The Australian Mudfish (*Neochanna cleaveri*) is a small (<15cm), secretive freshwater fish distributed across coastal Tasmania, Flinders Island, and small patches of southern Victoria (McDowall 1996). Recently two western outlying populations have been located in the south east of South Australia (Hammer *et al.* 2009; Hammer and Tucker 2011). The population at Lake Hawdon South is extensive, and demonstrates high abundance, robust population structure and broad distribution across the site to be a regional stronghold (Hammer and Tucker 2011). A necessary objective of the SEFRP is to maintain this population, but present management is hampered by a lack of understanding of the biology and ecology of the species.

An important, but unresolved, aspect of the ecology of the South Australian population relates to diadromy – the requirement for both a marine and freshwater phase in the lifecycle. Victorian forms are diadromous with spawning occurring in freshwater habitats in winter, eggs or larvae washing out to sea and then returning to freshwater as thin transparent juveniles (or whitebait) (Koehn and Raadik 1991). Tasmanian populations seem more variable with the species reported in whitebait runs, but with some populations appearing to be confined entirely to freshwater (Fulton 1986; Andrews 1991). Also, five Mudfish species in New Zealand complete their lifecycle wholly in freshwater (McDowall 2010). It is currently unresolved whether the Lake Hawdon South population of Australian Mudfish exhibit diadromous migrations. Noted congregations observed below weirs (e.g. Bray Drain, Lower Drain M) and observed absence upstream of such structures suggest that complete diadromous migrations may not be achieved in the Drain L Catchment, possibly due to their poor swimming ability. Additionally, Australian Mudfish migration was not recorded in the present movement study. Given the possible implications for the design and operation of any regulator and associated fishway on Drain L constructed to mitigate the potential impacts of the SEFRP, further insight is necessary.

An emerging technique to address such questions is otolith (ear bones) chemical analysis, which can reveal the habitats individual fish have occupied during their lifecycle (see Elsdon and Gillanders 2005a; Gillanders 2005; Crook *et al.* 2006). Variation in the chemical signatures (namely of strontium (Sr) to calcium (Ca) and barium (Ba) to calcium (Ca)) within fish otoliths have commonly been used to infer residency in marine and freshwater habitats due to consistent relationships between the concentrations of these elements in otoliths and the ambient water (Gillanders 2005). Otolith material accreted by fish living in seawater (high salinity) is generally characterised by relatively high Sr : Ca and low Ba : Ca ratios, with the reverse observed in fish occupying freshwater (low salinity) habitats (Elsdon and Gillanders 2005a). Thus, exploration of the chemical signatures of the otoliths of Australian Mudfish from Lake Hawdon South may provide information on whether they migrate annually to sea, to the Drain L estuary (e.g. Robe Lakes) or complete their lifecycle entirely within Lake Hawdon.

4.2 Methods

Field collection

A sample of ten Australian Mudfish were previously collected from key habitats in the stronghold population (Lake Hawdon South) in South Australia during population monitoring by Hammer and Tucker (2011) (Table 4.1). These individuals represented sexes across a range of size classes (32-114mm TL), ages (0.5-2.5 years) and stages of ovary and gonad development. Accompanying water samples taken from select sites were collected in acid washed bottles, filtered through a 0.45µm filter, preserved with 0.5mL analytical grade concentrate nitric acid and frozen until analysis. Reference Australian Mudfish samples were also obtained from Victorian and Tasmanian populations. Nearby ocean (e.g. Southend) salinity and Sr, Ca, Ba concentrations were sourced from Elsdon and Gillanders (2005b).

Table 4.1.Summary of Australian Mudfish utilised in microchemistry study

Fish no.	Site Code	Date	Waterway	Location	Total length (mm)	Approx. age (years)
1	SE10-32	17/09/2010	Lake	Lake Hawdon connector	113	2+
2	SE10-33	17/09/2010	Lake	Northern end	114	2.5
3	SE10-33	17/09/2010	Lake	Northern end	107	1.5+
4	SE10-33	17/09/2010	Lake	Northern end	105	1.5+
5	SE10-33	17/09/2010	Lake	Northern end	83	-
6	SE10-33	17/09/2010	Lake	Northern end	86	-
7	SE10-33	17/09/2010	Lake	Northern end	68	0.5+
8	SE10-35	18/09/2010	Lake	Southern wetland (Almanda)	69	0.5+
9	SE10-35	18/09/2010	Lake	Southern wetland (Almanda)	111	1.5
10	SE10-36	18/09/2010	Bray Drain	Junction with Lake Hawdon	32	-
11	MH05	Summer 2005	Port Creek	Wynyard, North Coast Tas.	-	1+
12	MH05	Summer 2005	Port Creek	Wynyard, North Coast Tas.	-	1+
13	TR11	23/05/2011	Aire River	Otway Ranges, Victoria	60	0.5-1.0
14	TR11	23/05/2011	Aire River	Otway Ranges, Victoria	60	0.5-1.0

Chemical analysis of water samples

Water samples were analysed for ambient elemental concentrations with dual-view inductively coupled plasma – atomic emission spectrometer (DV ICP-AESPerkin-Elmer 3000, USA) for calcium (Ca) and magnesium (Mg) and a dynamic reaction cell inductively coupled plasma – mass spectrometer (DRC ICP-MS Perkin-Elmer 6000, USA) for strontium (Sr) and Barium (Ba), both operated by the Australian Government National Measure Institute (NMI), Sydney, Australia. Lutetium and indium were used as internal standards to check for machine drift of each instrument respectively, standards of known concentrations were used every 10 to 15 samples to maintain precision. Analytical accuracies were measured (but averaged for all samples), - 107% for Ca, 105% for Sr and 100% for Ba - and all were within the acceptable range (i.e. 75-120%). Elemental concentrations were standardised to Ca and represented as ratios in units of mmol mol^{-1} (Sr : Ca) and µmol mol^{-1} (Ba : Ca) analysis due to the substitution of these trace elements for calcium in the growing otolith.

Otolith preparation and analysis

All sampled individuals were euthanised and then frozen until otolith extraction. In the laboratory fish were thawed and sagittal otoliths were extracted, washed in ultrapure water and allowed to dry before being stored in microcentrifuge tubes. One sagittal otolith from each fish was embedded in two part epoxy resin (EpoFix, Struers, Denmark) spiked with indium 40ppm and sectioned through the core in the transverse plane with an Isomet low speed diamond saw (Buehler Ltd) and polished using lapping film lubricated with ultra pure water to produce a 3 µm surface finish appropriate for chemical analysis. The section was mounted on a glass microscope slide using 40 ppm indium spiked thermoplastic cement (Crystalbond 509). The mounted otoliths were then sonicated for 5 min in ultrapure water and allowed to dry in a laminar flow hood. After curing for twelve hours, otolith sections were examined under a fluorescent microscope with transmitted light (DMLB, Leica Microsystems, Germany) to highlight otolith features not visible when the sample is under laser ablation inductively coupled mass spectrometry (LA-ICPMS). The transect path was chosen to capture the nucleus, growth axis and edge of the otolith (Figure 4.1), and whilst under the microscope approximate age (nearest 0.5 year) was recorded for fish where growth bands were defined.

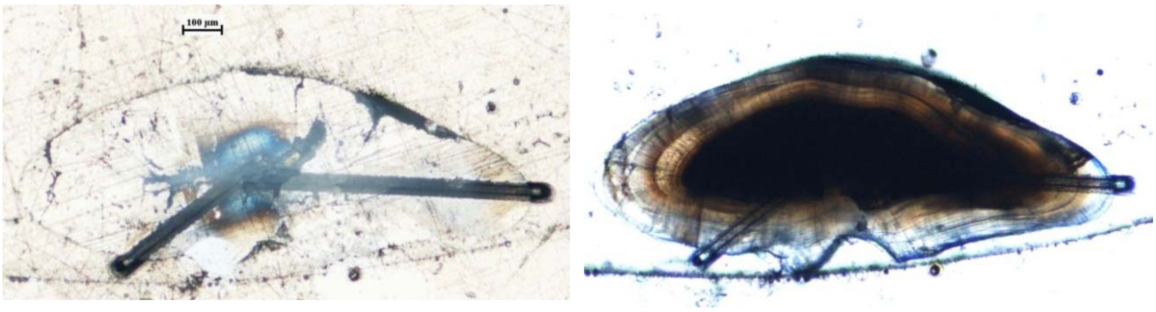


Figure 4.1. Reflected (left) and transmitted (right) light images of transverse otolith cross section (M8) depicting ablation scars (left) and growth rings (right) at 5 x magnification.

Transects across the otolith sections were conducted using inductively coupled plasma mass spectrometry (75000s ICP-MS, Agilent Technologies, USA), at Adelaide Microscopy, University of Adelaide, to measure concentrations of a strontium (Sr), barium (Ba) and calium (Ca). The sampling was performed using a Merchantek UP213 Nd: YAG deep UV Laser (New Wave Research, USA)) with a pulse rate of 5.00 Hz and an ablation width of 30 µm. A continuous transect from the core of the otolith to the outer margin of the otolith was conducted to sample larval phase to time of capture. A laser scan rate of 3 µm $s^{-1}$with data acquired every 1.425 seconds after a pre-ablation blank run to remove any impurities and allow the ablation to penetrate the otolith during moving operations was used for each otolith (Figure 4.1). Sample gases were extracted from the chamber through a smoothing manifold facilitated by a helium and argon stream. Analysis involved a 30 second background count for all otoliths to determine average detection limits for each element.

A reference standard (National Institute of Standards and Technology, NIST 612) was analysed regularly (i.e. beginning of the sampling session, end of session and after every 10 to 12 samples) to correct for long-term drift in the instrument. Similarly at the beginning of each session at least two transect analyses were run on a standard otolith sample of known concentrations. The raw ion counts for each element were converted to concentrations (ppm) using Glitter software (Macquarie University) and molar concentrations determined. Elemental concentrations were standardised to Ca and data represented as concentration ratios in units of mmol mol^{-1} (Sr : Ca) and µmol mol^{-1} (Ba : Ca) analysis.

4.3 Results

All sampled habitats were moderately fresh, with similar salinity recorded in the freshwater (e.g. Lake Hawdon South, 1970-3510µScm^{-1}) and estuary environments (e.g. Robe Lakes, 3000µScm^{-1}) when compared to freshwater reference sites in Tasmania and Victoria (1200µScm^{-1}) and nearby ocean concentrations (~37,000µScm^{-1}) (Table 4.2). Analysis of water samples from Lake Hawdon South and the Robe Lakes revealed higher Sr:Ca (mean 7.91 mmol mol^{-1}, normally 1-3mmol mol^{-1}) and lower Ba:Ca (mean 107µmol mol^{-1}, normally 500-4000µmol mol^{-1}) than generally observed in freshwater environments. For the nearby ocean (sampled during winter), the Sr:Ca was 8.48mmol mol^{-1} and the Ba:Ca was 6.58µmol mol^{-1}, consistent with typically ratios for marine environments.

Table 4.2.Summary of water quality and water analysis at sites where Australian Mudfish were collected for the microchemistry study

Site Code	Waterway	Location	EC (µScm^{-1})	Sr:Ca ($mmolmol^{-1}$)	Ba:Ca (µ$molmol^{-1}$)
SE10-32	Lake Hawdon South	Lake Hawdon connector	2630	9.42	55.8
SE10-33	Lake Hawdon South	Northern end	2680	-	-
SE10-35	Lake Hawdon South	Southern wetland (Almanda)	1970	-	-
SE10-36	Bray Drain	Junction with Lake Hawdon	3510	8.3	37.0
-	Robe Lakes	Middle lake	3000	10.7	72.0
MH05	Port Creek	Wynyard, North Coast Tas.	1200	-	-
-	Aire River	Otway Ranges, Victoria	930	-	-
-	Southern Ocean	Southend	~37,000	8.48	6.58

It is anticipated that the chemical signatures of fish moving from seawater (high salinity) to freshwater (low salinity) environments will be characterised by declines in Sr :Ca and increases in Ba:Ca. The reference Victorian and Tasmanian Australian Mudfish showed elemental profiles consistent with a transition from the ocean to freshwater environments at a very similar stage in their life history (Figure 4.2). In contrast, fish from Lake Hawdon South do not show a clear transition between habitats and appeared to have used a single habitat type only (e.g. 5, 7 and 9). Interestingly, nearly all fish display a marine type profile for their entire lives based on moderate Sr:Ca and low Ba:Ca (Figure 4.3). This is reflected in the water chemistry of Lake Hawdon which at the time of sampling had a marine like elemental profile (e.g. Sr :Ca between 2-6 mmol mol^{-1}). It is possible that the fish have moved between the sea and Lake Hawdon and this is not marked in the otoliths due to similar water chemistry in the two environments.

On the whole there is subtle difference between the reference (clearly diadromous results) samples from Victoria and Tasmania (consistently higher Sr:Ca values, >6 mmol mol^{-1}) compared to those from Lake Hawdon South (typically ~4 mmol mol^{-1}) tentatively supporting residence inland. Generally all Lake Hawdon fish show a similar Sr:Ca and Ba:Ca signature at the time of capture, however one fish shows evidence of being a new arrival based on different concentrations. Nevertheless, Robe Lakes water analysis was similar to Lake Hawdon South, hence movement between the two areas cannot be eliminated with the results of this analysis.

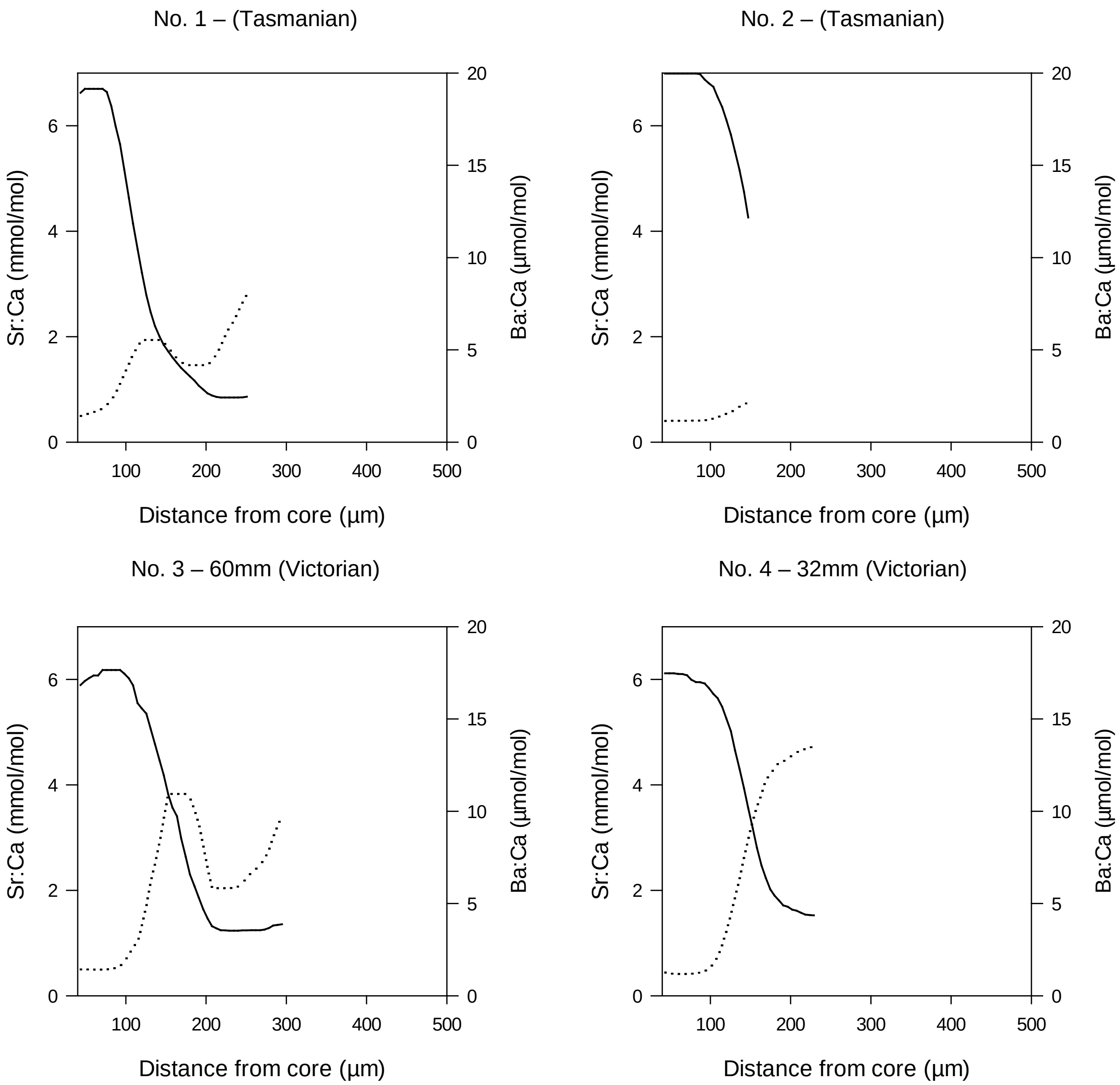


Figure 4.2 Transects across the sagittal otolith of Australian Mudfish (fish 1-4) from reference locations, Tasmania (fish1-2) and Victoria (fish 3-4); Sr:Ca – solid line and Ba:Ca – dotted line.

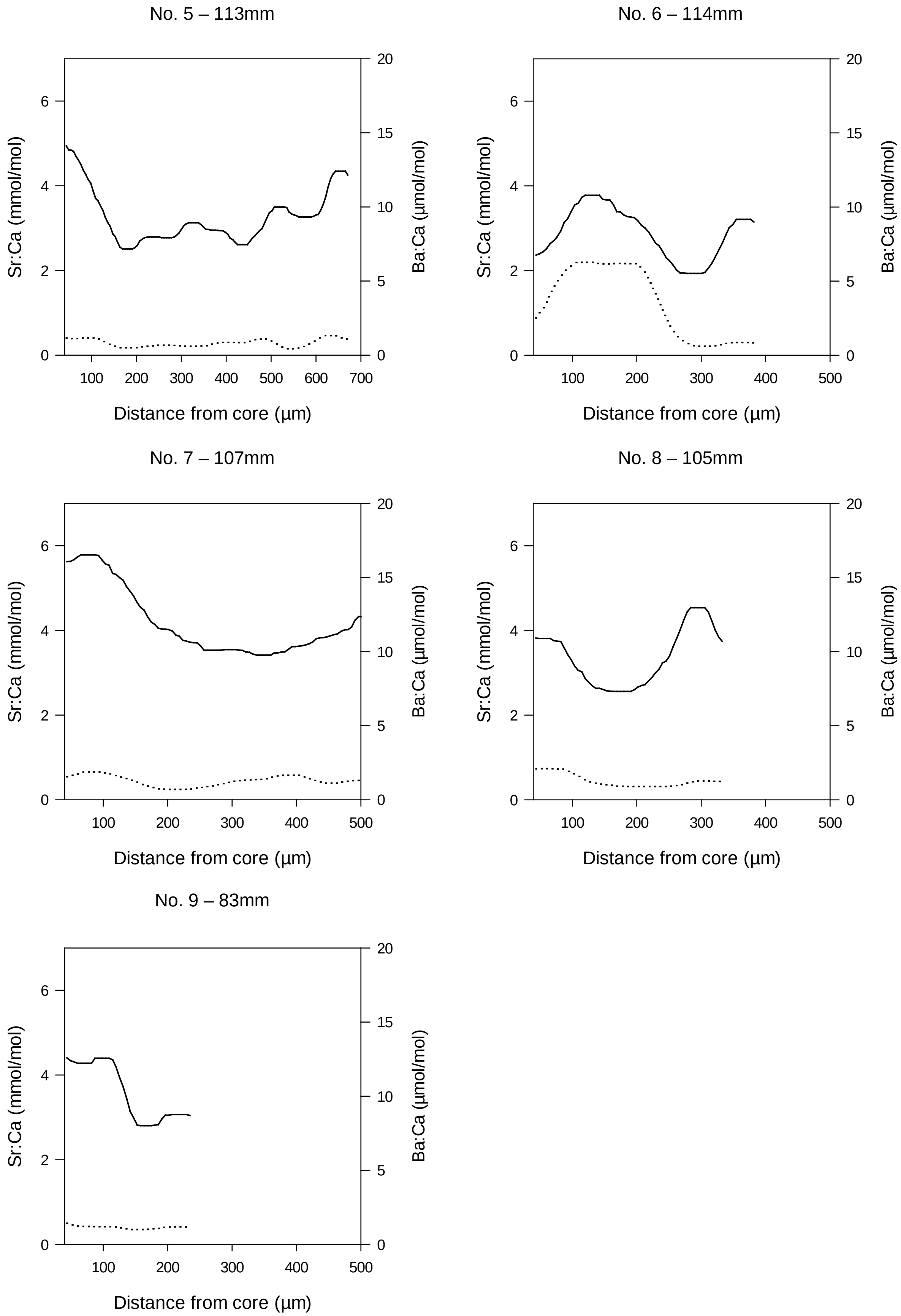


Figure 4.3. Transects across the sagittal otolith of Australian Mudfish (fish 5-9) from Lake Hawdon South Catchment; Sr:Ca – solid line and Ba:Ca – dotted line.

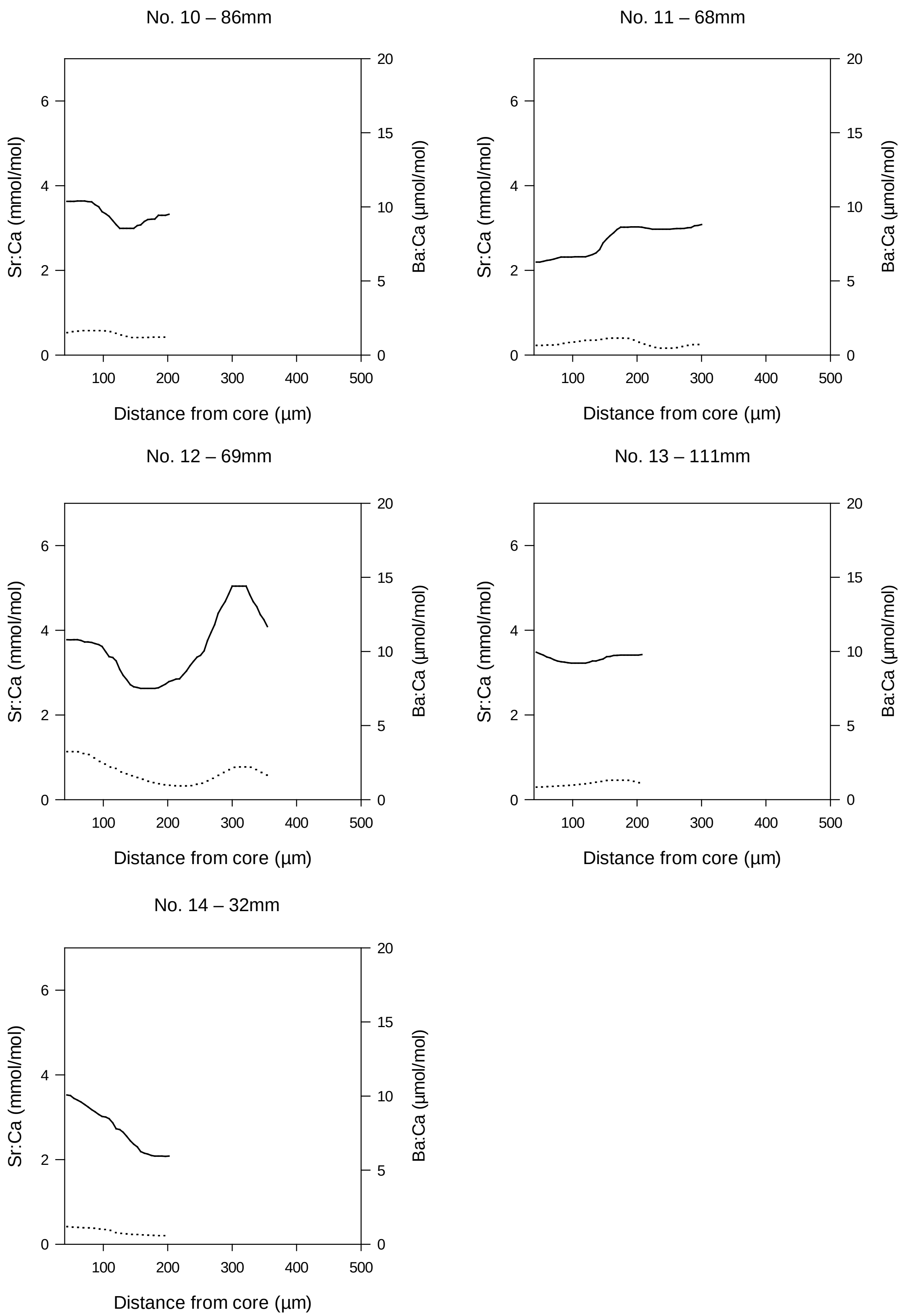


Figure 4.4. Transects across the sagittal otolith of Australian Mudfish (fish 10-14) from Lake Hawdon South Catchment; Sr:Ca – solid line and Ba:Ca – dotted line.

3.4 Discussion

The otolith microchemistry study explored the diadromy of Australian Mudfish in the Drain L catchment. The species is known to be flexible with regard to its life history in that some Victorian and Tasmanian populations are considered diadromous and others have been shown to be confined entirely to freshwater (Fulton 1986; Andrews 1991; Koehn and Raadik 1991). On the basis of water chemistry analysis and comparisons with the chemical signatures of Lake Hawdon South fish it is inconclusive as to whether Australian Mudfish in the Drain L Catchment undertake diadromous migrations. Elemental ratios for most Lake Hawdon South fish lacked the transition (i.e. Sr : Ca declines whilst Ba : Ca increases) typical of habitat shifts from marine to freshwater environments, and observed in the Victorian and Tasmanian reference fish and elsewhere (Crook et al. 2008). Rather, the ratios of these fish remained relatively constant over their lives, indicating the use of a single habitat. The single habitat is unlikely to be the marine environment as the elemental ratios of the fish are inconsistent to those of the prevailing in the ocean nearby (Elsdon and Gillanders 2005b). So a complete marine diadromy model appears to be ruled out at Lake Hawdon South.

However, comparable water chemistry (e.g. salinity and elemental ratios) between the Robe Lakes and Lake Hawdon South and Bray Drain make distinction between the estuarine and freshwater environments difficult. Hence they may make diadromous migrations between these freshwater environments and the Drain L estuary (i.e. juveniles washed to the estuary, grow to whitebait then head upstream), which are not represented in their chemical signatures due the comparable water chemistry. Conversely, it may be that the sampled fish spend their entire lives in the moderately saline freshwater environments of Lake Hawdon South. The wholly freshwater lifecycle is supported by the absence of Australian Mudfish whitebait in the directional fyke nets used in Drain L (present movement study) as well as the lower Drain M and Sutherland Drain (Hammer and Tucker 2011). Noted congregations of adults observed below weirs (e.g. Bray Drain, Lower Drain M) and acknowledged poor swimming ability suggest the species may be incapable of migrating through the lower Drain L, providing further evidence for a landlocked freshwater population.

Clearly, further work is necessary to resolve the requirement for diadromous movement in the species. Indeed, the movement study represented a snapshot investigation and it is possible that infrequent runs of Australian Mudfish whitebait were missed. Finer resolution movement sampling across multiple years would be useful to help detect migrating Australian Mudfish whitebait. Also, monitoring targeting larval Australian Mudfish in Lake Hawdon South may confirm wholly freshwater recruitment. The present study is based on the otolith analysis of a small sample of fish from one occasion and findings may not be broadly representative of the movement patterns of the Australian Mudfish from Lake Hawdon South. A comprehensive analysis of samples from other locations and across years would provide a more complete understanding of movement patterns. In the absence of this comprehensive study, analysis of previously collected samples for the other population of the species in South Australia - Drain M/Sutherland Drain - would allow for insightful comparison. Additionally, staple isotope analysis would complement the analysis of trace elements possibly providing more information on diadromy in the species.

Conclusions & recommendations

The present otolith microchemistry study was unable to conclusively resolve the requirement for diadromous movement in Australian Mudfish in the Drain L catchment. It can be concluded that the population is not obligate diadromous with recruitment noted in the wetland without signs of diadromous movement of whitebait. Several lines of evidence suggest that the population is wholly freshwater and capable of completing its lifecycle in Lake Hawdon South. However, the population could in fact be facultative diadromous, functioning as wholly freshwater for the majority of the time, but occasionally undergoing diadromy (which were missed by the present snapshot study). Clearly further work is necessary to investigate refined questions regarding the diadromous movements of the species. The Australian Mudfish population in the catchment is, however, of such significance that management needs to account for potential diadromous migrations in the species until conclusive resolution is achieved. A fishway associated with the potential regulator constructed across Drain L needs to be designed in such a way allow for Australian Mudfish upstream movement (be it fish undertaking upstream runs or fish getting washing out of the Lake and attempting to return). It is recommended to:

- Maintaining sufficient diversity of drain and wetland habitats (e.g. Lake Hawdon South), and their hydrological regime, to support Australian Mudfish.
- Larval monitoring in Lake Hawdon South to assess wholly freshwater recruitment.
- Undertake comparative analysis of Sutherland Drain Australian Mudfish.
- Investigate refined questions regarding the diadromous movements of the species.

5.0 General discussion

5.1 Project summary

The Drain L Catchment is an area with significant natural ecological assets persisting within a highly altered landscape, and where strong relationships now exist between aquatic fauna and the flow ecology of artificial drains (Hammer 2002; Wedderburn and Hammer 2002; Hammer and Tucker 2011). Relatively high rainfall, the creation of permanent aquatic habitat within artificial drains and relatively shallow groundwater appear to have buffered against change and promoted a new equilibrium which supports important species and processes. However, the water resources of the Drain L system are being targeted for new hydrological modifications, by diverting water for environmental purposes to other parts of the region, which has the potential to impact on downstream aquatic fauna values within or adjacent to Drain L.

The different aspects of the study document important considerations in determining future management needs of the system, with advances in knowledge and remaining information gaps explored below. Specifically, the project has addressed the objectives of describing the current distribution and abundance of fishes (section 2); assess population demographics of threatened species (sections 2 and 3); and improving understanding of the importance of connectivity to the fish fauna (sections 3 and 4). The final objective (to review overall data and propose a monitoring approach) is the focus of the sections that follow.

5.2 Fish species of the Drain L catchment

The findings of the present baseline and movement studies and collation of other previous data (Appendix 5) help to accurately catalogue the habitats and fish species of the Drain L catchment. The fish species recorded in the catchment along with their ecological functional group and conservation status are listed in Table 5.1.

Table 2 Updated list of fish species present in the Drain L catchment. Functional groups are diadromous, generalists (Dg); diadromous, specialists (Ds); obligate freshwater, specialised (wetland) (Fs); obligate freshwater, generalists (Fg); Euryhaline (Eu); and Estuarine (Es); and Marine variant (Mv). Conservation status are Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Rare (R); and Protected (P).

Common name	Scientific name	Functional group	EPBC Act	SA Protected	Action Plan 09
Australian mudfish	*Neochanna cleaveri*	Ds/Fw			CR
Australian salmon	*Arripis truttacea*	Es			
Black bream	*Acanthopagrus butcheri*	Es			
Bridled goby	*Acentrogobius bifrenatus*	Es			
Climbing galaxias	*Galaxias brevipinnis*	Ds			R
Common galaxias	*Galaxias maculatus*	Dg			
Congolli	*Pseudaphritis urvillii*	Dg			VU
Dwarf galaxias	*Galaxiella pusilla*	Fs	VU		VU
Jumping mullet	*Liza argentea*	Es			
Lagoon goby	*Tasmanogobius lasti*	Eu			
Pouched lamprey	*Geotria australis*	Ds			EN
Sea mullet	*Mugil cephalus*	Es			
Small-mouthed hardyhead	*Atherinosoma microstoma*	Eu			
Southern pygmy perch	*Nannoperca australis*	Fw		P	EN
Tamar goby	*Afurcagobius tamarensis*	Es			
Weedfish	*Heteroclinus flavescens*	Mv			
Western bluespot goby	*Pseudogobius olorum*	Eu			
Yelloweye mullet	*Aldrichetta forsteri*	Es			

In summary, a total of 18 species, including six species of state or national conservation concern, have been collected in the catchment. This includes previously recorded freshwater obligate (e.g. Dwarf Galaxias and Southern Pygmy Perch), diadromous (e.g. Australian Mudfish, Congolli, Pouched Lamprey) and euryhaline (e.g. Smallmouthed Hardyhead, Lagoon Goby and Western Bluespot Goby) species along with a new record of diadromous Climbing Galaxias. Five estuarine species (e.g. Australian Salmon, Black Bream, Bridled Goby and Jumping, Sea and Yelloweye mullets) and one marine variant (e.g. Weedfish) have also been recorded in the catchment. Other species not recorded, but that may still be encountered periodically or in very low abundance in future monitoring include Shortheaded Lamprey and Shortfinned Eel, and other estuarine species and marine vagrants are also likely.

Importantly no introduced species, particularly Gambusia, have been recorded in the catchment despite nearby source populations being present in adjacent catchments (see Figure 5.1).

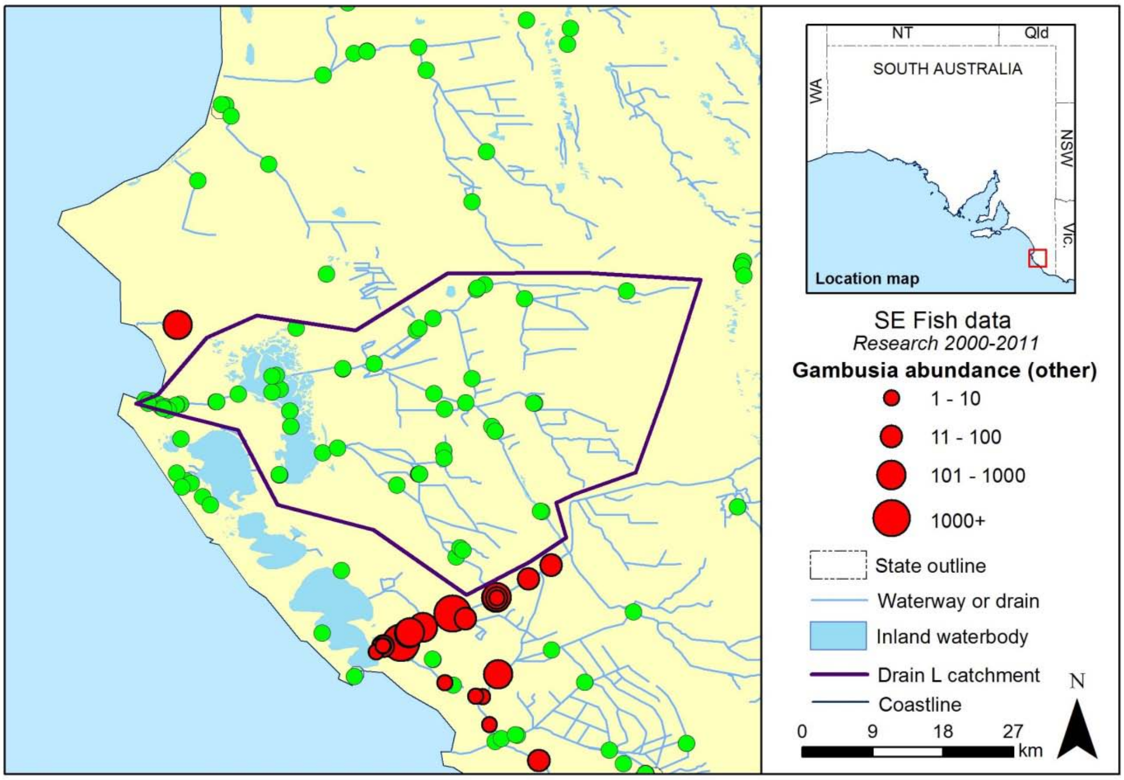


Figure 5.1 Updated distribution and abundance of Gambusia across the south east South Australia, highlighting absence from the Drain L Catchment (this survey and previous data; Appendix 5).

Summary of ecological assets

The fish species present in the Drain L Catchment are defined as ecological assets (E) by their functional groups as follows:

- E1. Threatened obligate freshwater fishes: Australian Mudfish, Dwarf Galaxias, Southern Pygmy Perch
- E2. Threatened diadromous fishes: Australian Mudfish, Climbing Galaxias, Pouched Lamprey, Congolli.
- E3. Other freshwater and estuarine species: Common Galaxias, Goby species, Smallmouthed Hardyhead, Mullet species, Black Bream.

5.3 Monitoring approach

The present study provides a sound framework for the use of fish populations as indicators of the conditions of aquatic environments in the Drain L Catchment. Future monitoring in the catchment should aim to evaluate the condition of ecological assets (E1-E3) and detect impacts associated with proposed management change. Table 5.2 describes a framework, detailing objectives and corresponding indicators, techniques and method notes. Implementation of the framework will ensure scientifically rigorous, robust/reliable and defensible data. Additionally, sampling should be conducted in a repeatable manner by experienced operators, with strong fish identification and sampling skills, and data should be maintained in a quality assured database. The framework will be applied to (a) broad baseline monitoring, and (b) specific assessment of the potential impacts of SEFRP in the following section.

Table 3 Monitoring framework for fishes in the Drain L catchment. Sampling net types: large fyke (LF); small fyke (SF); double wing (directional) fyke (DW), bait trap (BT); dip net (D); opportunistic (OPP); and dip tray (DT).

Monitoring objectives (with indicator)	**Technique**	**Method notes**
Assessing fish community composition (species inventory)	Use a variety of complementary gear types suited to sampling different habitat and species	Requires targeted sampling of distinct regions of the catchment. methods will vary according to fish community and habitat. Net types - LF, SF, DW, BT.
Determining that a species remains (presence)	Targeted sampling for a particular taxa at a particular monitoring site. (note: can be obtained from 'species inventory')	Methods vary according to target species as qualitative observations, but can be more comprehensive to incorporate species inventory targets. Needs to have minimal impact. Net types - LF, SF, DW, BT, D, OPP, DT
Mapping distribution during low flow periods (population extent)	Targeted sampling (presence) for particular taxa across available habitat in a particular region.	Methods vary according to target species, but incorporate 'species inventory' as rapid assessment of area. Net types - LF, SF, DW, BT, D, OPP, DT.
Snapshot of demographic structure) for (a) assessing presence of recruits and (b) assessing longer-term survivorship through presence of older size classes (recruitment)	Length-frequency measurements as temporal data to examine trends through time.	Method suited to habitat and species specific. A need for sampling to be standardised and also minimise impacts. Hence a balance - with the ultimate aim to provide reasonable snapshot of the population present. Net types - LF, SF, DW, BT.
Studies of diadromous migrations (movement)	Specific targeting monitoring to upstream movement	Method suited to habitat and species. typically employ directional fyke nets (larval & standard) to detect movement of diadromous species. Net types - DW, inc. fine mesh for whitebait
Presence of introduced species (introduced species)	Specific sampling targeting the presence and population extent of introduced species	Methods vary according to target species as qualitative observations, but can be more comprehensive to incorporate species inventory targets. Net types - LF, SF, BT, D, OPP

Long-term monitoring

Broad annual monitoring is necessary to assess the broad condition of the fish community composition in the catchment (species inventory). This sampling should incorporate temporally (e.g. annual) replicated inventory/baseline style methodology to document fish species richness and composition and their relative abundance and population dynamics (Hammer 2002). There should also be provision periodic movement sampling to document migration of diadromous species (Hammer 2008). The sites used for this monitoring need to provide spread representative of all habitat types across the spatial extent of the catchment and include:

- Habitat types home to E1 (e.g. Lake Hawdon South) – assess ecological asset condition.
- Estuary sites – assess diadromous movement patterns of E2 and the condition of the diverse and mobile euryhaline fish fauna (E3).
- Previously sampled sites – assess trends in population dynamics of key ecological assets to be assessed.
- Spatial gaps in the previous sampling – map distribution and identify new ecological assets.

Long-term monitoring should occur during late winter to spring. This is typically the time when water availability, fish activity and water temperature display the best combination for passive gear types such as small and large fyke net and bait traps. It is proposed that monitoring of potential reduced estuary connectivity and fish passage impacts should focus on movement sampling with a temporal focus on periods of migration activity (e.g. mid-winter through to mid-summer) for diadromous fishes, or be event based (e.g. onset or cessation of seasonal flows) to correspond with season or management decisions that impact on flows.

Specific assessment

A more comprehensive application of the monitoring framework is necessary to assess potential impacts associated with the SEFRP. The target functional group and suggested indicator and monitoring notes for each management change and associated potential impacts are highlighted in Table 5.3. The monitoring framework can be applied to assess potential impacts from additional management changes that may be implemented.

Table 4 Summary of monitoring approach for the specific assessment of the potential impacts of the SEFRP. Ecological assets are threatened obligate freshwater fishes (E1); threatened diadromous fishes (E2); and other freshwater and estuarine species (E3).

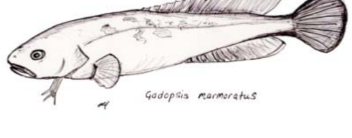
Management change	Potential impact	Ecological assets	Indicators						Monitoring notes
			Species inventory	Presence	Population extent	Recruitment	Movement	Introduced species	
Construction of diversion structures	Localised loss of species	E1		X	X	X			Before & after at point source and key downstream impact points
		E1, E3	X						
Hydrological connectivity with other catchments	Establishment of introduced species	-		X	X			X	Before & after (event-based) SEFRP flows
Reduced downstream Drain L flows	Loss of permanent drain/wetland habitat	E1		X	X	X			As part of annual baseline monitoring
		E1, E3	X						
	Changes in Lake Hawdon South habitat	E1		X	X	X			Specifically targeting Dwarf Galaxias and Australian Mudfish
	Reduced overbank flows in lake Hawdon North	E1, E2, E3	X						As part of annual baseline monitoring
	Reduced estuary connectivity ('mouth openness')	E2					X		Multiple temporal replicates at estuary sites
		E2, E3	X						As part of annual baseline monitoring & movement indicator (below
Regulatory structure with fishway	Impede fish passage	E2					X		Multiple temporal replicates upstream & downstream of fishway
		E1, E2, E3	X			X			
	Localised loss of species	E1, E2	X	X	X	X			Before & after at construction locations
		E1, E2, E3	X						

5.4 Recommendations

A number of recommendations emerge from the present study that relate to either management or monitoring. In terms of management of the Drain L catchment, it is recommended to:

- Maintain the catchment free of introduced fish species by preventing connectivity with pest species populations.
- Maintain sufficient diversity of drain and wetland habitats to support a diversity of fish species, particularly obligate freshwater fishes.
- Maintain sufficient flows through Drain L to ensure existing estuarine conditions are maintained at the Drain L outlet and the mouth remains open to allow continued marine/estuary connectivity.
- Ensure fish passage of diadromous species through the construction of a fish-way associated with any weir structures proposed under the SEFRP (and investigate fish passage improvements at existing structures).
- Determining and providing for environmental water provisions for different functional groups of fishes in the Drain L system.

Monitoring recommendations relate to the need to detect temporal changes throughout the catchment and changes associated with the proposed SEFRP. Specifically, (a) broad long-term monitoring program, and (b) specific assessment of the potential impacts of SEFRP in the Drain L Catchment is recommended. Long-term monitoring is necessary to assess the broad condition of the fish community composition, in what is a highly significant catchment. Additionally, periodic movement sampling should investigate more detailed questions (e.g. fine scale timing/flow requirements) to improve understanding of the migration of threatened diadromous species (Climbing Galaxias, Congolli and potentially Australian Mudfish) but also wholly freshwater recruitment of Australian Mudfish in the Lake Hawdon South. This will assist with determining the operating guidelines for minimum flows and water levels in the system. Specific (event-based and annual) site monitoring of fish indicators in response to changes imposed by the proposed SEFRP is also recommended.



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7.0 References

Andrews, A. P. (1991). Observations on the Tasmanian mudfish, *Galaxias cleaveri* (Pisces: Galaxiidae). *Papers and Proceedings of the Royal Society of Tasmania* **125**, 55-59.

Bunn, S. E., Arthington, A. H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* **30**, 492-507.

Crook, D. A., Macdonald, J. I., O'Connor, J. P., Barry, B. (2006). Use of otolith chemistry to examine patterns of diadromy in the threatened Australian grayling *Prototroctes maraena*. *Journal of Fish Biology* **69**, 1330-1334.

Ecological Associates (2009). *Native vegetation and restoration potential of Lake Hawdon North*. Ecological Associates, Adelaide.

Elsdon, T. S., Gillanders, B. M. (2005a). Alternative life-history patterns of estuarine fish: barium in otoliths elucidates freshwater residency. *Canadian Journal of Fisheries and Aquatic Sciences* **62**, 1143–1152.

Elsdon, T. S., Gillanders, B. M. (2005b). Consistency of patterns between laboratory experiments and field collected fish in otolith chemistry: an example and applications for salinity reconstructions. *Marine and Freshwater Research* **56**, 609–617.

Fulton, W. (1986). The Tasmanian mudfish *Galaxias cleaveri* Scott. *Fishes of Sahul* **4**, 150-151.

Gillanders, B. M. (2005). Otolith chemistry to determine movements of diadromous and freshwater fish. *Aquatic Living Resources* **18**, 291-300.

Hammer, M. (2002). *The South East fish inventory: distribution and conservation of freshwater fishes of south east South Australia*. Native Fish Australia (SA) Inc., Adelaide.

Hammer, M. (2008). *Pilot fish movement study in Lower South East, South Australia. Report to Department for Environment and Heritage, South Australian Government*. Aquasave Consultants, Adelaide.

Hammer, M. (2009a). *Freshwater fish monitoring in the Eastern Mount Lofty Ranges: environmental water requirements and tributary condition reporting for 2008 and 2009. Report to the SAMDB NRM Board*. Aquasave Consultants, Adelaide.

Hammer, M. (2009b). *Status assessment for nationally listed freshwater fishes of south east South Australia during extreme drought, spring 2008. Report to Department for Environment and Heritage, South Australian Government*. Aquasave Consultants, Adelaide.

Hammer, M., Tucker, M. (2011). *Baseline study and community monitoring of Australian Mudfish in South East, South Australia. Report to Department for Water, South Australian Government*. Aquasave Consultants, Adelaide.

Hammer, M., Wedderburn, S., van Weenan, J. (2009). *Action Plan for South Australian Freshwater Fishes*. Native Fish Australia (SA) Inc., Adelaide.

Hammer, M., Whiterod, N. (2012). *Freshwater fish survey of southern Eyre Peninsula, South Australia. Report to Eyre Peninsula Natural Resources Management Board*. Aquasave Consultants, Adelaide.

Hammer, M. P., Walker, K. F. (2004). A catalogue of South Australian freshwater fishes including new records, range extensions and translocations. *Transactions of the Royal Society of South Australia* **128**, 85-97.

Koehn, J. D., Raadik, T. A. (1991). The Tasmanian mudfish, *Galaxias cleaveri* Scott, 1934, in Victoria. *Proceedings of the Royal Society of Victoria* **103**, 77-86.

Lloyd, L., Knight, C. (2008). *Eastern Gambusia: a review and risk assessment for the REFLOWS project. Report to Upper South East Dryland Salinity and Flood Management Program, Department for Water Land and Biodiversity Conservation*. Lloyd Environmental, Melbourne.

McDowall, R. M. (1988). 'Diadromy in Fishes: Migrations Between Freshwater and Marine Environments.' (Croom Helm: London)

McDowall, R. M. (1996). 'Freshwater Fishes of South-Eastern Australia.' (Reed: Sydney)

McDowall, R. M. (2010). *Distribution, History and Biogeography of the Neochanna Mudfishes*. In 'New Zealand Freshwater Fishes: an Historical and Ecological Biogeography' pp. 303-314. (Springer: New York)

McNeil, D. G., Hammer, M. (2007). *Biological review of the freshwater fishes of the Mount Lofty Ranges. SARDI publication number: F2006/000335.* South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

South Australian Department for Water (2011). *Upper South East Drainage Network Management Strategy*. South Australian Department for Water, Adelaide.

Taylor, B. (2006). *Wetland Inventory for the Lower South East, South Australia*. Department for Environment and Heritage, Mount Gambier, South Australia.

VanLaarhoven, J., van der Wielen, M. (2009). *Environmental water requirements for the Mount Lofty Ranges prescribed water resources areas*. Department of Water, Land and Biodiversity Conservation & South Australian Murray-Darling Basin Natural Resources Management Board, South Australian Government, Adelaide.

Wedderburn, S., Hammer, M. (2002). *South East Fish Inventory supplement: Robe Lakes and Lake George*. Native Fish Australia (SA), Adelaide.

Zampatti, B. P., Bice, C. M., Jennings, P. R. (2010). Temporal variability in fish assemblage structure and recruitment in a freshwater-deprived estuary: the Coorong, Australia. *Marine and Freshwater Research* **61**, 1298–1312.

8.0 Appendices

Appendix 1.Environmental descriptors recorded

Location (description and GPS-WGS 84 datum, zone 54H), waterway, weather, land use, potential impacts and environmental characteristics were recorded for each sampling site to assist with the interpretation of results and future replication. Digital photos were taken of all sites. Environmental characteristics included details of aquatic and interlinked riparian condition under the following categories:

General descriptors: Habitat type (i.e. stream, wetland, instream dam).

- Pool size as an estimation of surface area.
- Bank slope (e.g. steep = 45º, vertical 90º).
- Depth (maximum and average).
- Substrate type (e.g. sand, gravel, mud).

Flow environment:

- A temporal measure of connectivity based on seasonal conditions and local landholder input (e.g. ephemeral, six months flow connection, or permanently connected), plus comments such as whether the area is spring fed.

Pool condition and flow:

A measure of water level in comparison to the normal bank level of a pool (e.g. concentrated, bank level, in flood) and recording of *Flow* at the time of sampling ranked relative to magnitude: low = <10 L/sec; medium 10-100 L/sec; high 100-200 L/sec; very high >200L/sec.

Contributions to cover (% of volume occupied and type):

- Submerged physical (e.g. snags, leaf litter, rock),
- Submerged biological (e.g. aquatic plants, *Chara*, other algae),
- Emergent (e.g. reeds, rushes and sedges, tea tree),
- Fringing vegetation within 2 metres of the waters edge (particular note of small amphibious species on the bank such as *Crassula*, *Centella*,*Ranunculus*).
- Canopy – measure of over hanging vegetation (shade),
- General surrounding terrestrial vegetation cover.

Water quality:

- TPS meters taken at 0.3m depth recording (a) temperature, (b) conductivity (k=10 probe, range 200-200,000$\mu S = \mu Scm^{-1}$), (c) pH, and (d) dissolved oxygen.
- Water transparency measured *in situ* against a white object with comments on contributions to low values such as natural tannin, colloids or algae.

Appendix 2.Sampling details

Project	Site Code	Date	Waterway	6m Seine reps	4m seine reps	Dip net	Large fyke reps	Small fyke reps	Double wing fyke reps	Larval fyke reps	Bait trap reps	Day observation
Drain L baseline 2011	SE11-12	17/08/2011	Drain L				2	2				
Drain L baseline 2011	SE11-19	7/09/2011	Drain L						3			
Drain L baseline 2011	SE11-20	7/09/2011	Lake Hawdon North				1	2	2			
Drain L baseline 2011	SE11-21	7/09/2011	Lake Hawdon North				1	2	2			
Drain L baseline 2011	SE11-22	8/09/2011	Lake Hawdon North				1	2	2			
Drain L baseline 2011	SE11-23	8/09/2011	Lake Hawdon North				1	2	2			
Drain L baseline 2011	SE11-26	26/09/2011	Drain L				2	2	2			
Drain L baseline 2011	SE11-27	27/09/2011	Reedy Creek			x						
Drain L baseline 2011	SE11-28	27/09/2011	Bray Drain				1	2	2			
Drain L baseline 2011	SE11-29	27/09/2011	Lake Hawdon South				2	2	2			
Drain L baseline 2011	SE11-30	28/09/2011	Reedy Creek				2	2	1		3	
Drain L baseline 2011	SE11-31	28/09/2011	Wilmont Drain				2	2	1		3	
Drain L baseline 2011	SE11-32	28/09/2011	Wilmont Drain				2	2	1		3	
Drain L baseline 2011	SE11-33	29/09/2011	Drain K				2	2				
Drain L baseline 2011	SE11-34	29/09/2011	Drain L				2	2				
Drain L baseline 2011	SE11-35	29/09/2011	Drain L				2	2	1			
Drain L baseline 2011	SE11-38	11/10/2011	Drain L				2	2	1			
Drain L baseline 2011	SE11-40	12/10/2011	Wilmont Drain				2	2	1			
Drain L baseline 2011	SE11-41	12/10/2011	Drain K				2	2				
Drain L baseline 2011	SE11-44	1/11/2011	Lake Hawdon South				2	2	2			
Drain L baseline 2011	SE11-45	2/11/2011	Reedy Creek								9	
Drain L baseline 2011	SE11-46	2/11/2011	Drain K			x						
Drain L baseline 2011	SE11-60	15/12/2011	Bray Drain			x						
Drain L baseline 2011	SE11-61	15/12/2011	Trib. Bray Drain			x						
Drain L baseline 2011	SE11-62	15/12/2011	Drain B31			x						
Drain L movement 2011	SE11-13	17/08/2011	Drain L						5			
Drain L movement 2011	SE11-14	17/08/2011	Drain L						2			
Drain L movement 2011	SE11-15	17/08/2011	Drain L						2			
Drain L movement 2011	SE11-16	5/09/2011	Drain L						4			
Drain L movement 2011	SE11-17	5/09/2011	Drain L						3			
Drain L movement 2011	SE11-18	5/09/2011	Drain L						3			
Drain L movement 2011	SE11-24	26/09/2011	Drain L						2			
Drain L movement 2011	SE11-25	26/09/2011	Drain L						2			
Drain L movement 2011	SE11-36	29/09/2011	Drain L						3			
Drain L movement 2011	SE11-37	11/10/2011	Drain L						2			
Drain L movement 2011	SE11-39	11/10/2011	Drain L						3			
Drain L movement 2011	SE11-42	1/11/2011	Drain L						2			
Drain L movement 2011	SE11-43	1/11/2011	Drain L						2			
Drain L movement 2011	SE11-47	14/12/2011	Drain L						2			
Drain L movement 2011	SE11-48	14/12/2011	Drain L						2			

Appendix 3.Opportunistic fauna records

Site Code	Waterway	Cherax	Paratya	Geocharax	FW crab (A lucustris)	Long Neck	Bell adults	Bell tadpoles	Other animals
SE11-12	Drain L	x			x	x			Mayfly, dragonfly,amphipod
SE11-19	Drain L			x					
SE11-20	Lake Hawdon North								Tadpoles, beetles, mites, shield shrimp
SE11-21	Lake Hawdon North	x							Tadpoles
SE11-22	Lake Hawdon North								Shield shrimp, tadpoles, beetles
SE11-23	Lake Hawdon North								
SE11-26	Drain L		x						
SE11-27	Reedy Creek								
SE11-28	Bray Drain	x							Tadpoles, frogs
SE11-29	Lake Hawdon South	x		x					Tadpoles, diving beetles
SE11-30	Reedy Creek					x			
SE11-31	Wilmont Drain	x		x					Dragonfly larvae
SE11-32	Wilmont Drain	x							Tadpoles, frogs
SE11-33	Drain K	x				x			Dragonfly larvae
SE11-34	Drain L	x							Adult frogs
SE11-35	Drain L								
SE11-38	Drain L								
SE11-40	Wilmont Drain	x		x					Striped marsh frog, leeches, tadpoles
SE11-41	Drain K								
SE11-44	Lake Hawdon South	x		x					Tadpoles, diving beetles, dragonfly larvae
SE11-45	Reedy Creek								Tadpoles, dragonfly
SE11-46	Drain K								
SE11-60	Bray Drain								Corixids, diving beetles
SE11-61	Trib. Bray Drain								Corixids, diving beetles
SE11-62	Drain B31								Corixids, diving beetles
SE11-13	Drain L								
SE11-14	Drain L				x				Needle bug
SE11-15	Drain L								Shore crab, estuarine prawns
SE11-16	Drain L								
SE11-17	Drain L				x				
SE11-18	Drain L								
SE11-24	Drain L								Estuarine shrimp
SE11-25	Drain L								
SE11-36	Drain L								
SE11-37	Drain L								
SE11-39	Drain L								
SE11-42	Drain L								
SE11-43	Drain L								
SE11-47	Drain L								
SE11-48	Drain L								

Appendix 4.Environmental data for 2011 sampling

Project	Site Code	Waterway	Depth max (m)	Flow	Subsurface physical %	Subsurface biological %	Emergent %	Edge vegetation %	Shade %	pH	Conductivity (µS/cm)	Temperature (°C)	Dissolved oxygen @0.2m (ppm)	Transparency (m)
Drain L baseline 2011	SE11-12	Drain L	1.0	High	15	20	10	50	0	7.6	2650	12.2	8.6	1.0
Drain L baseline 2011	SE11-19	Drain L	0.3	Low	10	1	5	50	5	8.2	3380	11.4	9.2	0.3
Drain L baseline 2011	SE11-20	Lake Hawdon North	0.4	None	10	15	70	0	0	8.6	5920	13.3	9.4	0.4
Drain L baseline 2011	SE11-21	Lake Hawdon North	0.5	None	5	20	10	40	0	8.7	5650	14.0	9.0	0.5
Drain L baseline 2011	SE11-22	Lake Hawdon North	0.3	None	5	30	0	0	0	8.9	7940	11.5	9.5	0.3
Drain L baseline 2011	SE11-23	Lake Hawdon North	0.3	None	5	20	0	10	0	8.6	8010	12.1	9.3	0.3
Drain L baseline 2011	SE11-26	Drain L	1.2	Medium	5	15	0	80	5	7.5	4970	16.1	9.1	1.2
Drain L baseline 2011	SE11-27	Reedy Creek	0.3	None	1	60	30	0	10	7.5	1830	20.5	6.7	0.3
Drain L baseline 2011	SE11-28	Bray Drain	0.5	Low	20	20	50	10	0	7.0	2100	12.9	2.5	0.5
Drain L baseline 2011	SE11-29	Lake Hawdon South	1.0	None	5	20	70	40	0	7.0	2800	13.8	8.4	1.0
Drain L baseline 2011	SE11-30	Reedy Creek	1.5	None	2	2	30	0	0	7.0	1930	13.3	8.4	1.5
Drain L baseline 2011	SE11-31	Wilmont Drain	0.6	Low	2	40	25	10	0	7.5	1800	12.6	8.9	0.6
Drain L baseline 2011	SE11-32	Wilmont Drain	0.6	Low	2	50	5	0	0	7.0	1755	13.3	9.2	0.6
Drain L baseline 2011	SE11-33	Drain K	1.0	Low	1	40	2	5	0	7.0	3320	12.2	4.0	1.0
Drain L baseline 2011	SE11-34	Drain L	1.1	Low	1	15	10	2	0	7.0	3290	11.9	7.3	1.1
Drain L baseline 2011	SE11-35	Drain L	1.0	Medium	1	40	10	2	1	7.0	3140	11.9	11.5	1.0
Drain L baseline 2011	SE11-38	Drain L	1.0	Medium	10	30	10	20	1	8.0	4590	14.1	8.9	1.0
Drain L baseline 2011	SE11-40	Wilmont Drain	1.3	Low	5	70	10	30	5	7.5	1860	15.5	5.4	1.3
Drain L baseline 2011	SE11-41	Drain K	1.3	Medium	5	30	15	10	10	8.0	3190	16.1	6.8	1.3
Drain L baseline 2011	SE11-44	Lake Hawdon South	0.6	None	5	20	60	10	0	7.7	2810	15.9	4.5	0.6
Drain L baseline 2011	SE11-45	Reedy Creek	0.2	None	5	5	80	50	5	7.6	5910	20.4	1.9	0.2
Drain L baseline 2011	SE11-46	Drain K	0.2	Low	10	10	0	20	0	7.9	4000	21.1	9.1	0.2
Drain L baseline 2011	SE11-60	Bray Drain	0.5	None	5	0	0	2	0	-	-	-	-	0.2
Drain L baseline 2011	SE11-61	Trib. Bray Drain	0.5	None	2	70	0	0	10	-	-	-	-	0.4
Drain L baseline 2011	SE11-62	Drain B31	0.7	None	2	0	0	1	0	-	-	-	-	0.2
Drain L movement 2011	SE11-13	Drain L	1.0	High	15	20	10	50	0	7.6	2650	12.2	8.6	1.0
Drain L movement 2011	SE11-14	Drain L	1.2	High	15	20	10	60	0	7.7	2740	12.5	9.4	1.2
Drain L movement 2011	SE11-15	Drain L	1.5	Medium	5	0	5	40	0	7.6	3990	13.1	9.4	1.5
Drain L movement 2011	SE11-16	Drain L	0.8	Medium	15	20	10	50	0	8.1	3190	11.1	8.5	0.8
Drain L movement 2011	SE11-17	Drain L	1.5	Medium	15	15	5	60	20	7.9	3140	13.2	8.7	1.5
Drain L movement 2011	SE11-18	Drain L	1.5	Medium	10	0	5	40	0	7.8	5320	11.9	8.5	1.5
Drain L movement 2011	SE11-24	Drain L	1.2	Medium	10	5	5	40	0	7.0	5070	12.6	9.4	1.2
Drain L movement 2011	SE11-25	Drain L	0.8	Medium	10	15	5	40	20	7.5	4110	13.7	9.8	0.8
Drain L movement 2011	SE11-36	Drain L	1.2	Medium	5	5	5	30	0	7.5	4400	12.7	7.9	1.2
Drain L movement 2011	SE11-37	Drain L	1.2	Medium	10	5	5	40	0	8.0	5480	12.3	8.9	1.2
Drain L movement 2011	SE11-39	Drain L	1.5	Medium	5	20	10	30	0	7.5	4490	13.2	8.9	1.5
Drain L movement 2011	SE11-42	Drain L	1.2	Low	5	10	5	40	0	8.7	7260	19.4	8.7	1.2
Drain L movement 2011	SE11-43	Drain L	1.2	Low	5	20	5	30	0	8.5	3510	18.5	7.1	1.2
Drain L movement 2011	SE11-47	Drain L	1.0	Low	5	10	5	25	5	8.4	8160	16.6	7.3	1.0
Drain L movement 2011	SE11-48	Drain L	1.0	Low	15	20	10	20	0	8.7	2980	16.9	7.9	1.0

Appendix 5.Other previous sampling by the authors in the Drain L catchment

Site Code	Date	Waterway	Location	Easting	Northing	Habitat type	Size	Pool condition	Depth max (m)	Flow	Subsurface physical %	Subsurface biological %	Emergent %	Edge vegetation %	Shade %	pH	Conductivity (µS/cm)	Temperature (°C)	Dissolved oxygen @0.2m (ppm)	Transparency (m)	Australian mudfish	Black bream	Common galaxias	Congolli	Dwarf galaxias	Lagoon goby	Pouched lamprey	Smallmouthed hardyhead	Southern pygmy perch	Western bluespot goby	Yelloweye mullet	No fish
SE10-37	18/09/2010	Bray Drain	Gauge weir	410420	5880195	Drain	Medium	Bank level	0.8	High	10	5	5	0	0	8.1	3550	14.5	9.9	0.1	96				2			21200	67			
SE10-36	18/09/2010	Bray Drain	At junction with Lake Hawdon	408898	5879589	Drain	Medium	Bank level	0.8	Low	5	5	10	20	0	8.2	3510	15.4	9.4	0.1	20		2		144			2540	78			
SE10-35	18/09/2010	Lake Hawdon South	Southern end (Almanda)	404493	5876722	Wetland	Large	Bank level	1.2	None	5	1	90	60	0	7.4	1970	14.1	7.7	>1.2	117				411			3	2			
SE10-34	17/09/2010	Drain L	Baxter Hill Road	410847	5890321	Drain	Large	Bank level	1.2	Medium	5	20	10	10	5	8.2	2220	14.0	3.9	>1.2			28	1	49		1	46	90		1	
SE10-33	17/09/2010	Lake Hawdon South	Northern end of wetland	405623	5882899	Wetland	Large	Bank level	0.8	None	5	0	90	50	0	7.5	2680	14.0	9.3	>0.8	29		3		140			19	96			
SE10-32	17/09/2010	Lake Hawdon South	Lake Hawdon connector	405468	5884867	Drain	Medium	Bank level	0.5	High	5	1	20	60	10	7.1	2630	12.5	9.9	0.5	5		9		216			108	130			
SE09-71	8/11/2009	Lake Hawdon South	Northern sedgelands	405623	5882899	Wetland	Open water	High level	0.4	None	0	0	85	30	0	-	3000	-	-	0.3	1				50							
SE09-62	5/11/2009	Reedy Creek-Wilmont Drain	Robe - Naracoorte Road	426511	5882515	Drain	Medium	Bank level	1.5	Seep	5	30	50	30	20	7.8	1579	16.6	-	0.5					210				2102			
SE09-58	5/11/2009	Bray Drain	Robe Road	418753	5876959	Drain	Small	Low level	0.6	Low	5	40	30	80	10	7.6	1880	14.5	2.2	0.6					214				7			
SE08-06	30/09/2008	Bray Drain	Robe Rd	418750	5876958	Drain	Small	Low level	0.6	Low	5	70	20	80	0	7.8	2000	12.4	8.9	0.5					21							
SE08-05	30/09/2008	Reedy Creek-Willmont Drain	Naracoorte Rd	426511	5882515	Drain	Medium	Bank level	1.5	None	2	40	40	30	0	8.6	1192	14.7	8.7	1.0					42							
SE08-04	30/09/2008	Drain L	Princess Hwy	418596	5895585	Drain	Small	Low level	0.6	Low	5	80	10	60	10	8.6	1860	16.1	14.4	0.8			5					5	43			
SE08-03	30/09/2008	Drain BR45	Princess Hwy	421249	5879940	Drain	Small	Low level	0.5	None	5	20	20	30	0	7.3	2890	11.7	6.9	0.5									26			
SE03-14	13/10/2003	Bray Drain	Robe Naracoorte Road	418800	5876950	Drain	Small	Bank level	0.8	Low flow	0	30	60	20	0	8.9	1570	15.1	-	0.6					20				1			
SE02-121	3/12/2002	Lake Battye	Channel downstream of lake	392508	5885248	Lake	Large	Bank level	1.0	None	-	-	-	-	-	-	-	-	-	-		28				1		5			2	
SE02-120	3/12/2002	Lake Nunan	Channel downstream from lake	392028	5885553	Lake	Medium	Bank level	1.0	None	-	-	-	-	-	-	-	-	-	-		3				1		15		1	12	
SE02-119	3/12/2002	Battye Lake	Lake edge	393063	5884882	Lake	Open water	Bank level	1.0	None	30	0	0	10	0	9.3	3920	19.0	-	0.4			30			17		5		40	12	
SE02-118	3/12/2002	Lake Nunan	Southern edge of Lake	392306	5885233	Lake	Open water	Bank level	1.2	None	10	10	5	60	0	9.2	4300	21.0	-	2.0				4		15		61		46		
SE02-99	2/07/2002	Biscuit Flat Drain	Robe Naracoorte Road	416500	5875500	Drain	Small	Concentrated pool	0.2	None	0	0	10	10	-	8.3	7400	14.1	-	0.1												x
SE02-101	2/07/2002	Earth Quake Springs Drain	Princess Hwy	421300	5885300	Drain	Small	Normal level	0.5	None	0	60	10	10	-	7.6	1200	13.0	-	0.5				1					30			
SE02-100	2/07/2002	Bray Drain	Robe Naracoorte Road	418767	5876980	Drain	Small	Bank level	0.5	Low flow	0	20	40	60	-	8.7	2130	11.8	-	0.3					2				2			
SE02-61	19/06/2002	Drain L	Baxter Hill Rd	410828	5890381	Drain	Large	Concentrated pool	0.2	None	0	40	10	30	-	7.5	4000	10.7	-	0.2								20				
SE02-60	19/06/2002	Drain L	Just below Lake Hawdon North	400200	5887000	Drain	Large	Normal level	1.5	None	0	60	10	10	-	8.4	3070	8.5	-	1.0								1	5			
SE02-59	19/06/2002	Wilmot Drain	Old Robe Naracoorte Road	414043	5890983	Drain	Medium	Concentrated pool	0.2	None	0	30	10	20	-	-	-	-	-	0.2									2			
SE02-58	19/06/2002	Drain K	West Avenue Road	424513	5900756	Drain	Medium	Bank level	1.0	Low flow	0	80	5	10	-	8.2	2980	7.9	-	1.0								10	13			
SE02-57	19/06/2002	Avenue Flat - K Drain	Old Robe Naracoorte Road	429361	5899472	Drain	Small	Concentrated pool	0.6	None	0	30	0	10	-	-	-	-	-	0.1												x
SE02-55	19/06/2002	Wilmot Drain	Robe Naracoorte Road xing	430413	5886129	Drain	Medium	Concentrated pool	0.3	None	0	5	10	30	-	8.6	5310	9.0	-	0.1												x
SE02-53	18/06/2002	Drain BR44	Princess Hwy xing	421300	5879000	Drain	Small	Normal level	0.5	None	0	10	10	20	-	-	-	-	-	0.1												x
SE02-52	18/06/2002	Drain BR45	Princess Hwy xing	421243	5879983	Drain	Small	Concentrated pool	0.4	None	0	60	10	30	-	7.4	3000	10.0	-	0.4					1				30			
SE02-50	18/06/2002	Lake Battyle	Southern shore	392546	5885032	Lake	Large	Normal level	1.0	None	0	40	10	50	-	-	9160	-	-	0.5			4							50		
SE02-54	17/06/2002	Reedy Creek Wilmot Drain	Robe Naracoorte Rd xing	426488	5882529	Drain	Medium	Normal level	0.5	None	0	70	10	10	-	8.1	1820	10.7	-	0.4					1				40			
SE02-22	16/01/2002	Unnamed swamp	Swamp (tea tree)	406000	5895500	Swamp	Medium	Dry	0.0	None	0	0	0	60	-	-	-	-	-	0												x