ECOLOGY OF AQUATIC FAUNA IN THE SERPENTINE RIVER IN RESPONSE TO LAND USE PRACTICES & RECOMMENDATIONS FOR IMPROVING FRESHWATER ECOSYSTEM HEALTH

Report to:

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Centre for Fish & Fisheries Research
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Frontispiece: from top to bottom - Western minnow (Galaxias occidentalis) photo: Mark Allen; Serpentine River within Lowland’s conservation block (Bush Forever site 368) photo: Michael Klunzinger; Carter’s freshwater mussel (Westralunio carteri) photo: Michael Klunzinger.
Summary

The Serpentine River is situated 60 km south of Perth, Western Australia, with headwater streams converging and flowing in the Serpentine Dam above the Darling Scarp, which continues westward through the Pipehead Dam, over Serpentine Falls in an uncleared national park, through agricultural land with a brief interruption of uncleared bush within Lowlands Bush Forever Site 368 before flowing through Lowlands/Riverlea cattle property and turning southward where it converges with Birrega Drain. Birrega Drain flows into a series of lakes that empty into the Peel-Harvey Estuary. This project addressed three investment priorities from the WA State NRM Program 2009/10 funding round including 1) Biodiversity, 2) Biosecurity and 3) Water Quality within the Serpentine River in Lowlands Bush Forever Site 368, Lowlands/Riverlea livestock properties and the Birrega Drain.

1) Biodiversity:
- Baseline surveys revealed that native freshwater fishes, crayfishes and well-developed tadpoles were generally more abundant in the heavily vegetated areas with complex habitats which included sandy/silty sediments overlain with woody debris, macrophytes and overhanging riparian vegetation.
- Degraded sites, which included two gauging stations and areas formerly impacted by cattle housed fewer of the Vulnerable Priority 4 Carter’s Freshwater Mussel (Westralunio carteri) and native fishes and had an increased density of feral fishes as well as the presence of feral crayfishes (The Yabby: Cherax destructor).
- Glochidia (larval W. carteri) were more prevalent in native than feral fish and were more prevalent within the Bush Forever sites which contained more freshwater mussels/m² than the degraded sites.

2) Biosecurity:
- The feral Eastern Gambusia dominated the fish fauna and reached plague proportions in the late spring and early summer, more so in the degraded sites downstream of the Lowlands Gauging Station, but upstream habitats also housed the pest species in reasonably large numbers. This species was probably responsible for the extreme fin nipping observed on juvenile Western Pygmy Perch and may have been responsible for the relative rarity of this native fish in the area.
- Goldfish were restricted primarily to a turbid breeding pool in the Birrega Drain and below the Lowlands Gauging Station weir within the Serpentine River. Electro-fishing and seine netting was successful in reducing the species in terms of both subsequent size captures and number of fishes captured.
3) Water Quality:

- The exceptionally dry year in 2010 adversely affected native freshwater fauna such as Carter’s Freshwater Mussel (*Westralunio carteri*) populations through mortality from extreme drying within the Birrega Drain, but populations within the Lowlands Bush Forever Site 368 were more resilient due to up to seven degrees (°C) cooler water temperatures, moist sediments and shading from riparian vegetation and woody debris.

- The Serpentine River remained fresh (<1.0 ppt salinity), but the Birrega Drain became salinised (>1.0 ppt salinity) with the onset of hot, dry weather and evaporation. Had salinities risen much above 2.0 ppt, more Carter’s Freshwater Mussels could have perished.

- Regular water sampling revealed that Total Phosphorus concentrations rose as water levels receded and indicated that the system is essentially eutrophic for much of the year.

- During rainfall events, the water from the Serpentine River leaving Lowlands was visually far less turbid than that of the Birrega Drain.

- Flow was noticeably greater in 2011 than in the previous year which probably assisted with more prevalent aquatic macrophytes such as *Triglochin* and the upstream migration of gravid native freshwater fishes in August 2011.

Recommendations

1) Install a bridge at the cattle crossing over Serpentine River on the Lowlands/Riverlea property to reduce erosion, sedimentation and nutrient inputs from cattle and enhance the river with woody debris to encourage native freshwater fish and freshwater mussel re-colonisation and follow-up monitoring.

2) Re-plant native riparian vegetation, especially shading sedge, shrubs and trees in degraded sites including the cattle crossing (post bridge construction) and impacted areas downstream from Lowlands Gauging Station and within the Birrega Drain.

3) Re-planting native riparian vegetation and trees lining the Birrega Drain and placing more large woody debris within the stream should allow recolonisation of native freshwater fish, crayfish, mussels and other fauna and improve water quality by reducing ambient and thus water temperature as well as surface water evaporation.

4) Providing adequate supplies of good freshwater, low in contaminants and chemicals, particularly during times of hot, dry weather will help maintain aquatic ecosystem integrity through flows that will allow the system to remain perennial, maintain deep refuge pools and maintain water supplies for river users.
Introduction

Study area

The Serpentine River, located 60 km south of Perth, WA, drains into the Peel-Harvey Estuary. The first order streams in the upper catchment converge and flow into the Serpentine Dam, which was completed in 1961. Below the Serpentine Dam is the Pipehead Dam which was completed in 1957. The Serpentine River continues to flow through Lowlands (Bush Forever Site 368) and Riverlea properties (Figure 1) before converging with the channelized Birrega Drain which flows into a series of lakes that empty into the Peel-Harvey Estuary. The study area of the Serpentine River and Birrega Drain is classified as freshwater with salinities typically less than 1 g/L (Pen 1999). The study area includes Lowlands Bush Forever site 368, Riverlea and Lowlands cattle properties and a short section of the Birrega Drain adjacent to Dog Hill Gauging Station (AWRC 614030).

Bush Forever

Bush Forever is a strategic plan to protect ca. 51,200 hectares of regionally significant vegetation complexes of the natural vegetation of the Swan Coastal Plain, or, if altered, still represents the structure and floristics of natural vegetation which provides the necessary habitat for native fauna (WAPC 2000). Bush Forever site 368 is located within the Eastern Block of the Lowlands property, Peel Estate, which is owned by the Richardson family and managed as a conservation area by Lowlands Conservation Association.
Figure 1. Sites sampled for freshwater fishes, crayfishes and mussels in the Serpentine River catchment during this study. Images adapted from GoogleMaps™. Red represents ‘Degraded’ sites and green represents ‘Natural’ sites.
Aquatic freshwater biodiversity of south-western Australia

Freshwater fishes

The freshwater fishes of the South West Coast Drainage Division of Western Australia (WA) belong to four families and are few in terms of number of species, but highly endemic with nine of the 11 being found nowhere else (Morgan et al. 1998, Allen et al. 2002; Morgan et al. 2011). In fact, this drainage division has the highest proportion of endemic freshwater fishes of any of Australia’s 11 major drainage divisions (Morgan et al. 1998). None of the south-west freshwater fishes is shared with the other two WA divisions; the Pilbara and Kimberley (Morgan et al. 1998, 2011; Allen et al. 2002). Two species are listed federally under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act 1999): the Western Trout Minnow (Galaxias truttaceus), Australia’s only Critically Endangered freshwater fish, and Balston’s Pygmy Perch (Nannatherina balstoni) listed as Vulnerable. A few species, including those mentioned above and the Western Mud Minnow (Galaxiella mundu), are listed as Schedule 1 (rare or likely to become extinct and in need of special protection) under State legislation (Wildlife Conservation Act 1950).

While the fishes of the Peel-Harvey estuaries have been well studied (e.g. Potter et al. 1983, Lenanton et al. 1984, Loneragan et al. 1986, McComb & Humphries 1992, Potter & Hyndes 1994, Lavery et al. 1999, Veale et al. 2010), the freshwater fishes of its major tributaries, namely the Serpentine River, have received far less research attention. Apart from a technical report by Davis et al. (1988), there appears to have been no focused studies on the freshwater fishes and other fauna in the Serpentine River. Elsewhere in SWWA however, a large body of research has done much to increase our understanding of the biology and ecology of the freshwater fishes and crayfishes of the region (Morgan et al. 2011 and references therein).

Recent studies have quantified the salinity tolerances of some of SWWA’s endemic freshwater fish species and found that Western Minnow (Galaxias occidentalis) and Western Pygmy Perch (Nannoperca vittata) are negatively affected by salinities greater than 14 g/L and the federally listed Vulnerable Balston’s Pygmy Perch (Nannatherina balstoni) is more sensitive to salt with salinities above 8 g/L producing ill effects (Beatty et al. 2011). Beatty et al. (2010) showed the importance of groundwater contribution in maintaining freshwater fish populations.

The presence of an introduced parasitic crustacean Lernaea on freshwater fishes in the Canning River by Marina et al. (2008) also raises species conservation concerns. Watts et al. (1995) examined the genetics and morphology of the Western Minnow (Galaxias occidentalis). There are also a number of unpublished technical reports and theses on fishes in the region. For the Swan Coastal Plain some examples include studies reported by Aquatic Research Laboratory (1988), Morrison (1988), Hewitt (1992), Bamford et al. (1998), Morrissy (2000), Morgan et al.
In light of the lack of published data and/or technical reports detailing the freshwater fishes of the Serpentine River, it is important to note that there is a large unpublished data set of fishes in the ‘freshwaters’ of the catchments of SWWA (>1800 sites), which is maintained by the Freshwater Fish Group in the Centre for Fish & Fisheries Research, Murdoch University.

**Freshwater crayfishes**

Each of the 11 freshwater crayfish species is endemic to the south-west region. This includes six species in the genus *Cherax*; the most widely distributed freshwater crayfish genus in Australia (Austin & Knott 1996; Austin & Ryan 2002). The long period of separation of south-western Australia from the rest of the continent, has led to the native Western Australian *Cherax* species being monophyletic (Crandall et al. 1999). The *Cherax* species are perhaps best known for the iconic Smooth Marron (*Cherax cainii*), a favoured recreational species managed by the WA Department of Fisheries, and a delicacy for seafood connoisseurs. The species is farmed by licensed WA aquaculturalists, sold locally and exported live to North Asian and European markets (Alonso 2009). Other species include the more common and widespread Gilgie (*Cherax quinquecarinatus*) and Koonac (*Cherax preissii*) as well as the less common Restricted Gilgie (*Cherax crassimanus*) from Margaret River to Denmark and Glossy Koonac (*Cherax glaber*), restricted to the extreme south-western corner between Dunsborough and Windy Harbour (Morgan et al. 2011). Listed as Critically Endangered under the EPBC Act 1999, the Hairy Marron (*Cherax tenuimanus*) is now found only in the upper reaches of Margaret River (TSSC 2004; Morgan et al. 2011). There are also five native species of obligate burrowing freshwater crayfish that belong to the endemic genus *Engaewa* (Horwitz & Adams 2000), with three of these recently being listed under the EPBC Act 1999 as Critically Endangered (Dunsborough Burrowing Crayfish (*Engaewa reducta*) and Margaret River Burrowing Crayfish (*Engaewa pseudoreducta*)) or Endangered (*Engaewa walpolea*). Another decapod crustacean, the South-west Glass Shrimp (*Palaemonetes australis*) is common and widespread throughout the region, an important food source for other aquatic species (Horwitz 1995; Morgan et al. 2011) and has been suggested as being important in the release of glochidia from freshwater mussels (Klunzinger 2011).
Freshwater mussels

Freshwater mussels are benthic bivalve molluscs, which play important functional roles in aquatic ecosystems through biological filtration of water, contributing to clarity; through their burrowing movements, they oxygenate sediments; their shells provide structure and refuge for other organisms such as juvenile fishes and crayfishes; they provide food for predators and were traditionally used as a food source by indigenous peoples (e.g. McNally 1960; Vaughn and Hakenkamp 2001; Walker et al. 2001; Strayer 2008; Bettink 2011; Morgan et al. 2011). Freshwater mussels are sensitive to environmental changes (Ponder & Walker 2003) and, like freshwater fish fauna, can be considered important bioindicators of aquatic ecosystem condition.

The region’s only freshwater mussel: Carter’s Freshwater Mussel (*Westralunio carteri*) is endemic to the south-west (McMichael & Hiscock 1958; Walker 2004). This bivalve has a unique life cycle in which its larvae, known as ‘glochidia’ must attach to a host, which is generally a fish to complete its development to the juvenile mussel stage. This interaction is thought to serve as a dispersal mechanism (Bauer & Wächtler 2001; Strayer 2008). Until recently, little was known of the species biology, reproductive development, ecology and its host fishes (Lymbery et al. 2008; Klunzinger et al. 2011a). Kendrick (1976) documented the disappearance of *W. carteri* from the Avon River, presumably as a result of secondary salinisation. In recent years, the species has undergone population contractions in parts of its range, also presumed to be linked with salinisation of waterways within the south-west agricultural zones (Keighery et al. 2004) and was listed as ‘Vulnerable’ under international conservation criteria (IUCN 2011). The species is categorized as ‘Priority 4’ fauna under an interdepartmental listing by the Western Australian Department of Environment and Conservation (DEC 2011), meaning that the species is in need of monitoring. Recent work by Klunzinger et al. (2010) has shown that the species is intolerant of salinities above 3.0 g/L, dehydration can cause localized population reductions (Klunzinger et al. 2011b) and field reports have shown that low dissolved oxygen (<20%) also causes mortality (Klunzinger et al., unpublished data).

Fauna declines

These aquatic fauna have undergone major declines in population range due to a combination of habitat change, such as riparian vegetation degradation and secondary salinisation of inland reaches of the major rivers (Morgan et al. 1998, 2003) and impacts of introduced species such as Eastern Gambusia (*Gambusia holbrooki*) and Goldfish (*Carassius auratus*) (e.g. Morgan et al. 1998, 2002, 2004, Gill et al. 1999). The major impact on the distribution of these populations
has been dryland secondary salinisation of inland areas, which has resulted in only ~44% of flow in the largest 30 rivers in the south-west of WA being fresh (Mayer et al. 2005).

Exacerbating these impacts on our unique aquatic fauna is the continuing decline in rainfall. Average annual rainfall in the south-west of WA has declined by 10% since 1970. The ranges of predicted future average annual rainfall declines are: by 2030 between 3-22% and 0-22% for the extreme south-west and the remainder of the region, respectively (Suppiah et al. 2007). By 2070, models predict annual average rainfall to decline by 7-70% and 0-70% for the extreme south-west and the remainder of the region, respectively (Suppiah et al. 2007). The reduction in stream flow and groundwater recharge due to the continued decline in rainfall has considerable implications in sustainably managing surface and groundwater resources.

The freshwater fishes of the region have recently been identified as important bioindicators of water quality decline (such as salinisation, Beatty et al. 2011) and, being at the top of the aquatic food chain, play an important role in the structuring of aquatic food webs (Beatty & Morgan 2010). Freshwater mussels have also been shown to be bioindicators of aquatic ecosystem condition for their propensity to bioaccumulate contaminants, are relatively long lived (>20 years), limited mobility and are sensitive to environmental changes in water quality (Storey & Edward 1989; Mutvei & Westermark 2001). These freshwater fauna should, therefore, be a key consideration in developing and monitoring the success of river management plans.

**Feral freshwater species**

Several ‘waves’ of non-endemic (feral) fish introductions to the south-west have occurred since the 1870s (Figure 2). Brown Trout (*Salmo trutta*), Rainbow Trout (*Onchorhynchus mykiss*), Silver Perch (*Bidyanus bidyanus*) and Redfin Perch (*Perca fluviatilis*) were introduced as game fish between the 1870s and early 1900s. Several populations of these large predatory fishes have established self-maintaining populations within freshwater rivers, lakes and reservoirs of the region and government stocking programs often continue to this day (Morgan et al. 2004, 2011). These feral species have been shown to deplete local stocks of the much smaller endemic native freshwater fishes and can have a devastating effect on the iconic Marron (see Morgan et al. 2004, Tay et al. 2007).

During the 1930’s, Eastern Gambusia were introduced in great numbers to control mosquito infestations throughout Australia by the government health department with the aim to reduce mosquito-borne human and livestock diseases; it was thought that the tremendous breeding capacity of this species, bearing live offspring, would control mosquito populations (Morgan et al. 2004). In reality, native freshwater fishes, such as Western Pygmy Perch have been shown to be more effective in control nuisance insects (Gill et al. 1999). Gambusia are
very territorial and often outcompete native species for habitat and through their aggressive habit of fin-nipping (Morgan et al. 2004).

Since the 1970’s, the new wave of feral fishes has been steadily increasing with the introduction of ornamental fishes such as Goldfish and Koi Carp (*Cyprinus carpio*) and, more recently, the introduction of Pearl Cichlid (*Geophagus brasiliensis*), amongst others. These fishes negatively impact aquatic habitats through bioturbation of sediments, stimulation of cyanobacterial growth and re-suspension of nutrients, preying on native molluscs, native fish eggs and native fish larvae (Morgan et al. 2004; de Graaf & Coutts 2010; Beatty et al. 2010a).

The freshwater crayfish Yabby (*Cherax destructor*) was introduced into WA as an aquaculture species, but has escaped from farm dams into local waterways where they have taken up residence and often out compete other native freshwater crayfishes such as Marron or Gilgies due to their life-history traits and greater tolerance to environmental water quality extremes, such as higher temperatures and hypoxic conditions during summer (Morrissy et al. 1984; Horwitz 1990; Beatty et al. 2005a).

**Figure 2.** History of exotic fish species introductions in Western Australia (1870-2010).
Aims of the study

Given that very little is known about the aquatic fauna of the lower Serpentine River, the current study aimed to collect information required to assess the current and future health of the aquatic ecosystems of this river. The aims of this study, therefore, were to:

- Establish and classify habitats present within the study area.
- Determine the distribution and population structure of fish, decapods and freshwater mussels in Lowlands Bush Forever Site 368, Riverlea and Lowlands agricultural properties.
- Monitor water quality, fishes, decapods and freshwater mussels and to quantify any differences in these fauna between sites.
- Eradicate feral fish species.
- Identify priorities for management adaptation.

*Carter’s freshwater mussel and Western pygmy perch, two of south-western Australia’s freshwater bioindicators of river health.*

(photographs M. Klunzinger and M. Allen)
Methodology

Sampling sites

A total of six sites were assessed using qualitative (presence/absence) and quantitative (abundance and density) methods to provide details of the freshwater fishes, crayfishes and mussels within a 7 km section of the Serpentine River within Lowlands Bush Forever Site 368 and Riverlea and Lowlands cattle grazing properties as well as a section of the Birrega Drain (Figure 1). When sites were accessible, sampling occurred every 4-8 weeks from June 2010 to September 2011. Sampling was discontinued when either (1) water levels were too high and flow was too strong or (2) the river was too dried out to sample. Riparian vegetation surveys were used to assist in site classifications.

In order to provide an overall summary of the previously known distribution of fishes in the Serpentine catchment, the Freshwater Fish Group (Murdoch University) distributional database was accessed and the distribution of each species in this catchment were then mapped and included in the species synopses. Additional information was accessed from Western Australian Museum records and technical reports from other researchers.

Habitat characterisation and riparian vegetation surveys

Habitats within each site were subjectively characterised as either ‘Degraded’ or ‘Natural’. Degraded sites were those which were heavily influenced by disturbance from livestock or human activity. Natural sites were those in which disturbance was less evident and habitats more closely resembled a typical undisturbed riparian zone. We are careful to point out, however, that no site was truly undisturbed because they had, at one time or another, been either impacted by human activity and/or influenced by livestock at some point in the family history of the property (see appendix for examples).

Baseline information was collected on the riparian vegetation communities at the six sites along the Serpentine River and Birrega Drain. An approximate percentage cover of vegetation comprising the over-, middle- and under-storey for a distance up to 20 metres either side of the stream line was estimated visually for each site and the most dominant species comprising each vegetation layer recorded. In cases where identification of taxa could not be determined on site, a voucher specimen was collected, pressed and dried for subsequent identification at the Western Australian Herbarium using the collection and various botanical identification references (e.g. Marchant 1987, Wheeler et al. 2002, Hussey & Keighery 2007).
Freshwater fish and crayfish sampling

A variety of sampling techniques were deployed during the study, depending on the type of in-stream habitat present at each site. The use of such a variety of specialised sampling techniques helped to ensure that all species present at each site were recorded. Fyke nets (0.8 m height, 5 m wide wings, 1.2 m wide opening, 5 m long pocket with two funnels all comprised of 2 mm woven mesh) were set at a number of sites for a 24 hr period, ensuring an adequate proportion of the funnel was above the water surface to ensure survival of any incidentally captured air-breathing animals such as reptiles, birds and mammals (Figure 3). A Smith-Root (Model LR20) backpack electro-fisher were also employed to capture fishes to estimate fish density and was the most effective methods to capture feral fishes, which are often under-represented in fyke net captures (Figure 3). Fishes were measured for total length (TL) and crayfishes were measured for orbital carapace length (OCL) (see Figures 4 and 5). Where possible, the sex and reproductive status of fishes and crayfishes was determined by external examination.

Sub-samples of fishes from each site were transported live in aerated eskies containing river water to the laboratory and then euthanized with an overdose of AQUI-S™ and examined microscopically for the presence of glochidia attached to the fins and gills during November, December 2011 and January and September 2011. Before this study, nothing was known of the host fishes of this Vulnerable, P4 freshwater mussel.

Michael Klunzinger checking fyke nets at Rapids Rd; Photo: Stefania Basile.
Figure 3. Methods used to capture fishes in the study area. (A) Electro-fishing. Dr Stephen Beatty (left) and James Keleher, BSc[Hons] (right), Murdoch University. (B) Fyke nets (upstream movement [white arrow], downstream movement [black arrow]). Notice spaces above water line that form pockets for air-breathing animals that may be inadvertently captured.
Figure 4. Orbital Carapace Length (OCL) of freshwater crayfish (Gilgie – *Cherax quinquecarinatus* shown here).
**Figure 5.** Total Length (TL) of fish measured using a measuring board with ruler. (A) Nightfish – *Bostockia porosa*. (B) Freshwater cobbler – *Tandanus bostocki*.
Freshwater mussel sampling

At each site, a 50 m stretch of stream was visually examined for freshwater mussels from the water surface or feeling for mussels by hand when water clarity was poor. To determine the relative density of freshwater mussels, 10 x 1 m² quadrats were randomly placed on the stream bed at each site. Quadrats were constructed of 15 mm diameter round PVC tubing and open elbows. The number of mussels in each quadrat were then counted to estimate population density, as recommended by Strayer & Smith (2003). At each site, we recorded substrate type on the river bottom (rock, gravel, sand, mud, silt and/or detritus, woody debris, etc.). For each mussel collected from the quadrats, the maximum length (ML), maximum height (MH) and width (W) of the shell was measured with vernier callipers to the nearest 0.01 mm (Figure 6). Mussels were identified to species level using taxonomic keys of McMichael & Hiscock (1958) and Walker (2004). The majority of mussels were released after being measured, with a small number retained for future genetic analyses. Using these measurements, Maximum Height Index (MHI) and Shell Obesity Index (WLI) according to McMichael & Hiscock (1958) was derived from the following formulas:

\[ MHI = \frac{MH}{ML} \times 100 \quad \text{and} \quad WLI = \frac{W}{ML} \times 100. \]

Fish that were captured in fyke nets and through electro-fishing were examined for glochidial cysts, which appeared as small, white, bladder-like cysts on fish epithelial tissue. Glochidia prevalence (GP) was calculated as a percentage of fish infected of the total number of each individual fish species examined. Glochidia intensity (GI) was calculated by counting the number of cysts on each infected fish.

Water quality sampling methods

Physico-chemical parameters of water quality (temperature (°C), pH, dissolved oxygen (DO as % and ppm), NaCl concentration (ppt), total dissolved solids (TDS as ppt) and conductivity (µS/cm)) were measured using an Oakton™ PCD650 waterproof portable multimeter at three locations at each site and a mean and standard error (SE) determined on each sampling occasion. Additionally, water samples (200 mL) were collected from a depth of ca. 200 mm below the surface before entering the water at each site on each sampling occasion from June 2010 to February 2011. Water samples were subsequently analysed for total phosphorus (tP) at Murdoch University’s Marine and Freshwater Research Laboratory (MAFRL) as an indicator element according to trigger values under ANZECC guidelines for freshwater ecosystem health (ANZECC & ARMCANZ 2000).
Statistical Analysis

Mapping of faunal distributions was undertaken using MapInfo. Graphical and statistical analysis of the fish, decapods and mussel abundance, densities, and length-frequencies were undertaken using MS Excel®, JMP®4 and SigmaPlot®11.0. Baseline information was collected on the riparian vegetation communities at six sites along the Serpentine River.

An approximate percentage cover of vegetation comprising the over-, middle- and under-storey for a distance up to 20 metres either side of the stream line was estimated visually for each site and the most dominant species comprising each vegetation layer recorded. In cases where identification of taxa could not be determined on site, a voucher specimen was collected, pressed and dried for subsequent identification at the Western Australian Herbarium using the collection and various botanical identification references (e.g. Marchant 1987, Wheeler et al. 2002, Hussey & Keighery 2007). Differences in riparian vegetation among sampling sites were tested using methodology from Lymbery et al. (2003).

For each fish species at each sampling site and for each fish species over all sampling sites, glochidia prevalence (percentage of fish infested) and mean intensity (number of glochidia per infested fish) was calculated. Ninety five percent confidence limits were calculated for prevalence, assuming a binomial distribution and intensity, from 2,000 bootstrap replications, using the software Quantitative Parasitology 3.0 (Rozsa et al. 2000). Differences in prevalence among fish species or sampling sites were tested by Chi-square analysis and differences in intensity by a non-parametric Kruskal-Wallis test. The relationships of fish species among sampling sites for peak glochidia prevalence and intensity were tested by Regression Analysis.

Figure 6  Morphological measurements of freshwater mussels (from McMichael & Hiscock 1958).
Results and discussion

Habitat characterisation and riparian vegetation surveys

For the purpose of this study, sites were classified as either ‘Degraded’ or ‘Natural’. Canopy, middlestorey and understorey species composition and percentage of cover of riparian vegetation were the primary factors used to classify each site.

‘Degraded’ sites

1) Dog Hill Gauging Station

This lowermost section of the Serpentine River was highly degraded. There was a large human-made levee on the side of the river where the gauging station was built and the stream bed itself has been lined with rock in parts. Remnant pools are extremely turbid and sedimented. The overstorey was sparse (~ 10% canopy cover) and dominated by Flooded Gum (*Eucalyptus rudis*). Other tree species included Swamp Sheoak (*Casuarina obesa*) and Swamp Paperbark (*Melaleuca rhaphiophylla*). The middlestorey was also sparse (~ 25% cover) with isolated occurrences of River Astartea (*Astartea leptophylla*), Robin Red Breast (*Melaleuca lateritia*) and Stinkwood (*Jacksonia sternbergiana*). The continuous understorey (> 85% cover) consisted mostly of weeds, the most common of which were Water Couch (*Paspalum dilatatum*) at the edge of the river, and Watsonia (*Watsonia* sp.) and Perennial Veldtgrass (*Ehrharta calycinus*) further up the bank. A number of sedges, mostly invasive weed species, occurred in the riparian zone such as Scaly Sedge (*Cyperus tenuiflorus*), *Cyperus congestus*, and *Juncus microcephalus*. Large thickets of the native Jointed Twig-rush (*Baumea articulata*) also occurred on the margins of the river at this site.

2) Serpentine River - Birrega Drain Confluence

This degraded site abuts extensive cleared land beyond the banks of the river on either side. The riparian zone was fenced off from stock and the overstorey was relatively intact (~ 60% canopy cover) being dominated by Flooded Gum (*Eucalyptus rudis*) and Swamp Paperbark (*Melaleuca rhaphiophylla*). However, the middlestorey was very sparse (< 10% cover) and represented by a solitary species: River Astartea (*Astartea leptophylla*). The understorey at this site was somewhat patchy (~ 65% cover) and again dominated by weeds such as Watsonia (*Watsonia* sp.), Water Couch (*Paspalum dilatatum*), *Cyperus congestus*, Common Rush (*Juncus usitatus*), and the herb *Grammatotheca bergiana*. There was considerable bank erosion at this site from vehicles crossing the stream.

3) Lowlands Gauging Station

This was another degraded site, similar floristically to the previous site. The overstorey was patchy (~ 40% canopy cover) with Flooded Gum (*E. rudis*) and Swamp Paperbark (*M. rhaphiophylla*) and the middlestorey was virtually non-existent (< 5% cover), with only isolated taller thickets of Common Rush (*Juncus usitatus*). The dense (~ 70% cover), weedy understorey was dominated by Water Couch (*Paspalum dilatatum*), *Cyperus congestus*, Common Joyweed (*Alternanthera nodiflora*), and other weed...
grass species (Poaceae). There was extensive evidence of bank collapse and erosion on both sides of the river at this site. It was used as a stock watering point but the riparian zone is mostly fenced off. A large section of riparian zone was undergoing revegetation at this site but most seedlings did not survive the extremely hot and dry summer conditions.

‘Natural’ sites

4) Coffee Rocks

This site was located on a part of the Lowlands property that was isolated from livestock so was in much better condition than previous sites, with an intact overstorey. The overstorey again consisted of Flooded Gum (E. rudis) and Swamp Paperbark (M. rhaphiophylla) and was fairly continuous (> 85% canopy cover). The middlestorey was dense (~ 60% cover) and more diverse than the downstream sites. Common species in this vegetation layer were River Astartea (A. leptophylla), Spreading Sword-sedge (Lepidosperma effusum), and Bracken Fern (Pteridium esculentum). Weeds predominated in the patchy understory (~ 30% cover) with Water Couch (P. dilatatum), Common Rush (Juncus usitatus), and Cyperus congestus most common near the water’s edge and Perrenial Veldtgrass (E. calycinus) and Watsonia (Watsonia sp.) occurred further up the bank. Isolated clumps of the native aquatic plant Water Ribbons (Triglochin linearis) occurred at this site.

5) Horse Drink

This site, located near the old Lowlands homestead, had an intact overstorey (> 85% canopy cover) dominated by Flooded Gum (E. rudis) and Swamp Paperbark (M. rhaphiophylla). The middlestorey was patchy (~ 40% cover) but was notable for the occurrence of the Priority 4 listed taxa Parsonsia diaphanophleba a woody climber. Other common species were River Astartea (A. leptophylla) and the exotics: Common Rush (Juncus usitatus) and Tall Fleabane (Conyza sumatrensis). The understory was patchy (~ 30% cover) and dominated by weeds such as Water Couch (P. dilatatum), Cyperus congestus, Grammatotheca bergiana, and Pennyroyal (Mentha pulegium). Water Ribbons (Triglochin linearis) occurred in the stream and at the water’s edge.

6) Lowlands Forest

This site was located uppermost in the catchment of all sites sampled during the study and was very similar floristically to Horse Drink with a mostly intact overstorey. The overstorey consisted of Flooded Gum (E. rudis) and Swamp Paperbark (M. rhaphiophylla) and was almost continuous (~ 70% canopy cover). The middlestorey was patchy (~ 40% cover) and featured a mix of native species such as River Astartea (A. leptophylla), Orange Wattle (Acacia saligna), Bracken Fern (Pteridium esculentum), Parsonsia diaphanophleba and introduced weeds like the Common Fig (Ficus carica), Tall Fleabane (C. sumatrensis) and Common Rush (J. usitatus). The understory was patchy (~ 20% cover) and almost exclusively comprised of weeds such as Water Couch (P. dilatatum), Cyperus congestus, Pennyroyal (M. pulegium), Grammatotheca bergiana, and Mexican Tea (Dysphania ambrosioides). Water Ribbons (Triglochin linearis) occurred sporadically in the stream. There was severe bank collapse along the
southern side of the river at this site. Large high voltage power lines cross the river here and maintenance has also caused disturbance to the understorey.

**Plant-species richness and diversity**

Table 1 shows the mean number of dominant plant species (S), Margalef’s index (d) and Shannon-Wiener index (H) for each site. There were no significant differences in S between degraded and natural sites.

**Table. Mean number of dominant plant species (S), Margalef’s index (d) and Shannon-Wiener index (H) for each site qualitatively sampled for riparian vegetation within the Serpentine River and Birrega Drain.**

<table>
<thead>
<tr>
<th>Site</th>
<th>S</th>
<th>d</th>
<th>H’(loge)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dog Hill</td>
<td>10</td>
<td>3.91</td>
<td>2.30</td>
</tr>
<tr>
<td>Serpentine-Birrega Confluence</td>
<td>9</td>
<td>3.64</td>
<td>2.20</td>
</tr>
<tr>
<td>Lowlands Gauging Station</td>
<td>7</td>
<td>3.08</td>
<td>1.95</td>
</tr>
<tr>
<td>Horse Drink</td>
<td>10</td>
<td>3.91</td>
<td>2.30</td>
</tr>
<tr>
<td>Coffee Rocks</td>
<td>10</td>
<td>3.91</td>
<td>2.30</td>
</tr>
<tr>
<td>Lowlands Forest</td>
<td>14</td>
<td>4.93</td>
<td>2.64</td>
</tr>
</tbody>
</table>

**Differences in plant communities across sites**

**Overall**

When all plant species included the overstorey, the middle storey and the understorey were considered together, the two-dimensional ordination plot of Bray-Curtis similarity coefficients of overall plant-species composition among sites suggest there was no apparent separation among sites along both axes (Figure 7), ANOSIM (R = 0.43, P = 0.20).

Considering only native plant-species in the understorey, the two-dimensional ordination plot of Bray-Curtis similarity coefficients of native plant-species composition among sites suggest that there was some separation among sites along both axes (Figure 8), although this separation was not strongly significant and appeared merely as a trend, as confirmed by ANOSIM (R = 0.67, P = 0.10). This separation was due to the fact that riparian native plant-species were virtually non-existent in the understorey within Coffee Rocks and Lowlands Gauging Station sites and that Horse Drink and Lowlands Forest were similar in that they had fewer weeds and a greater number of native plant-species in the understorey (Figure 9).
Figure 7. Two-dimensional ordination plot of Bray-Curtis similarity coefficients of overall plant species composition among sites sampled for riparian vegetation within the riparian zone of the Serpentine River and Birrega Drain. Site codes: DH = Dog Hill; SBC = Serpentine-Birrega Confluence; LGS = Lowlands Gauging Station; CR = Coffee Rocks; HD = Horse Drink; LF = Lowlands Forest.

Figure 8. Two-dimensional ordination plot of Bray-Curtis similarity coefficients of native plant species composition among sites sampled for riparian vegetation within the riparian zone of the Serpentine River and Birrega Drain. Site codes: DH = Dog Hill; SBC = Serpentine-Birrega Confluence; LGS = Lowlands Gauging Station; CR = Coffee Rocks; HD = Horse Drink; LF = Lowlands Forest.
**Plant coverage**

In terms of plant coverage in the riparian zone, regardless of plant-species, the two-dimensional ordination plot of Bray-Curtis similarity coefficients suggests that there was some separation among sites along both axes (Figure 9), although this separation was not strongly significant and appeared merely as a trend, as confirmed by ANOSIM (R = 0.852, P = 0.10). In terms of the ecological function of plant coverage along riparian zones, canopy cover of the overstorey, middlestorey and understorey influence stream temperature, fauna biodiversity, instream habitat, etc. (Pen 1999). The average dissimilarity between sites was 36.52; average abundances, given as percentage cover, are presented in Figure 10. From ANOVA, degraded sites had significantly more understorey coverage than natural sites (t = 6.791, df = 4, P = 0.002) and significantly less middlestorey coverage than natural sites (t = -3.714, df = 4, P = 0.021) and the difference in the average abundance of overstorey coverage between degraded and natural sites was also significant (t = -2.820, df = 4, P = 0.0048), with average overstorey coverage of degraded sites being nearly 50% less than in the natural sites. When middlestorey and overstorey species (i.e. trees and shrubs) were combined, degraded sites had a lower proportion of woody plants (28.33%) compared to natural sites (63.33%) (t = -2.734, df = 10, P = 0.021).

![Figure 9](image-url)  
*Figure 9.* Two-dimensional ordination plot of Bray-Curtis similarity coefficients of plant coverage among sites sampled for riparian vegetation within the riparian zone of the Serpentine River and Birrega Drain. Site codes: DH = Dog Hill; SBC = Serpentine-Birrega Confluence; LGS = Lowlands Gauging Station; CR = Coffee Rocks; HD = Horse Drink; LF = Lowlands Forest.
Although we did not quantify in-stream habitat within the Serpentine River and Birrega Drain, natural sites, clearly had greater amounts of leaf litter, woody debris, tree fruits and large woody debris within the stream bed than the degraded sites, which was reflective of a larger proportion of woody plants in the riparian vegetation (i.e. middlestorey and overstorey species combined).

**Figure 10.** Percent coverage of plants within the overstorey, middlestorey and understorey of natural and degraded sites sampled in the Serpentine River and Birrega Drain.

*In-stream woody debris*

Although we did not quantify in-stream habitat within the Serpentine River and Birrega Drain, natural sites, clearly had greater amounts of leaf litter, woody debris, tree fruits and large woody debris within the stream bed than the degraded sites, which was reflective of a larger proportion of woody plants in the riparian vegetation (i.e. middlestorey and overstorey species combined).
Environmental variables of water quality

South-western Australia undergoes a highly seasonal climate with hot dry summers (December-February), mild autumns (March-May), cool wet winters (June-August) with gradually warming and drying springs (September-November). Environmental variables of water quality are presented in Figure 11. During the current study, temperature ranged from 11.1°C in June 2010 (Serpentine River – Lowlands Forest) to 32.3°C in February 2011 (Birrega Drain – Dog Hill). Temperatures increased from August and peaked in February. Water temperatures were as much as 7°C warmer in Birrega Drain than sites within Serpentine River and water temperatures were generally cooler in sites with larger concentrations of overstorey and middlestorey riparian vegetation. The pH varied seasonally from alkaline (>8.0) during June and August to near neutral (~7.0) during spring and summer months. All sites were generally fresh (<1000 mg/L NaCl) for most of the sampling period with the exception of Birrega Drain (Dog Hill) which became mildly brackish (>2000 mg/L NaCl) during mid-February probably due to the effects of evaporative concentration of salts during the dry summer period. Dissolved oxygen was greatest in winter and spring (62-88%) declining to 24.8-49.9% within heavily vegetated sites in summer, probably due to the lack of flow and larger concentrations of decaying plant or animal material as compared to degraded sites which were more prone to higher concentrations of algae, as indicated by super-saturated dissolved oxygen concentrations (128.4%) in the Birrega Drain (Dog Hill) during the day in February.

By February 2011, all sites were observed to have extremely low water levels and were often restricted to very small intermittent pools with much of the river bottom exposed to drying (see Figures 12-17 for examples). Total phosphorus (TP) ranged from 40 to 980 μg/L with the highest concentrations occurring in February probably due to a greatly increased concentration of decaying plant material when water levels were lowest. According to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ 2000), the TP concentration values observed in this study were often above the ‘Trigger Value’ (=65μg/L) for physical and chemical stressors for slightly disturbed lowland river ecosystems of south-west Australia, meaning that concentrations above this value present a risk of eutrophication.
Figure 11. Environmental variables within Serpentine River and Birrega Drain during the sampling period.
Figure 12. Examples of seasonal differences in water flow at Dog Hill Gauging Station during a (1) low rainfall winter – June 2010, (2) extremely dry, hot summer – February 2011, (3) restored flows during normal to above average rainfall – 31 August 2011
Figure 13. Changes in water flow in the Serpentine River – Birrega Drain Confluence site. Photos taken from the Serpentine River mouth facing upstream towards Lowlands: (1) June 2010, (2) February 2011, (3) August 2011
**Figure 14.** Lowlands Gauging Station: (1) August 2010, (2) November 2010, (3) February 2011, (4) August 2011, (5) controlled livestock access, (6) pool just below and downstream from the gauging station weir which was sampled for freshwater mussels and fishes.
Figure 15. Coffee Rocks: (1) June 2010, (2) March 2011, (3) August 2011.
Figure 16. Horse Drink: (1) February 2011, (2) August 2011.
Figure 17. Lowlands Forest: (1) June 2010, (2) February 2011.
Summary of fish, crayfish and other fauna captures

Freshwater Fauna

A total of 132380 fish, freshwater crayfish, shrimp and tadpoles were captured during the survey of six sites in the Serpentine River and Birrega Drain in 2010/2011 (Tables 2 and 3). Of these captures, 3597 (2.71%) were native freshwater fish, 419 (0.32%) were native estuarine fish, two (0.002%) were native anadromous (migrate into rivers from the ocean to breed) fish 124661 (94.17%) were feral fish, 900 (0.68%) were native freshwater crayfish, 2578 (1.95%) were native freshwater shrimp, 25 (0.02%) were feral freshwater crayfish and 198 (0.15%) were tadpoles.

There were four species of native endemic freshwater fishes recorded during the survey (Table 2), including: Western Minnow (*Galaxias occidentalis*) (3208 individuals, 89.19% of native freshwater fish captured), Western Pygmy Perch (*Nannoperca vittata*) (220 individuals, 6.11%), Nightfish (*Bostockia porosa*) (164 individuals, 4.56%) and Freshwater Cobbler (*Tandanus bostocki*) (five individuals, 0.14%). There were two estuarine species recorded in this system: the Swan River Goby (*Pseudogobius olorum*) (418 individuals, 99.76% of native estuarine fish captured) and Western Hardyhead (*Leptatherina wallacei*) (one individual, 0.25%). There was one species of native anadromous fish, Pouched Lamprey (*Geotria australis*). The feral fish species captured consisted of the Eastern Gambusia (*Gambusia holbrooki*) (124343 individuals, 99.75% of feral fishes captured) and Goldfish (*Carassius auratus*) (318 individuals, 0.25%) (Tables 2 and 3). While the Eastern Gambusia was widespread, the Goldfish was restricted in distribution.

The native freshwater crayfishes were the Gilgie (*Cherax quinquecarinatus*) (885 individuals, 98.33% of the native freshwater crayfishes captured) and the Marron (15 individuals, 1.67%). The feral eastern Australian Yabby (*Cherax destructor*) was also recorded (25 individuals) (Table 3).

Other non-targeted species captured included two species of native aquatic reptiles: the Long-neck Turtle (*Chelodina oblonga*) (38 individuals in fyke nets) and, observed during electrofishing but not in fyke nets, the Western Tiger Snake (*Notechis scutatus*) (five individuals); 198 individual tadpoles, which were not identified to species, but adults seen in the sites included Motorbike Frog (*Litoria moorei*), Slender Tree Frog (*Litoria adelaidensis*) and Squelching Froglet (*Crinia insignifera*); and one native Pacific Black Duck (*Anas superciliosa*) which accidentally entered a fyke net. All these bycatch or observed animals were released un-harmed at the site of capture.
A number of species of freshwater macroinvertebrates were also present in the fyke nets, which included caddisfly larvae (Trichoptera), Diving Beetles (Coleoptera: Dytiscidae), Dragonfly Larvae (Odonta: Anisoptera), Damselfly Larvae (Odonta: Zygoptera), the introduced freshwater snail (Gastropoda: Physidae: Physa sp.), Leeches (Hirudinea), Freshwater Worms (Oligochaeta), Water Spiders (Arachnida); Backswimmers (Insecta: Hemiptera: Notonectidae), Water Scorpions (Insecta: Hemiptera: Nepidae) and larval midges (Insecta: Diptera: Chironomidae and Ceratopogonidae) (see Davis & Christidis 1999 for descriptions). No further analyses of species other than fishes and freshwater crayfishes will be presented.

### Table 2. Total number of fishes captured in the Serpentine River and Birrega Drain (June 2010 – August 2011).

| Species codes: BP – Nightfish; Go – Western Minnow; Nv – Western Pygmy Perch; Tb – Freshwater Cobbler; Ga – Pouched Lamprey; Lw – Western Hardyhead; Po – Swan River Goby; Ca – Goldfish; Gh – Eastern Gambusia. Site codes: LF – Lowlands Forest; HD – Horse Drink; CR – Coffee Rocks; LGS – Lowlands Gauging Station; SBC – Serpentine-Birrega Confluence; DH – Dog Hill Gauging Station. |
|------------------|------------------|------------------|------------------|------------------|
| Site             | Bp   | Go   | Nv   | Tb   | Ga   | Lw   | Po   | Ca   | Gh   |
| LF               | 29   | 446  | 13   | 1    | 0    | 0    | 23   | 1    | 1216 |
| HD               | 28   | 353  | 51   | 0    | 1    | 0    | 33   | 0    | 427  |
| CR               | 25   | 336  | 16   | 0    | 0    | 0    | 44   | 1    | 1418 |
| LGS              | 77   | 1942 | 65   | 1    | 1    | 0    | 190  | 110  | 4925 |
| SBC              | 2    | 129  | 51   | 3    | 0    | 0    | 120  | 7    | 1896 |
| DH               | 3    | 2    | 24   | 0    | 0    | 1    | 8    | 199  | 114461 |
| **Totals**       | **164** | **3208** | **220** | **5** | **2** | **1** | **418** | **318** | **124343** |

### Table 3. Total number of freshwater crayfishes and other fauna captured in the Serpentine River and Birrega Drain (June 2010 – August 2011). Species codes: Cc – Smooth Marron; Cq – Gilgie; Pa – South-west Glass Shrimp; Co – Longneck Turtle; Ns – Western Tiger Snake; As – Pacific Black Duck; Cd – Yabbie. Site codes: LF – Lowlands Forest; HD – Horse Drink; CR – Coffee Rocks; LGS – Lowlands Gauging Station; SBC – Serpentine-Birrega Confluence; DH – Dog Hill Gauging Station.

| Species codes: Cc – Smooth Marron; Cq – Gilgie; Pa – South-west Glass Shrimp; Co – Longneck Turtle; Ns – Western Tiger Snake; As – Pacific Black Duck; Cd – Yabbie. Site codes: LF – Lowlands Forest; HD – Horse Drink; CR – Coffee Rocks; LGS – Lowlands Gauging Station; SBC – Serpentine-Birrega Confluence; DH – Dog Hill Gauging Station. |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Site             | Cc   | Cq   | Pa   | Co   | Ns   | Tadpoles | As   | Cd   |
| LF               | 3    | 255  | 398  | 1    | 1    | 103      | 0    | 0    |
| HD               | 4    | 117  | 311  | 5    | 0    | 40       | 0    | 0    |
| CR               | 3    | 124  | 24   | 2    | 1    | 41       | 0    | 0    |
| LGS              | 4    | 218  | 64   | 10   | 2    | 9        | 0    | 0    |
| SBC              | 0    | 129  | 1781 | 20   | 0    | 2        | 1    | 7    |
| DH               | 1    | 42   | 0    | 0    | 1    | 3        | 0    | 16   |
| **Totals**       | **15** | **885** | **2578** | **38** | **5** | **198** | **1** | **23** |
**Patterns of fish migration**

Movement patterns of the Western Minnow, Nightfish, Swan River Goby, Western Pygmy Perch and Eastern Gambusia are illustrated in Figures 18-22. Due to the paucity of Freshwater Cobbler captures, no migration patterns were apparent. Two individual juvenile Pouched Lampreys were captured in fyke nets moving downstream at Horse Drink and Lowlands Gauging Station during August 2010, suggesting that the study area and/or areas upstream in the Serpentine River may be a spawning ground for the species.

From fyke net captures, movement strength of native freshwater fishes was strongest during winter and early spring, which is best illustrated by the considerable number of Western Minnows moving upstream in many of the sites during those periods and a larger number of upstream-moving Western Pygmy Perches captured during August 2011 at Horse Drink when compared to other months. These species are known to spawn during winter and spring and this movement most likely reflected a spawning migration as suggested by the large proportion of gravid females and sexually ripe males during these sampling periods.

In September 2010, when water levels were receding and temperatures were increasing, a mass downstream movement of Western Minnows and Nightfishes was observed at most sampling sites, with a large concentration of fishes appearing at Lowlands Gauging Station during that time. A relatively large concentration of smaller (<50mm TL), presumably immature minnows was also observed at the Serpentine – Birrega Confluence. These data therefore strongly indicate this study section and probably other areas upstream in the Serpentine River provide breeding and nursery habitat for these native freshwater fishes.

Upstream movement of Swan River Gobies was relatively strong at Serpentine – Birrega Confluence and Lowlands Gauging Station during November 2010 and these fishes were gravid with eggs, suggesting the movement was related to spawning. Eastern Gambusia captures peaked during summer months and downstream movement was generally stronger, although this species is generally under-represented in fyke net captures as it is not known to migrate strongly. Furthermore, being a live-bearing species, Eastern Gambusia movement is not generally associated with spawning migrations as opposed to the native freshwater fishes of the region. Goldfish were generally restricted to sites below Lowlands Gauging Station and no strong movement patterns were observed during this study.
Figure 18. Upstream and downstream migration of Western Minnow (*Galaxias occidentalis*) in the Serpentine River and Birrega Drain sites.
Figure 19. Upstream and downstream migration of Nightfish (*Bostockia porosa*) in the Serpentine River and Birrega Drain sites.
Figure 20. Upstream and downstream migration of Western Pygmy Perch (*Nannoperca vittata*) in the Serpentine River and Birrega Drain sites.
Figure 21. Upstream and downstream migration of Swan River Goby (*Pseudogobius olorum*) in the Serpentine River and Birrega Drain sites.
Figure 22. Upstream and downstream migration of Eastern Gambusia (*Gambusia holbrooki*) in the Serpentine River and Birrega Drain sites.
**Distribution patterns and population structure of native fishes**

The most common of the four freshwater fish species captured was the widespread Western Minnow. The ambush predator Nightfish and the Western Pygmy Perch however, were captured less frequently and in smaller numbers. In general, native freshwater fishes were more common in the Serpentine River than Birrega Drain which was probably due to the availability of complex habitats housing more woody debris, overhanging and in-stream vegetation on a variety of substrates which has been shown to support prey items such as macroinvertebrates and terrestrial insects and support favourable temperature regimes and spawning habitats (e.g. Pen 1999).

Densities of native freshwater fishes (Tables 4 and 5) captured by electro-fishing ranged from 0.034 to 0.235 Western Minnows/m², 0.018 to 0.038 Nightfish/m² and up to 0.015 Western Pygmy Perch/m² within natural sites. Within degraded sites of the Birrega Drain densities ranged from 0.005 to 0.088 Western Minnows/m², 0.003 to 0.099 Nightfish/m² and 0.003 to 0.180 Western Pygmy Perch/m². Within the Lowlands Gauging Station Site of the Serpentine River however, native freshwater fishes became more concentrated during spring with densities of 0.424-0.920/m², 0.099/m² and 0.5/m² for Western Minnow, Nightfish and Western Pygmy Perch, respectively. This probably resulted from a mass migration of fishes from further upstream as water supplies began to dwindle in September and fishes were moving downstream to seek refuge in deeper waters, but could have also been due to the gauging station weir acting as a barrier to prevent upstream migration of fishes as flows ceased. Within the Birrega Drain, native freshwater fishes (Nightfish and Western Pygmy Perch) were limited to cooler waters within deeper pools and rocky overhangs which also contained reeds and overhanging grassy habitats and Western Minnows were only found at the base of shallow waterfalls associated with the weir and turbulent riffles at Dog Hill Gauging Station. Statistically, there were no differences in densities among native freshwater fishes in any of the capture sites. Densities of the two feral fish species captured became most concentrated during the spring and summer months when nutrients and water temperatures were greatest.

Although there were no statistical differences in catch per unit effort of native freshwater fishes in fyke nets, (i.e. number of fishes captured per fyke unit), native freshwater fishes tended to be more abundant in natural sites than degraded sites with the exception of Lowlands Gauging station where a large concentration of fishes were captured in September and November 2010 (Tables 6 and 7). The greater number of fishes captured within natural sites during winter periods is probably again indicative of favourable habitats which support dietary and spawning activities.
A nocturnal species, Freshwater Cobbler was observed moving up and down the riffle zone near the bridge (Junior, pers. comm.), possibly as a foraging activity (Beatty et al. 2006). In the current study, very few were recorded within the sampling sites (Table 2 and Figure 23). Several individuals were captured in fyke nets in late winter and early spring within the Serpentine River – Birrega Drain Confluence, Lowlands Gauging Station and Lowlands Forest sites (Table 2). In an additional site in the Serpentine River, a resident population within a deep pool near Rapids Rd Bridge, was found to house several size classes, probably representing a self-maintaining population (Figure 24). This population was heavily burdened with Lernaea sp., an introduced parasitic copepod, presumably originating from the introduction of feral Goldfish (see Appendix I).

The Swan River Goby (also known as Blue-spot Goby) is a common and widespread species found throughout south-western and south-eastern Australia, primarily in estuaries but is also found inland from estuaries in completely fresh rivers and lakes. This typically estuarine species has become increasingly common in salinised systems such as the Blackwood River (Morgan et al. 2003). Although not recorded in the current survey, a number of species, such as the South-west Goby (Afurcagobius suppositus), Black Bream (Acanthopagrus butcheri) and Sea Mullet (Mugil cephalus) may also, at least seasonally, utilise the lower reaches of the system. Rupert Richardson recalls large numbers of Sea Mullet being present in the Birrega Drain up to Lowlands Gauging Station during early spring. The Swan River Goby appears to breed within the Serpentine River with favourable habitats including sandy bottoms and rocky crevices. The species was found at every site within the study area (Table 2). Fishes captured in summer (November – December) were gravid with eggs.

The Pouched lamprey is a widespread anadromous species which inhabits marine environments for much of its life before migrating inland from estuaries upstream into freshwater rivers where it spawns and dies. Using a rasping toothed suctorialis disc, adults feed on the body fluids of larger marine fishes as ectoparasites. The brown larval or ‘ammocoete’ stage lives in sandy sediments where it filter feeds for several years before metamorphosis to the vibrantly coloured aqua blue coloured juvenile stage, which closely resembles the adult morphology. Listed as a Priority 1 species (DEC 2011), it has become increasingly uncommon throughout much of its former range within south-western Australia believed to be due to salinisation and loss of shading riparian vegetation. Juveniles were captured in fyke nets moving downstream during August 2010 at Horse Drink and Lowlands Gauging Station, suggesting the species breeds within the Lowlands Bush Forever site. Lampreys are an important food source for marine birds, such as Wandering Albatross (Diomedea exulans), and other freshwater fauna such as Marron (Gill, pers. comm.; see marron section). Unlike other
fishes, un-natural barriers such as weirs are less of an obstacle since the species is able to climb using its suctorial disc.

The population structure and distribution pattern of the Western Minnow, Western Pygmy Perch, Nightfish and Swan River Goby within the Serpentine River and Birrega Drain is presented in Figures 24-47 below. Generally speaking, native freshwater fishes were represented by multiple cohorts which demonstrate that the species are probably utilizing Lowlands and possibly other upstream areas of the Serpentine as a spawning ground.

### Table 4. Average densities (No./m²) of fishes and crayfishes captured during electro-fishing in ‘Degraded’ sites within the Serpentine River and Birrega Drain study area.

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<th>Site</th>
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<th>Native euryhaline fishes</th>
<th>Native freshwater crayfishes</th>
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Table 5. Average densities (No./m$^2$) of fishes and crayfishes captured during electro-fishing in ‘Natural’ sites within the Serpentine River study area. Species codes: Bp = Nightfish; Go = Western Minnow; Nv = Western Pygmy Perch; Po = Swan River Goby; Cc = Smooth Marron; Cq = Gilgie; Ca = Goldfish; Gh = Eastern Gambusia; Cd = Yabby.

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Table 6. Average catch per unit effort (CPUE) of fishes and crayfishes captured during overnight fyke netting in ‘Degraded’ sites within the Serpentine River and Birrega Drain study area.

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<th>Native freshwater crayfishes</th>
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<td>Ca Gh Cd</td>
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Table 7. Average catch per unit effort (CPUE) of fishes and crayfishes captured during fyke netting in ‘Natural’ sites within the Serpentine River study area. Species codes: Bp = Nightfish; Go = Western Minnow; Nv = Western Pygmy Perch; Po = Swan River Goby; Cc = Smooth Marron; Cq = Gilgie; Ca = Goldfish; Gh = Eastern Gambusia; Cd = Yabby.

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**Distribution and Population structure of Freshwater Cobbler** (*Tandanus bostocki*)

![Image of Freshwater Cobbler]

**Figure 23.** Distribution of Freshwater Cobbler (*Tandanus bostocki*) within the Serpentine River Catchment, South-Western Australia.
Table 8. Total Length (TL), sex and reproductive status of Freshwater Cobbler (Tandanus bostocki) captured within the Serpentine River sites.

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<td>Male</td>
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</table>

Figure 24. Length-frequency histograms of Freshwater Cobbler (Tandanus bostocki) at Rapids Road Bridge pool.
**Distribution and Population structure of Western Minnow (Galaxias occidentalis)**

![Image of Western Minnow](image)

**Figure 25.** Distribution of Western Minnow (*Galaxias occidentalis*) within the Serpentine River Catchment, South-Western Australia.
Figure 26. Length-frequency histograms of Western Minnow (*Galaxias occidentalis*) within the Serpentine River – Birrega Drain Confluence.
Figure 27. Length-frequency histograms of Western Minnow (*Galaxias occidentalis*) at Lowlands Gauging Station.
Figure 28. Length-frequency histograms of Western Minnow (*Galaxias occidentalis*) at Coffee Rocks.
Figure 29. Length-frequency histograms of Western Minnow (*Galaxias occidentalis*) at Horse Drink.
Figure 30. Length-frequency histograms of Western Minnow (*Galaxias occidentalis*) at Lowlands Forest.
Distribution and Population structure of Western Pygmy Perch (Nannoperca vittata)

Fig 31. Distribution of Western Pygmy Perch (Nannoperca vittata) within the Serpentine River Catchment, South-Western Australia.
Fig 32. Length-frequency histograms of Western Pygmy Perch (*Nannoperca vittata*) in the Serpentine River - Birrega Drain Confluence.
Fig 33. Length-frequency histograms of Western Pygmy Perch (\textit{Nannoperca vittata}) at Lowlands Gauging Station.
Figure 34. Length-frequency histograms of Western Pygmy Perch (*Nannoperca vittata*) at Coffee Rocks.
Figure 35. Length-frequency histograms of Western Pygmy Perch (*Nannoperca vittata*) at Horse Drink.
Figure 36. Length-frequency histograms of Western Pygmy Perch (*Nannoperca vittata*) at Lowlands Forest.
Distribution and Population structure of Nightfish (Bostockia porosa)

Figure 37. Distribution of Nightfish (*Bostockia porosa*) within the Serpentine River Catchment, South-Western Australia.
Figure 38. Length-frequency histograms of Nightfish (*Bostockia porosa*) within the Serpentine River – Birrega Drain Confluence.
Figure 39. Length-frequency histograms of Nightfish (*Bostockia porosa*) within at Lowlands Gauging Station.
Figure 40. Length-frequency histograms of Nightfish (*Bostockia porosa*) within at Coffee Rocks.
Figure 41. Length-frequency histograms of Nightfish (*Bostockia porosa*) within at Horse Drink.
Figure 42. Length-frequency histograms of Nightfish (*Bostockia porosa*) within at Lowlands Forest.
**Distribution and Population structure of Swan River Goby** (*Pseudogobius olorum*)

*Figure 43.* Distribution of Swan River Goby (*Pseudogobius olorum*) within the Serpentine River Catchment, South-Western Australia.
Figure 44. Length-frequency histograms of the Swan River Goby (*Pseudogobius olorum*) at Serpentine River-Birrega Drain Confluence
Figure 45. Length-frequency histograms of the Swan River Goby (*Pseudogobius olorum*) at Lowlands Gauging Station.
Figure 46. Length-frequency histograms of the Swan River Goby (*Pseudogobius olorum*) at Coffee Rocks.
Figure 47. Length-frequency histograms of the Swan River Goby (*Pseudogobius olorum*) at Horse Drink
Figure 48. Length-frequency histograms of the Swan River Goby (*Pseudogobius olorum*) at Lowlands Forest.
Distribution, movement patterns and population structure of freshwater crayfishes

All 11 native freshwater species of south-western Australia are endemic to the region (Austin & Knott 1996, Horwitz & Adams 2000, Morgan et al. 2011) and freshwater crayfish are known to play important roles in the structure and function of aquatic ecosystems. The Gilgie is one of the most widespread of these species, found in nearly every freshwater habitat within the southwest including ephemeral wetlands, streams and major rivers (Austin & Knott 1996; Beatty et al. 2005a). The Gilgie was very widespread in both the Serpentine River and Birrega Drain, being found in all sites that were surveyed. Movement was strongest in the spring and summer months, which may have been related to breeding, seeking refuge from receding water levels or food availability, although the movement pattern of this species has not previously been examined in detail. Both systems housed self-sustaining populations of this species as indicated by their widespread distribution, high abundances, and the relatively wide size range including juvenile individuals and older age classes (Figures 49-55) (see Beatty et al. 2005a).

The ability of the Gilgie to burrow into the water table during the summer dry periods has facilitated the use of seasonally inundated habitats. The species is also known to have a life-history strategy that allows it to rapidly re-colonise habitats, such as potentially breeding multiple times a year (Beatty et al. 2005a).
Figure 49. Upstream and downstream migration of Giligie (*Cherax quinquecarinatus*) in the Serpentine River and Birrega Drain sites.
Figure 50. Distribution of the Gilgie (*Cherax quinquecarinatus*) within the Serpentine River Catchment, South-Western Australia. N.B. The only information available was from this study, circled in green.
Figure 51. Length-frequency histograms of the Gilgie (*Cherax quinquecarinatus*) within the Serpentine River – Birrega Drain Confluence.
Figure 52. Length-frequency histograms of the Gilgie (*Cherax quinquecarinatus*) at Lowlands Gauging Station.
Figure 53. Length-frequency histograms of the Gilgie (*Cherax quinquecarinatus*) at Coffee Rocks.
Figure 54. Length-frequency histograms of the Gilgie (*Cherax quinquecarinatus*) at Horse Drink.
The Marron was recorded at four of the survey sites in the Serpentine River, which included Lowlands Gauging Station, Coffee Rocks, Horse Dine and Lowlands Forest.

Figure 55: Length-frequency histograms of the Gilgie (Cherax quinquecarinatus) at Lowlands Forest.
Additionally, a single Marron was seen exiting a small, visually turbid green pool during a survey of freshwater mussels near the Dog Hill Gauging Station in March 2011 (Figure 56). The species generally relies on permanent habitat for survival. Within the study area, the largest Marron were found at the Coffee Rocks site with two individual females measuring 60 and 65 mm OCL. Marron were relatively uncommon throughout the survey sites, with only a few smaller examples being captured during winter and spring 2010 (Table 9). From the few individuals that were captured, the population there probably consisted of three age classes (see growth rates in Beatty et al. 2005b) and therefore it appears to be breeding in the system. Additional survey effort would be required to confirm the sustainability of the population in that system and the other sites where it was recorded in the study.

The Smooth Marron supports an iconic inland recreational fishery and is the world’s third largest freshwater crayfish species (Morgan et al. 2011). Originating from between Harvey and west of Albany, the species has been translocated north to the Hutt River (north of Geraldton) and east to Esperance since European Arrival. Its inland range, which receives less rainfall and has been cleared of much of its original vegetation, has been reduced due to secondary salinisation and eutrophication (Morrissy 1978; de Graaf et al. 2010). Unlike smaller crayfish species, the Marron is a seasonal breeder, reproducing annually, maturing at the end of its second year of life, and has a fast growth rate (Beatty et al. 2003, 2005b, 2010a). Like most freshwater crayfishes, its diet consists largely of detritus; however, it has recently been shown to also be an opportunistic omnivore assimilating considerable amounts of animal material including Eastern Gambusia (Beatty 2006). Within Margaret River, for example, ‘Mossy-back’ or Hairy Marron (Cherax cainii) were known to feast on Pouched Lamprey (Geotria australis) once they had spawned and died. Within the recent educational film footage of ‘Freshwater Crayfishes of South-western Australia’, a Marron was observed eating a freshwater mussel (W. carteri).

The Freshwater Shrimp (also known as South-west Glass Shrimp) was recorded at four sites within the Serpentine River and one site at the Serpentine River – Birrega Drain Confluence (Figure 57). The species is endemic to south-western Australia and is found in a wide range of water bodies including freshwater and salinised lakes and rivers (Morgan et al. 2011). Little is known about its biology or ecology. The species is believed to breed during spring and summer (Beatty & Morgan, unpubl. data) and is an important dietary component of larger endemic freshwater fishes such as Freshwater Cobbler, Nightfish and Western Minnows (Morgan et al. 1998). The species may be an important cleaner or grazer of freshwater mussels and is also thought to stimulate glochidia release in W. carteri (Klunzinger 2011).
Figure 56. Distribution of Smooth Marron (*Cherax cainii*) within the Serpentine River Catchment, South-Western Australia. N.B. The only information available was from this study, circled in green. Photo: Simon Visser.
Table 8 Orbital carapace length (OCL), sex and reproductive status of Marron captured within the Serpentine River sites.

<table>
<thead>
<tr>
<th>Date</th>
<th>Site</th>
<th>OCL (mm)</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 June 2010</td>
<td>Horse Drink</td>
<td>15</td>
<td>Male</td>
</tr>
<tr>
<td>18 June 2010</td>
<td>Coffee Rocks</td>
<td>60</td>
<td>Female</td>
</tr>
<tr>
<td>18 June 2010</td>
<td>Coffee Rocks</td>
<td>65</td>
<td>Female</td>
</tr>
<tr>
<td>24 November 2010</td>
<td>Lowlands Gauging Station</td>
<td>27</td>
<td>Female</td>
</tr>
<tr>
<td>24 November 2010</td>
<td>Lowlands Gauging Station</td>
<td>20</td>
<td>Male</td>
</tr>
<tr>
<td>24 November 2010</td>
<td>Lowlands Forest</td>
<td>30</td>
<td>Male</td>
</tr>
<tr>
<td>14 January 2011</td>
<td>Horse Drink</td>
<td>32</td>
<td>Male</td>
</tr>
<tr>
<td>16 March 2011</td>
<td>Dog Hill</td>
<td>65 (estimated)</td>
<td></td>
</tr>
</tbody>
</table>
This study (Present)
Davis et al. 1988
Morgan, unpublished data

Figure 57. Distribution of Southwest Glass Shrimp (*Palaemonetes australis*) within the Serpentine River Catchment, South-Western Australia.
Distribution patterns population structure and eradication of feral fishes

**Eastern Gambusia**

The Eastern Gambusia was recorded at all sites in the Serpentine River and Birrega Drain (Figure 58) and dominated the total species capture, particularly in summer when maximum densities numbered in the 100’s to 1000’s of fish/m² (Table 2). The Eastern Gambusia captured in this study was represented by several size classes and included breeding populations of males and live-bearing females (Figures 59-64). The species is not known to be a migratory fish, so this movement was probably related to localised feeding activity rather than migration.

The species has invaded the majority of the Swan Coastal catchments, including the Serpentine River (Figure 58) and in particularly disturbed habitats it dominates the fish fauna, as was found in the Birrega Drain and Lowlands Gauging Station. It is likely that the species has been found in this system since it was first introduced in the 1930s into WA for mosquito control. The Eastern Gambusia is a well known fin-nipper of south-western Australia freshwater fishes (Gill *et al.* 1999), which was probably responsible for the observed fin loss in juvenile Western Pygmy Perch and Western Minnows in early summer. This may be especially detrimental to the swimming ability of pygmy perches and minnows (Keleher 2011) and could have negative consequences for glochidia that may be attached to the fins of these fishes.
Figure 59. Distribution of Eastern Gambusia (Gambusia holbrooki) within the Serpentine River Catchment, South-Western Australia.
Figure 60. Length-frequency histograms of the Eastern Gambusia (*Gambusia holbrooki*) within the Serpentine River – Birrega Drain Confluence.
Figure 61. Length-frequency histograms of the Eastern Gambusia (Gambusia holbrooki) at Lowlands Gauging Station.
Figure 62. Length-frequency histograms of the Eastern Gambusia (*Gambusia holbrooki*) at Coffee Rocks.
Figure 63. Length-frequency histograms of the Eastern Gambusia (*Gambusia holbrooki*) at Horse Drink.
Figure 64. Length-frequency histograms of the Eastern Gambusia (*Gambusia holbrooki*) at Lowlands Forest.
**Goldfish**

Very few Goldfish were captured in natural sites during the sampling period and most were captured within the Birrega Drain and Lowlands Gauging Station sites (Figure 65). Average density of Goldfish was reduced from January to February 2011 (Figure 66), indicating that our sampling methods were successful in eradicating Goldfish in degraded sites. While sampling in the Birrega Drain, a turbid pool downstream from the Dog Hill Gauging Station was located and found to contain a number of fishes ranging from 58 to 202 mm TL (Figure 67). A fairly sizeable population of Goldfish was also observed in a turbid pool below Lowlands Gauging Station in January and February 2011. Following a cull of fishes from the Birrega Drain in November 2010, TL was reduced from to a range of 30 – 135 mm during these sampling periods (Figure 67). The elimination of larger individuals in November 2010 reduced the average TL from 104.8 mm to 64.4 mm and 75.1 mm TL in the subsequent sampling periods of January and February 2011 in the degraded sites. Very few Goldfish were captured during winter flows in June 2010 and August 2011.

As a result of illegal releases, Goldfish are now well established in many artificial wetlands as well as a number of lakes and rivers of south-western Australia (Morgan *et al.* 2004, 2011). The biology and ecology of the species within the Vasse River was examined by Morgan & Beatty (2007), who found that the population is probably the fastest and largest growing in the world. Goldfish were captured in the study area between November 2010 and February 2011 and were primarily restricted to pools within degraded sites below Lowlands Gauging Station in the Serpentine River and Birrega Drain near Dog Hill Gauging Station.

The species seems to thrive well and dominate eutrophic waters where growth is rapid and their diet is composed largely of blue-green algae (Morgan & Beatty 2007). The species is less common in the cooler, well-vegetated mesotrophic waters of the south-west. Goldfish have been responsible for the introduction of foreign disease and parasites (such as the ectoparasitic crustacean *Lernea cyprinacea* (Marina *et al.* 2008), out competing native species for food and habitat, predating native fishes and their eggs and, potentially fuelling algal blooms through re-suspension of nutrients during feeding and re-activation of blue-green algae through their intestines (Kolmakov & Gladyshev 2003), all much to the detriment of the south-west’s unique biodiversity. The tolerance to adverse environmental conditions, such as high temperatures, low dissolved oxygen and increased salinisation is partly why they are a favoured aquarium species, but is also one of the reasons why they have survived followed their introduction to the south-west (Morgan *et al.* 2004; Morgan & Beatty 2007).
Figure 65. Distribution of Goldfish (*Carassius auratus*) within the Serpentine River Catchment, South-Western Australia.
Goldfish Density Reduction

Figure 66. Goldfish eradication within degraded sites of the Serpentine River and Birrega Drain showing reduction in fish densities during summer 2010-2011.
Figure 67. Length-frequency histograms of Goldfish captured in the Serpentine River and Birrega-Drain sites during summer 2010-2011. Images – Top: turbid pool in Birrega Drain, downstream from Dog Hill; Middle: Goldfish (*Carassius auratus*) captured during this study; Bottom: Serpentine River, pool below Lowlands Gauging Station.
Yabby

The Yabby is the only feral freshwater crayfish species currently known from south-western Australia. In the current study, it was recorded in Birrega Drain primarily in February 2011 (Figure 68). Figure 69 illustrates that there were at least two and possibly three age classes present (see biology of the species in Beatty et al. 2005c) suggesting this was a breeding population. Furthermore, the presence of ‘berried’ eggs attached to the pleopods of an individual female was recorded in February 2011. Originally introduced into south-western Australia in the 1930’s for aquaculture, this species has escaped into numerous wild aquatic systems in this region (Beatty et al. 2005c). Its life-history traits allow it to rapidly colonise new systems and these include: maturing in its first year of life, breeding multiple times during warmer months; burrowing to escape drought; tolerance of extreme temperatures and low dissolved oxygen; and a varied omnivorous diet (e.g. Beatty et al. 2005c, Beatty 2006). The species is known to compete with Marron (also having a similar growth rate in its first year of life) for food sources and undoubtedly competes with other endemic species when present (Beatty 2006). Lynas et al. (2002) showed that the yabby displayed aggressive dominance over Marron in laboratory trials when the two species were of similar size and body mass. Yabbies also have the potential to introduce diseases such as ‘porcelain disease’ which is caused by microsporidians *Thelohania parastaci* and *Vavraia parastacida* (Beatty 2005). Once established in a wild aquatic system, eradication of the Yabby is extremely unlikely.
Figure 68. Distribution of Yabby (*Cherax destructor*) within the Serpentine River Catchment, South-Western Australia.
Figure 69. Length-frequency histograms of Yabby (*Cherax destructor*) captured within the Dog Hill Gauging Station and Serpentine River-Birrega Drain Confluence during the study.
Distribution, abundance, population structure and glochidia host-fish of Carter’s Freshwater Mussel

Mussel distribution and abundance

Museum records indicate that Carter’s Freshwater Mussel once ranged from Moore River in the north, east to the Avon River, extending southward and westward to regions of the west coast and eastwardly along the south coast to the Kalgan River (Morgan et al. 2011; Klunzinger et al., unpublished data). Early records suggest the species may have been more widespread from the Gascoyne River (BMNH_MP_110 c.a. 1824) in the north to King George Sound (AMS_47295 and AMS_126151 c.a. 1877) with one record extending as far east as Esperance town Beach (WAM_34289 c.a. 1978) in the south. The distribution of the species within the Serpentine River catchment extends from the Serpentine Dam in the east, westward through Lowlands and southward within the Birrega Drain and bounded by tidal influence in Goegrup Lake, although the distribution of the species within Birrega Drain is not entirely known (Figure 70). Live W. carteri was found at every site apart from Lowlands Gauging Station.
Figure 70. Distribution of Carter’s Freshwater Mussel (*Westralunionio carteri*) within the Serpentine River Catchment, South-Western Australia.
Localised population densities of freshwater mussels within the Australasian region and elsewhere is generally patchy with densities ranging from 1 to as many as 814/m² (Walker et al. 2001). From our surveys throughout south-western Australia, where *W. carteri* is found, they can be locally abundant with patch densities ranging from a few individuals to as many as 250/m², influenced strongly by the level of disturbance within the localized habitats.

Within the current study, mussel densities ranged from 1 to as many as 87 mussels/m². Average densities within sampling sites ranged from 0.15 to 13.39 mussels/m² ($F = 2.413$, $df = 5$, $P = 0.04$) (see Figure 71). Average mussel density within Horse drink was significantly greater than in Lowlands Gauging Station (13.39 vs. 0.15 mussels/m²; $t = 3.189$, $df = 1$, $P = 0.027$), but no other statistically significant differences between sites were observed. This difference suggests that the gauging station may be less suitable mussel habitat than Horse Drink, probably due to the greater buildup of fine sediments above and below the weir and the more favourable habitats of sandy mud, woody debris and macrophytes such as *Triglochin* spp. which are also favourable to potential host fishes for the glochidia of *W. carteri* within Horse Drink. The observed differences in mussel density between sites are probably attributed to a number of factors. Walker et al. (2001) and Strayer (2008), for example suggest that factors important to distribution and abundance of freshwater mussels include dispersal rate, habitat composition, availability of host fishes, and availability of food and potential threats from feral predators, parasites and macroinvertebrates which predate vulnerable juvenile-stage mussels.

Prior to this study in January 2010, only a few live mussels were observed at Lowlands Gauging Station (LGS), but surveys after June 2010 failed to recover any live mussels at the site. Because baseline surveys before the construction LGS were not conducted, it is difficult to determine whether the construction activity resulted in losses of *W. carteri* from the site or whether the presence of cattle may have also been a contributing factor, although these activities have been known to deplete hyriid colonies of freshwater mussels elsewhere (Jones & Byrne 2010). The build-up of anoxic organic debris and extremely fine, soft, unstable sediments downstream of LGS decreases the likelihood of mussel survival. The large amount of mobile sand from erosion near the Serpentine – Birrega Confluence (SBC) may have prevented the settlement of juvenile mussels and prevented a stable platform for normal adult mussel activity. Within Birrega Drain itself, mussel distribution was patchy and populations were generally clustered along the banks, often nestled amongst vegetation and tree roots within stable sandy sediments. Much of the drain was unsuitable mussel habitat due to the impenetrable nature of the solid stream bottom. The natural sites were generally more biodiverse and generally had a greater amount of leaf litter, woody debris, overhanging vegetation and canopy cover which probably buffered against temperature extremes and provided exceptional fish habitat as well as supplying adequate oxygen during higher flow periods. Between November and February 2011, much of the area within the study sites had
dried excessively to the point where mussels became exposed (Figures 72-73). Within the Birrega Drain, many mussels were found dead, which was a result of drying and/or increased predation by other animals, as was found in the Lower Helena Pipehead Dam and elsewhere within the south-west (Klunzinger et al. 2011a,b). During the same period, mussels within the natural sites were found clustered within small puddles and dug into soft mud and sand that does not collapse as mussels burrow, essentially creating ‘tubes’ which remain moist as water levels recede, all of which were alive.

**Mussel Density**

<table>
<thead>
<tr>
<th>Site</th>
<th>Average density (No. mussels/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH</td>
<td>0</td>
</tr>
<tr>
<td>SBC</td>
<td>3</td>
</tr>
<tr>
<td>LGS</td>
<td>6</td>
</tr>
<tr>
<td>CR</td>
<td>9</td>
</tr>
<tr>
<td>HD</td>
<td>12</td>
</tr>
<tr>
<td>LF</td>
<td>15</td>
</tr>
</tbody>
</table>

**Figure 71.** Average density of freshwater mussels (*Westralunio carteri*) within sampling sites of the study area. Site codes: DH = Dog Hill; SBC = Serpentine – Berriga Confluence; LGS = Lowlands Gauging Station; CR = Coffee Rocks; HD = Horse Drink; LF = Lowlands Forest.
Figure 72. Freshwater mussels (*Westralunio carteri*) exposed to drying in the Birrega Drain during February 2010.
Figure 73. **A)** An area of the Serpentine River within the Horse Drink site consisting of a mostly dry river bed with small pools of receding water remaining, which contained many freshwater mussels (*Westralunio carteri*). The pool was excavated and found to contain >100 mussels, all alive in February 2010. Note shading from riparian vegetation. The stream bed remained moist, exposed to drying in the Birrega Drain during February 2010. **B)** The same area in December 2009 showing mussels burrowed in sand near tree roots and **C)** water level at the same tree.
Mussel population structure

Mean MHI was 60.0%, which is within the reported range for *W. carteri* (60-70%; McMichael & Hiscock 1958). All other taxonomic characters matched keys for *W. carteri* (McMichael & Hiscock 1958; Walker 2004). Mussels in Dog Hill and Lowlands Forest were the largest, dominated by individuals in the 70-80 mm shell length range (Figure 74) followed by Serpentine-Birrega Confluence, Lowlands Gauging Station and Coffee Rocks, dominated by individuals in the 60-70 mm shell length range and the smallest mussels were found at Horse Drink, the majority of which fell within the 60-65 mm length range. Average shell lengths of mussels among and between sites were statistically different (F = 14.562; df = 5, 780; P < 0.001).

A preliminary growth trial where a representative sample of various size classes within Horse Drink and Dog Hill were marked and recaptured annually from March 2010 to March 2011, growth rates of mussels in Dog Hill were six times greater than for mussels in the Horse Drink site for individuals within the 30-60 mm shell length range (t = 4.934, df = 48, P < 0.001). Also, mussels within Birrega Drain were significantly more obese (using MHI as an indicator) than mussels within the Serpentine River (F = 6.883; df = 5, 589; P < 0.001), suggesting greater visceral mass, which is probably due to increased temperature and eutrophication within the drain as suggested from other international studies (Agrell 1948; Arter 1989; Franke 1993; Müller 1995).

From the location of smaller individuals (<30 mm), the population of *W. carteri* within the Serpentine River of the Lowlands Bush Forever site appears to have had some recent recruitment, but the lack of a greater number of individuals in the smaller size classes suggests the population is aging and recruitment has become less frequent in recent history. A validated age-at-length growth study of *W. carteri* within several populations of its distributional range will be published in 2012 and will help explain whether this is the case.
Figure 74. Length-frequency histograms of *Westralunio carteri* in the Serpentine River and Birrega Drain.
Glochidia-host fish relationships

During this study, six fish species (n = 1275 individual fishes) were examined for glochidia of *W. carteri* and were found attached primarily to the fins, but occasionally to the body, eye, mouth and very rarely to the gills. Glochidia obtained from the gills of gravid adult female *W. carteri* were similar in morphology to those reported by Klunzinger et al. 2010b, 2011, suggesting they were *W. carteri* offspring. Glochidia prevalence and intensity peaked in November, gradually reducing in subsequent months. By January, virtually no glochidia remained attached to any fishes, suggesting a seasonal pattern of glochidia attachment. Recent work by the authors has shown that glochidia of *W. carteri* remain attached to host fishes for 21-27 days under laboratory conditions and glochidia release occurs from October and December within freshwater tributaries of the Swan-Canning estuary based on data collected in 2009-2010 (Klunzinger et al. unpublished data). During this study however, we were surprised to find glochidia being released from *W. carteri* during late August. Studies of other species of freshwater mussels have suggested that reproduction and recruitment is boosted in wetter years (e.g. Hastie et al. 2003).

Overall, peak glochidia prevalence ranged from 5.3 to 62.9% (Figure 75) and intensities ranged from 1 to 19 glochidia per infested fish (Table 9). For each fish species (≥10 fish) among the sites sampled, peak glochidia prevalences were significantly different (χ² = 56.977, df = 7, P < 0.001), as were intensities (H = 34.11, df = 12, P < 0.001). Peak glochidia prevalence of fishes captured within ‘natural’ sites was significantly greater than fishes captured from ‘degraded’ sites (63.4% vs. 23.9%; χ² = 43.336, df = 1, P < 0.001). Considering each species separately among sampling sites, glochidia prevalence and intensity was positively associated with adult mussel density (R² = 0.884 – 1.00) (see Figures 76-77), such that greater adult mussel densities within sites led to greater glochidia prevalences and intensities for each species. Prevalence was greater in native fishes than in ferals (70.6% vs. 29.45%, respectively; χ² = 18.823, df = 1, P < 0.001). A recent study testing the suitability of various fishes as hosts suggests that feral fishes may be less suitable from their inability to produce juvenile *W. carteri* (Klunzinger et al., in review). Like other freshwater mussels found throughout Australia, this freshwater mussel appears to be a host generalist utilising a number of host fishes also endemic to the south-west, probably to maximise its chances for recruitment (Walker 1981; Humphrey 1984; Widarto 1996; Klunzinger et al., in review). Survival and growth rates of *W. carteri* glochidia and juvenile mussels on fishes and in sediments is likely to vary with a number of factors including ammonia concentration, sediment type, the presence of predators or contaminants such as salt, chlorine and other harmful chemicals, based on studies of other freshwater mussels elsewhere (Walker 1981; Strayer 2008).
Fishes that undergo long distance spawning migrations, such as Western Minnows, probably help to maintain connectivity of freshwater mussel colonies by distributing their glochidia to new areas on a large scale and perhaps prevent inbreeding by distributing the gene pool from various colonies (Pen 1999; Strayer 2008). Some fishes however, may be responsible for maintaining recruitment of freshwater mussels in localised patches (Strayer 2008; Jones & Byrne 2010). More information on the movement patterns of host fishes and the genetic diversity of freshwater mussels within catchments as well as the longevity of *W. carteri* is necessary to determine long-term population viability of the species within the Serpentine River and other systems across the south-west.

![Glochidia prevalence chart](image)

**Figure 75.** Overall glochidia prevalence in fishes examined from the Serpentine River and Birrega Drain with 95% Confidence Intervals given in brackets. Red bars represent feral fishes and green bars are native fishes.

<table>
<thead>
<tr>
<th>Fish Species</th>
<th>No. examined</th>
<th>Intensity range</th>
<th>Average intensity (No./infested fish ±S.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Gambusia†</td>
<td>110</td>
<td>1-9</td>
<td>1.46 ± 0.29</td>
</tr>
<tr>
<td>Western Minnow</td>
<td>80</td>
<td>1-19</td>
<td>2.39 ± 1.09</td>
</tr>
<tr>
<td>Swan River Goby</td>
<td>47</td>
<td>1-16</td>
<td>2.84 ± 0.94</td>
</tr>
<tr>
<td>Western Pygmy Perch</td>
<td>30</td>
<td>1-17</td>
<td>3.58 ± 1.76</td>
</tr>
<tr>
<td>Goldfish†</td>
<td>19</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Nightfish</td>
<td>21</td>
<td>1-16</td>
<td>6.17 ± 3.84</td>
</tr>
</tbody>
</table>

Table 9. Overall peak glochidia intensity for each fish species captured within the Serpentine River and Birrega Drain. Sample means were significantly different at the *P*<0.05 level. Feral fish species
Figure 76. Regression plots of mean adult freshwater mussel (*Westralunio carteri*) density vs. peak glochidia prevalence in four individual fish species captured from sampling sites within the Serpentine River or Birrega Drain. Each data point represents individual fish species within individual sampling sites.
Figure 77. Regression plots of mean adult freshwater mussel (*Westralunio carteri*) density vs. peak glochidia intensity in four individual fish species captured from sampling sites within the Serpentine River or Birrega Drain. Each data point represents individual fish species within individual sampling sites.
Conservation significance and management recommendations

From the regular monitoring of the six sampling sites, it is clear that native freshwater fishes are utilizing the Lowlands Bush Forever conservation block as an important spawning ground, particularly with the discovery of downstream migrating juvenile Pouched Lamprey, suggesting that this Priority 1 fauna, a species which requires specific habitats for development, is using the area to breed. The Vulnerable, Priority 4 Carter’s Freshwater Mussel was present in the Serpentine River and Birrega Drain.

Generally speaking, the complex woody, well vegetated habitats which received little to no human impacts in recent years, within the Lowlands Bush Forever sites were more conducive to freshwater mussel recruitment and native freshwater fish and crayfish populations. Conversely, the degraded habitats within and downstream from the cattle crossing were more heavily laden with feral fishes and crayfishes. In some cases, the sites were virtually devoid of freshwater mussels. Although we have not presented very much information about the heavily impacted cattle crossing upstream from Lowlands Gauging Station, the area was surveyed for freshwater mussels by students from the Central Institute of Technology, but none were found (see Appendix). The construction of a bridge to reduce the impacts from cattle crossing the river will help to reduce erosion and sedimentation as well as nutrient inputs and riparian re-vegetation, restricting livestock from using the river banks and improving the river with the introduction of woody debris to encourage native freshwater fish habitation and freshwater mussel re-colonisation and follow-up monitoring is recommended. The fencing throughout the property is in good condition and should continue to be maintained to protect the integrity of the riparian zone. The controlled access point for cattle below the Lowlands Gauging Station is proving to be beneficial in terms of riparian vegetation re-generation and possibly a reduction in sedimentation, but the buildup of fine detritus within the pool below the access point is concerning. The low winter rainfall in 2010 and lack of flow in the summer of 2011 undoubtedly played a role in the buildup of fine sediments, which should have been flushed with adequate winter rains and environmental water provisions.

The rarity of Western Pygmy Perch within the study area may be due, in part, to the large numbers of Eastern Gambusia which were probably responsible for the extreme fin nipping of juvenile Western Pygmy Perches observed during the study. Although few Smooth Marron were captured in the study, the deep pools near Coffee Rocks and Rapids Road housed sizeable males and females.

The discovery of the parasitic crustacean (*Lernaea cyprinacea*) or ‘Anchor Worm’ on native freshwater fishes at Rapids Road and pools within the Birrega Drain is particularly concerning and probably has been spread by Goldfish. No *Lernaea* were found on any of the Goldfishes captured, suggesting that the native fishes are now a preferred host. A dedicated study to determine whether this parasite is causing native species declines is necessary in the
near future. We also found that feral fish eradication was most successful through electro-fishing and seine netting during late spring and summer, when we successfully eradicated a number of Goldfish within the Birrega Drain and just below the Lowlands Gauging Station. Indeed, the gauging station weir may be acting as a barrier to prevent upstream migration of Goldfish from the Birrega Drain into the upstream regions of the Serpentine River, although weirs have also been shown to be detrimental to native fishes by blocking upstream spawning migrations and disconnecting freshwater mussel patches by preventing the movement of glochidia on host fishes, which could have implications for maintaining genetic integrity of the rare Carter’s Freshwater Mussel.

Also worth mentioning, besides Carter’s Freshwater Mussel and the Pouched Lamprey, there were several other significant flora and fauna observed during the study, which included the Priority 4 listed Dusky Moorhen (Gallinula tenebrosa), the Southwestern Silkpod (Parsonsia diaphenophleba) and, as confirmed by Karen Bettink’s concurrent study, the charismatic Water Rat (Hydromys chrysogaster).

From this study, monitoring freshwater mussels, fishes and crayfishes has proven useful as an indication of adaptive management success and using native species, particularly Carter’s Freshwater Mussel and its native host fishes as bioindicators of freshwater river health should be used in future ecological work to monitor and manage natural resource integrity.
References


Beatty, S., Morgan, D., Sarre, G., Cottingham, A. & Buckland, A. (2010a). *Assessment of the distribution and population viability of the Pearl Cichlid in the Swan River catchment, Western Australia*. Murdoch University, Centre for Fish & Fisheries Research report to the Swan River Trust.


APPENDIX I

*Extension of this study*
This study created mutually beneficial opportunities for community natural resource managers as well as training opportunities for postgraduate researchers and vocational training of Environmental Science students in the (formerly TAFE) vocational and university level tertiary education sectors. A summary of projects are included below:

Michael Klunzinger, PhD candidate

Ecology and Life History of the Freshwater mussel: *Westralunio carteri*
Iredale, 1934

Program of Study

The PhD thesis is focused on the freshwater mussel *Westralunio carteri*, an endemic freshwater mussel of south-western Australia. Until this study began in 2009, very little information existed on the distribution, abundance and life cycle of the species existed, apart from a few sporadic declarations of species loss from salinisation, brief mentions of its existence in macroinvertebrate studies and occasional use as a bioindicators of contaminants. The objectives of the thesis were to:

1. Establish distributional information of the species
2. Quantify environmental tolerances and habitat occupancy
3. Examine reproductive biology and growth rates
4. Identify host fish for the larval stage (‘glochidia’)

**Supervisors:** Alan Lymbery, David Morgan, Stephen Beatty

**Commencement date:** 22 June 2009

**Expected completion date:** 22 June 2012

**Relevant publications submitted during this NRM project:**


Stefania Basile, BSc (Hons)

Impacts of the introduced parasite *Lernaea cyprinacea* (Linnaeus, 1758) (Lernaeidae) on the native and exotic fishes of south-western Australia

**ABSTRACT**

Exotic species present a major threat to native freshwater fishes in south-western Australia through predation, competition for habitat and resources and in some cases the alteration of habitat and water quality. They may also introduce diseases, although much less is known about the threat posed to native freshwater fishes by exotic diseases. Until very recently, records of the introduced parasitic crustacean *Lernaea cyprinacea* (Linnaeus, 1758) (Lernaeidae) in Australia were limited and restricted to the eastern states (Victoria and New South Wales). The first published records of *L. cyprinacea* found on freshwater fishes in Western Australia was in 2008. The current study examines the distribution of this parasite in the south-west of Western Australia, compares the prevalence and intensity of parasite infestation in different host species, as well as the potential causes of differences in prevalence and intensity and examined these findings in the light of management practices for exotic fish species.

*Lernaea cyprinacea* was found on fishes in three river systems of the South West Coast Drainage Division (SWCDD): the Canning River and its tributary the Southern River, in which the parasite had been previously recorded, and the **Serpentine River** (Rapids Rd & Birrega Drain) and Murray River, which represent new distribution records for *L. cyprinacea*.

As well as an expansion in the geographical range of *L. cyprinacea* that was observed in the SWCDD during this study, two new native fish species were found to be hosts for *L. cyprinacea*.

The results of the current study have implications regarding the control or eradication of exotic fish species in Western Australia in terms of potential consequences on the host-parasite association between native fish species and *L. cyprinacea*. Although requiring further research, the removal of *C. auratus* from the wild could potentially increase *L. cyprinacea* disease risk in native fish species by promoting *L. cyprinacea* transmission to the more susceptible native fish species. However, there are ecological benefits in the control of feral fishes.
‘Anchor worm’ (*Lernaea cyprinacea*) infections on feral Goldfish (*Carassius auratus*). Photos: Stefania Basile

‘Anchor worm’ (*Lernaea cyprinacea*) infections on native Freshwater Cobbler (*Tandanus bostocki*). Photos: Simon Visser

‘Anchor worm’ (*Lernaea cyprinacea*) infections on native Western Pygmy Perch (*Nannoperca vittata*) – left and native Nightfish (*Bostockia porosa*) - right. Photos: Stefania Basile
Freshwater Mussel Ecology Project 2010

Project Outline — As part of their studies at the Central Institute of Technology the Certificate IV, Environmental Science students have been involved with ecological studies of Carter’s Freshwater Mussel (Westralunio carteri), a species listed as Vulnerable by the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species. The students have assisted our lecturer, Michael Kluunzerer who is writing his PhD thesis on the species biology and ecology, to gain vital information about the species habitat requirements, distribution and abundance, as well as impacts from human activities. The students gained practical knowledge and field activity skills.

Aims

• Delivery of training in the environmental industry that links directly to ongoing environmental industry tasks and outcomes, specifically to research.
• Familiarisation and identification of freshwater habitats.
• Collection of base line data required for adaptive management planning and research.
• Participation in field survey and ecology activities.
• Completion of activities related to working in the environmental industry with research scientists.

How was it achieved?

A whole of qualification cluster was linked to on-ground project work. The qualification was delivered approximately 20/80 in the field and in the classroom.

The field component was completed at Lowlands Conservation Association (Bush Forever Site 368) and provided landowners with information about completion of many of the tasks the students were undertaking.

Field work included water quality monitoring, vegetation assessment, mussel density sampling, shell measurements, substrate classification and impact assessment. Occupational health and safety instruction, hazard and risk assessments, completion of job safety analyses, was also part of the course. Navigational activities using GPS and UHF radios was also completed.

The ultimate aim was to create an opportunity for the students to participate in work in this industry and to assist them in understanding aspects of it to help them make a decision regarding future employment and ongoing training in this industry. Completion of this qualification has the potential to lead to employment as field hands for this and related industries.
Project Outcomes

This activity benefitted not only the students but also Murdoch University, the wider community and the state NRM programme (W.A.) (2009-2010). The College remains an active industry participant and values the involvement of staff and students with industry partners. This project demonstrates the potential value that linking the qualification to on-ground actions can have.

After recording baseline habitat, water quality and freshwater mussel ecological data, researchers and landowners gained knowledge of previously unknown information which will be used in a larger state NRM project entitled ‘Protecting and Restoring Freshwater Ecosystem Health in the Serpentine River: An Adaptive Management Approach.’ Water quality information included pH, conductivity, temperature, dissolved oxygen as well as Phosphate and Nitrate concentrations. Freshwater mussel density quadrats revealed that mussels were most abundant in areas containing a mud/sand base with some protection from stream flow. Shell measurements revealed a good range of size classes, including very small juveniles, suggesting recent recruitment. Within the ‘near pristine’ sites of Lowlands forested block, mussels were more abundant. In the ‘impacted’ sites near a cattle crossing, only one dead mussel was found and there was evidence of eutrophication as well as deep detritus with anaerobic decay. The third water body was found to have ongoing acid issues and will now be filled in to control the acidity. Plans are in place to build a more ecologically friendly cattle crossing with fenced-off riparian areas to improve environmental conditions. The completion of safety training, which is identified as a critical aspect to working in the field, gave the students the opportunity to complete tasks related to hazard identification and risk management and emergency planning as well as completion of job safety analyses for environmental activities.

Impacted cattle crossing planned for adaptive management measures.

Future work

This clustered qualification will be developed to fit in even better with on-ground project work.

It is ideally suited as an introduction to working in the environmental industry with employment prospects, as field hands working in impact assessment and environmental management planning in the conservation, agricultural, catchment management, project developments (e.g. Mining and construction) and scientific research (biological, ecological and environmental sciences) industry.
Characteristic riparian vegetation observed during this study
Overstorey plant species

Eucalyptus rudis

Photos: N.D. Burrows & S.D. Hopper

Melaleuca rhaphiophylla

Photos: G. Byrne & A. Ireland

Castarina obesa

Photos: J.M. Richardson & K.R. Thiele
Middlestorey plant species

*Acacia saligna*  Photos: M.I.H. Brooker, B.R. Maslin, M. McDonald, B. Oversby & K.C. Richardson

*Astartea leptophylla*  Photos: P.J. Rye
Middlestorey plant species (cont’d)

Jacksonia sternbergiana
Photos: K.C. Richardson & K.R. Thiele

Melaleuca lateritia
Photos: J.R. Dixon & M. Hancock

Lepidosperma effusum
Photos: B.A. Fuhrer & C. Hertis
Middlestorey plant species (cont’d)

*Pteridium esculentum*  
Photos: A. Ireland & J. Smith

*Parsonsia diaphanophleba*  
Photo: Mark Allen
(INTRODUCED MIDDLESTOREY SPECIES)

*Ficus carica*  
Photos: [http://www.designrulz.com](http://www.designrulz.com)

*Coryza sumatrensis*  
Photos: K. Richardson
**Understorey plant species**

*Baumea articulata*  
*Photos: C. Miller*

*Alternanthera nodiflora*  
*Photos: G. Byrne*
Understorey plant species (cont’d)

Grammatotheca bergiana

Photos: J.F. Smith

Triglochin linearis

Photos: R. Davis
Understorey plant species (cont’d)

(INTRODUCED UNDERSTOREY SPECIES)

- *Paspalum dilatatum*  
  Photo: L. Fontaine

- *Ehrharta calycina*  
  Photos: S.M. Armstrong

- *Cyperus teneriflorus*  
  Photos: R. Davis

- *Juncus usitatus*  
  Photo: [http://www.plantsandlandscapes.com](http://www.plantsandlandscapes.com)
Understorey plant species (cont’d)

(INTRODUCED UNDERSTOREY SPECIES)

*Juncus microcephalus*
*Photos: J. Stevens*

*Cyperus congestus*
*Photos: J.E. Smith*

*Mentha pulegium*
*Photos: R. Knox*

*Dysphania ambrosioides*
*Photo: J. Dodd*
Understorey plant species (cont’d)

(INTRODUCED UNDERSTOREY SPECIES)

Poaceae sp.  Photo: Mark Allen

Watsonia sp.  Photo: Mark Allen
APPENDIX III

The Serpentine River – Then and Now
‘Horse Drink’, Lowlands, Serpentine river ca. 1918, horses pulling logs out of river to make way for the steam pump on the Richardson family property. Photo was originally sent to the boys serving in World War I.

Serpentine River, near Coffee Rocks (December 1940). Bill Richardson and cousin David in homemade canoes.

Serpentine River, near Coffee Rocks (23 February 2011).

Serpentine River in flood over livestock paddocks at Lowlands/Riverlea (1955).
Photo taken from the roof of Bill Richardson’s homestead overlooking the Serpentine River, Riverlea and Lowlands; Midge Richardson’s homestead can be seen in the distance (1939).
Serpentine Falls, before the dam was built (pre World War I).

End of Coffee Rocks facing upstream with child’s play hut built on the rocks near Bill Richardson’s homestead (ca. 1936).

Lucy and Midge Richardson riding their ponies across the Serpentine River after winter rains near ‘Cottage Field Gully’ in the Serpentine River, upstream from the area where Lowlands Gauging Station now stands (1947).

The old bridge crossing the Serpentine River near Midge Richardson’s homestead to the right; an old mail coach track which linked the area to Perth, Mandurah and Bunbury can be seen in the foreground (pre-1942).

Serpentine River in flood over cattle paddocks (ca. 1940’s).