Centre for ecosystem management

EDITH COWAN UNIVERSITY
PERTH WESTERN AUSTRALIA

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Current State of Knowledge of the Black-stripe Minnow *Galaxiella nigrostriata* (Pisces: Galaxiidae) in Western Australia

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Kemerton Silica Sand Pty Ltd

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1 Executive Summary

1. Edith Cowan University (ECU) researchers were commissioned by Kemerton Silica Sand Pty. Ltd. (KSS) to assess and advise on the direction of rehabilitation of dredge ponds and effected natural wetlands within the KSS project area. This report is a part of that commitment and focuses on the aquatic fauna found in the wetlands of the KSS project area and the adjoining Kemerton Nature Reserve.

2. This is the first of three reports on the aquatic fauna of the wetlands at Kemerton with a focus on the black-stripe minnow (*Galaxiella nigrostriata*), to be submitted to KSS by David Galeotti, culminating in a 'Master of Environmental Management' thesis by February 2010.

3. This report is based on information available from an extensive desktop study, and from speaking to a number of experts in the field of freshwater ecology. The current knowledge is described, knowledge gaps documented and suggestions for research directions listed.

4. The KSS mining lease is located on a 1 600 ha block of land at the northern end of Kemerton Industrial Park, near Bunbury south-west Western Australia. The company mines silica sands by mechanically removing the topsoil and then dredging the resource from below the water table.

5. Kemerton Industrial Park contains large areas of remnant or regenerating bushland, lakes and wetlands, surrounded by cleared farmland. Bushland and wetlands include Threatened Ecological Communities, Threatened Fauna and Declared Rare Flora, some of which have national and international conservation significance.

6. Lakes with more than 1 000 m^2 of standing water on 1/12/91 are protected by the Environmental Protection (Swan Coastal Plain Lakes) Policy 1992 (EPP). Having transferred some project land back to state government, KSS has only one and half EPP wetlands remaining on site.

7. In 1993 the black-stripe minnow, a registered conservation species with a number of local, national and international agencies, was found to live in KSS wetlands. Black-stripe minnows' are only found in Western Australia, and in three locations: KSS wetlands, Melaleuca Park north of Perth, and between Augusta and Albany.

8. The aim of this report is to supply background information about black-stripe minnow biology and habitat requirements, highlight any unknown areas of knowledge and suggest questions to be researched.

9. Black-stripe minnows are small slender freshwater fish, distinguishable by two almost full-length longitudinal black stripes on its sides separated by an orange stripe.

10. Although sub-population information is unknown, it is thought that black-stripe minnows are descendants from a Gondwanan lineage, and have been isolated within Western Australia for over 5 million years.

11. Although black-stripe minnows are generally found in acidic seasonal wetlands that are tannin stained and have fringing vegetation, exact habitat requirements are unknown.

12. Knowing their population size is important for conservation purposes, however, the density of known black-stripe minnow populations have not been quantified.

13. Black-stripe minnows are thought to aestivate during the dry periods within the wetland substrate. Anecdotal evidence suggests that crayfish burrows are used to gain entry into the cracks in the substrate, however, particulars of their aestivation has not been scientifically studied.

14. Black-stripe minnows are thought to have a dietary preference for terrestrial insects, although, the studies to date have only looked at what they ate, not what was available.

15. Some reproductive behaviour of the black-stripe minnow has been well documented, however, knowledge gaps remain. Information of the reproductive behaviour is required for captive breeding programs, so fish can be reintroduced into rehabilitated wetlands, and for conservation management strategies.

Frontispiece

Figure 1. Black-stripe minnow Galaxiella nigrostriata, approximately 35 mm total length (McDowall et al. 2004)

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2 Contents

3 Background

Edith Cowan University (ECU) researchers were commissioned by Kemerton Silica Sands Pty. Ltd. (KSS) to assess and advise on the direction of rehabilitation of dredge ponds and effected natural wetlands within the KSS project area. Researchers are acquiring knowledge of existing and future rehabilitation efforts, native vegetation of the area, physio-chemical properties of the water in the wetlands, and aquatic invertebrate and macroinvertebrate communities (C. McCullough, Centre for Ecosystem Management ECU 2008, pers. comm.). In March 2008 a Masters by research student, David Galeotti, began a 2 year project examining the fish and macrocrustacean communities within the wetlands.

The KSS mine is located on a 1 600 ha block of land at the northern end of Kemerton Industrial Park, near Bunbury south-west Western Australia. The company mines silica sands by mechanical removal of topsoil and then extraction of the ore from below the water table by dredging. Kemerton Industrial Park consists of large areas of remnant or regenerating bushland, with areas of lakes and wetlands, surrounded by cleared farmland. The environmental importance of the area is highlighted by the presence of Threatened Ecological Communities, Threatened Fauna and Declared Rare Flora, some of which have national and international conservation significance.

The KSS project area and the adjacent Kemerton Nature Reserve (herein jointly referred to as the Kemerton Wetlands) contain up to 12 mostly seasonal wetlands (McCullough *et al.* 2007). The wetlands range from heavily disturbed, the surrounding land was cleared for farming and has no remaining riparian vegetation, to relatively pristine wetlands only affected by occasional off road vehicles and feral pigs (C. McCullough, CEM ECU 2008, pers. comm.; Bamford *et al.* 2006; McCullough *et al.* 2007). Black-stripe minnow (*Galaxiella nigrostriata*) were discovered during initial aquatic fauna surveys in the Kemerton Wetlands in 1993 (M. Bamford, Bamford Consulting Ecologists 2008, pers. comm.). The discovery was significant because the nearest known population at the time was *ca.* 180 km south, at Doggerup Lake near Northcliffe (Jaensch 1992). Black-stripe minnow are now known from Augusta to Albany, Melaleuca Park north of Perth and Kemerton Wetlands (Morgan *et al.* 1998; Allen *et al.* 2002; Bamford *et al.* 2006).

Surveys at the Kemerton Wetlands have recorded four fish species endemic to the south-west of Western Australia and one exotic species. These are: black-stripe minnow (*G. nigrostriata*), western minnow (*Galaxias occidentalis*), western pygmy perch (*Edelia vittata*), nightfish (*Bostockia porosa*) and exotic mosquitofish (*Gambusia holbrooki*) (Bamford *et al.* 2006). All of the above species are well represented in most watersheds in south-west Western Australia, except for black-stripe minnow, which have a limited distribution and are mainly found in seasonal wetlands. However, black-stripe minnow have been the most consistently found fish species during surveys of the Kemerton Wetlands (Bamford *et al.* 2006). Black-stripe minnow were listed in 1994 as a priority species with the Department of Environment Conservation Western Australia (DEC) and are currently still listed (P. Mawson, Threatened Species Scientific Committee DEC 2008, pers. comm.).

Galaxiella nigrostriata was originally given the common name of black-striped minnow when described by Bruce Shipway in 1953. Since that time the name black-striped minnow, and more generally black-stripe minnow, has been used within virtually all of the known literature. It has only been in the last 10-15 years that occasional reports have used the name black-striped jollytail. This report follows the majority of work by referring to *G. nigrostriata* as the black-stripe minnow.

4 Biology and Ecology

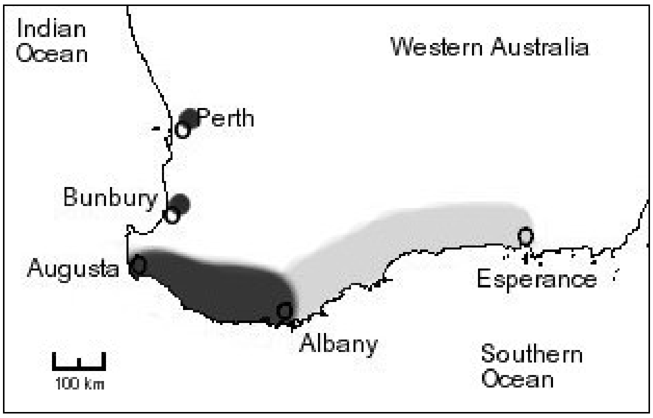
4.1 Distribution

The Galaxiidae family are found below 32° south within cool temperate regions in the southern hemisphere, namely, South America, southern Africa, New Caledonia, New Zealand and Australia (Allen *et al.* 2002; McDowall 2006). Galaxiidae live in a range of aquatic habitats including fast flowing upland streams, slow moving rivers, swamps, permanent lakes and seasonal pools (McDowall 1990; Allen *et al.* 2002). Galaxiidae consist of 8 genera and *ca*. 56 species worldwide; in Australia there are 4 genera and 20 species and the highest diversity (4 genera, 17 species) is found in Tasmania (Allen *et al.* 2002; McDowall 2006).

The south-west region of Western Australia is inhabited by ten native freshwater fish species, of which eight are endemic (Morgan *et al.* 1998). Of the endemic species there are three Galaxiidae which include the black-stripe minnow (Morgan *et al.* 1998). There are only three species of the genera *Galaxiella* in the world, and are all located in southern Australia (McDowall *et al.* 1981). The black-stripe minnow and mud minnow (*G. munda*) inhabit the south-west of Western Australia, and the dwarf or eastern little galaxiid (*G. pusilla*) is found from south-eastern South Australia to western Victoria and northern Tasmania (McDowall *et al.* 1981; Morgan *et al.* 1998; Knott *et al.* 2002). The black-stripe minnow was originally described as *Galaxias pusillus nigrostriatus* subsp. by Shipway (1953) from specimens collected near Albany, Western Australia, due to its similarities with the dwarf galaxiid.

Black-stripe minnow are typically found in seasonal pools up to 100 km from the coast, with limited connectivity to surrounding wetlands (Pusey *et al.* 1990; Morgan *et al.* 2000). Their main habitat is located between Augusta and Albany (see Figure 2), with the main population centred around Windy Harbour in the D'Entrecasteaux National Park (Morgan *et al.* 1998; Morgan *et al.* 2000). There are two known outlier populations, one about 30 km NNW of Perth at a Melaleuca Park wetland designated EPP173 and the other 130 km south of Perth in wetlands within the Kemerton Wetlands near Bunbury (Morgan *et al.* 1998; Bamford *et al.* 2002; Knott *et al.* 2002).

The outlier locations are *ca.* 360 and 210 km north of the main southern population. The two northern populations are believed to be naturally occurring remnants of a greater distribution on the Swan Coastal Plain (SCP), prior to the widespread habitat destruction that followed British settlement over 150 years ago (Hill *et al.* 1996; Smith *et al.* 2002b).



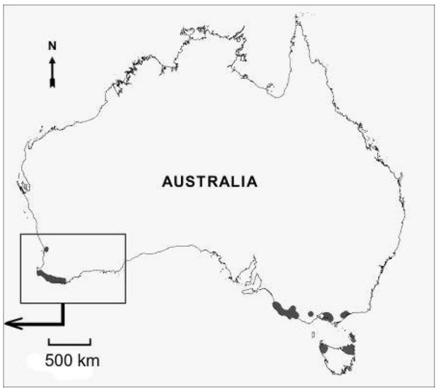


Figure 2. Distribution of black-stripe minnow (Left) – dark shaded areas show their reported distribution after 1996, light shading before 1996. Shading indicates distribution of mud minnow in Western Australia and dwarf galaxiid in eastern Australia (Right).

Since 1996, black-stripe minnow distribution is thought to be from Augusta to Albany, and includes the two outlier populations (Gill *et al.* 1996; Morgan *et al.* 1998; Allen *et al.* 2002; McDowall 2006). Confusion surrounds the distribution of the black-stripe minnow prior to 1996. Gill *et al.* (1994) list the distribution as between Northcliffe and Esperance, while previous to 1994 other researchers suggested black-stripe minnow distribution was between Albany and Esperance (Coy 1979; McDowall *et al.* 1981) and also near Busselton (Griffiths 1972). However, one researcher has consistently recorded black-stripe minnow distribution as between Augusta and Albany (Allen 1982; 1989; Allen *et al.* 2002). The research prior to 1990 does not list any specimens taken or wetlands surveyed east of Albany. The change of distribution over the past four decades is also not explained by specimens held by local museum collections (except one individual specimen from near Esperance, nearly 400 km east of Albany (WAM 2003), which warrants re-examination). Specimens misidentified as black-stripe minnow, as has happened with *G. munda* (McDowall *et al.* 1981), may have been collected prior to 1990 during surveys east of Albany and held at other national or international museums. Knowledge of the past distribution of black-stripe minnow is important for determining the rate at which their range is contracting (if it is?), which would give more cause for conservation efforts to be increased.

How black-stripe minnows move between unconnected wetlands or how they appear in wetlands that have been dry for extended seasons or years is not fully understood. The dwarf galaxiid is thought to move between water bodies in as little as 2 mm of water (Beck 1985), which could occur during sheet flow from heavy rainfall. Understanding black-stripe minnow movement between wetlands would help determine the types of barriers (natural or man made) that may restrict their dispersal into other wetlands. Knowledge of the dispersal ability of black-stripe minnows may also direct conservation management such as habitat rehabilitation.

4.2 Physical Description

Galaxiidae consists of fish that are scaleless, have only one dorsal fin, average from 40 mm to 150 mm in length and typically have slender cylindrical bodies (McDowall 1990; Allen *et al.* 2002). *Galaxiella*, along with another small genera *Brachygalaxias* (only one or two species), are distinct within the *ca.* 56 species of Galaxiidae for having, among other differences, longitudinal orange stripes, less than 7 pelvic fin rays, a large eye relative to their head size (28–30% of head length) and a fleshy abdominal keel (McDowall *et al.* 2004). Black-stripe minnow are small freshwater fish (see Figure 1), with the males reaching a maximum total length (TL) of 44 mm and the females 48 mm TL (Morgan *et al.* 1998). Black-stripe minnow have an elongate body that is mostly grey-tan with a white underside (Morgan *et al.* 1998; Allen *et al.* 2002). From the early larval stages, black-stripe minnow have two black longitudinal stripes that run from the eye to the base of the tail and are divided by a yellow to red stripe (Gill *et al.* 1994; McDowall *et al.* 2004). In males, it is possible the stripe becomes brighter as the fish sexually mature and may start to fade after spawning in September, and has disappeared by January (Gill *et al.* 1994; Morgan *et al.* 1998).

The black-stripe minnow's fading stripe has not been explicitly associated with male or female fish, or their stage of sexual maturity. It has been suggested that sexual dimorphism may occur in the black-stripe minnow as it does with the congeneric dwarf galaxiid (Backhouse 1983; Chilcott *et al.* 1996), but has not been specifically examined (McDowall *et al.* 2004). If an observer is not aware of the fading stripes on black-stripe minnow they may confuse it with the similarly coloured mud minnow (as has already happened (McDowall *et al.* 1981)). Misidentification may affect distribution and population abundance estimates of species or male to female ratios. Presently the black-stripe minnow needs to be euthanized to determine the gender and sexual maturity by removing and weighing the gonad and, if developed, the testis or ovaries (Pen *et al.* 1993). If black-stripe minnow were sexually dimorphic, then determining their sex from external characteristics would be less damaging to populations. Captive breeding could be used to restock rehabilitated wetlands or to build up numbers in diminishing populations. Establishing the sex and stage of maturity of live individuals may also allow for a more appropriate selection process for captive breeding programs.

4.3 Evolution

Galaxiidae evolved from lower euteleostean fishes which diverged over 200 million years ago (Ma) during the early Jurassic era (McDowall 2006; Inoune 2008). Galaxiid fishes are believed to have a Gondwanan origin given that there are representative species on all southern hemisphere landmasses except Antarctica (see 4.1 Distribution) (Morgan *et al.* 1998; Allen *et al.* 2002; McDowall 2006). Therefore, high endemism found in Galaxiidae in Australia is a result of the long-term geographical isolation of Australia (over 37 million years), plus the paucity of river systems and high occurrence of temporary wetlands (Morgan *et al.* 1998; Allen *et al.* 2002; McDowall 2006).

Given how similar the three *Galaxiella* species are and the *ca.* 2 000 km gap between western and eastern populations (see Figure 2 right), it has been suggested that their origins are from the same location, i.e., the *Galaxiella's* dispersed either from eastern Australian to the west, or vice-versa (Chilcott *et al.* 1996). This may have been possible when rivers were more plentiful as seas transgressed the continent several times from the Eocene to mid Miocene (*ca*. 55 – 15 Ma) (Unmack 2001). The most recent time period that freshwater fish might have migrated from east to west may have been *ca.* 5 Ma at the end of the Miocene (Unmack 2001). This may have been the case for now non-diadromous Galaxiidae species, having evolved to live in freshwater after becoming landlocked into freshwater systems as sea levels subsided (as in other Galaxiidae: Waters *et al.* 2001).

Allozyme electrophoresis and morphometric analyses compared the black-stripe minnows' northern outlier population with the main southern populations to examine any possible genetic divergence (Smith *et al.* 2002b). Both populations were genetically and morphologically very similar. However, the northern population were genetically monomorphic while the main southern population had a low degree of polymorphism, indicating the northern population may have been affected by inbreeding as a result of isolation (Smith *et al.* 2002b).

To further assess the genetic differences between black-stripe minnow populations, it has been suggested that mitochondrial DNA (mtDNA) analysis may provide a more accurate measure than the allozyme electrophoresis method (D. Morgan, Centre for Fish and Fisheries Research 2008, pers. comm.). The use of mtDNA may allow the path of dispersal to be more accurately mapped, and furthermore, mtDNA analysis may help determine whether the southern and two northern populations of black-stripe minnow are part of a meta-population, or are separate populations or subspecies. If the populations are genetically identical then deliberate translocations could occur between them to restock diminishing populations or rehabilitated wetlands and their conservation priority value might be re-evaluated (see Section 5, Table 2). However, a finding of three genetically divergent populations may conversely justify applying a higher conservation status and more intensive management of each sub-population.

4.4 Habitat Preferences

Black-stripe minnow larvae are thought to spend most of their time in flooded riparian vegetation, and frequent the open water as they mature (Morgan *et al.* 1998). Adults are thought to school and spend much of their time in the middle of the water column (metalimnion), which is typically where they feed (Thompson *et al.* 1999). Black-stripe minnow are an entirely freshwater species along with the congeneric mud minnow and dwarf galaxiid (Chilcott *et al.* 1996). Black-stripe minnow typically inhabit vegetated water that is *ca.* 30 cm deep, is highly tannin stained and has a pH and temperature range of 3.0–8.0 and 11–30°C respectively (Jaensch 1992; Gill *et al.* 1996; Morgan *et al.* 1998; Allen *et al.* 2002). Black-stripe minnow have aby this project. lso been recorded in slow-moving streams and lakes (McDowall *et al.* 1981; Trayler *et al.* 1996; Morgan *et al.* 1998).

Wetlands that black-stripe minnow inhabit are generally surrounded by fringing vegetation such as paperbarks (*Melaleuca* sp.) and rushes (*Baumea* sp.) (see Figure 3) (Morgan *et al.* 1998; Knott *et al.* 2002). These wetlands can be found within karri and jarrah forest (*Eucalyptus diversicolor* and *E. marginata*) and coastal peat flats in the south, and *Banksia menziesii* open woodlands where the northern outlier populations exist (Morgan *et al.* 1998; Knott *et al.* 2002). Black-stripe minnow have not been found in wetlands surrounded by cleared farmland (Morgan *et al.* 1998). Wetlands within the southern populations' main area of distribution generally dry up around December and remain dry until the early wet season begins in around June (see Table 1 Page 16 for season descriptions) (Pusey *et al.* 1990).

The presence of black-stripe minnow have only been correlated to surrounding vegetation on a landscape scale and not an individual wetland scale. It is therefore unknown what preference the larvae and adult black-stripe minnow have for emergent vegetation type, shade requirements, submerged logs and woody debris, or the type of benthic substrate. Apart from Jaensch (1992), available reports have not described where traps have been set, for example the type of fringing vegetation or water depth. Understanding their preferred niche would limit areas to be surveyed and provide information for rehabilitation requirements.

Figure 3. Black-stripe minnow habitats.
Above left - Melaleuca Park (dry)
Above right - Kemerton Wetlands
Bottom - Roadside pool in coastal heathlands, Scott River Road near Augusta.

Photos – C. McCullough and D. Morgan.

Little is known about the preferred physico-chemical water properties in black-stripe minnow habitats. To fully understand their habitat requirements, water properties such as dissolved oxygen, salinity, water depth ranges or flow velocity, are required. Knowledge of physico-chemical water properties are important for rehabilitating wetlands for fish re-introductions and baseline information for future monitoring of water quality as an indicator of fish health.

Table 1. Seasonal descriptions from close to the centre of the black-stripe minnow's southern population range (Pemberton), as determined by Pusey and Edward (1990) and Pusey and Bradshaw (1996).

	Seasons			
	Early wet	Mid wet	Late wet	Dry
Months	June/July	August/ September	October to December	January to May
Description	Rain begins, pools start to fill, streams start to connect pools	Highest rainfall, flooding on the plains, most pools connected to permanent water	Rainfall easing, stream flow slows, pools drying and are no longer connected to permanent water	Evaporation exceeds rainfall. Most streams and pools dry

4.5 Population Size

Some earlier general fish surveys recorded zero or low numbers of black-stripe minnows because of a lack of knowledge of habitat requirements for black-stripe minnows (i.e. preference for seasonal wetlands) and consequently surveyed when seasonal wetlands were dry (Christensen 1982; Jaensch 1992). More recent surveys have targeted specific areas and seasons to include their capture (Morgan *et al.* 1998; Smith *et al.* 2002a). When found, black-stripe minnow are described as common to locally abundant (Pusey *et al.* 1990; Gill *et al.* 1996; Morgan *et al.* 1998). However, none of the studies have quantified wetland population abundances or densities. Black-stripe minnow were reported as extinct in one pool at Kemerton Wetlands, only to appear in abundance in subsequent surveys the following season (Bamford *et al.* 2003).

The recent finding of populations of black-stripe minnow outside established distribution areas leave open the possibility that other relic populations may exist. Most rivers and wetlands within south-west Western Australia have been systematically surveyed for freshwater fish species over the last three decades (D. Morgan, CFFR 2008, pers. comm.; Christensen 1982; Jaensch 1992). However, many of the wetlands surveyed were within National Parks or on Crown Land. There are *ca.* 10 000 wetlands on the SCP alone (Balla 1994). So it is possible some water bodies have not been surveyed, particularly wetlands on private property. New populations would have value to conservation management as new genetic brood stock for captive breeding programs or for stock to be translocated or reintroduced into local rehabilitated wetlands.

4.6 Aestivation

Aestivation within Galaxiidae is limited to black-stripe minnow, dwarf galaxiid and possibly all six mudfish (*Neochanna* sp.) (McDowall 2006). The mud minnow is not known to aestivate (McDowall 2006). Black-stripe minnow appear to aestivate as a survival mechanism, given the temporary nature of their preferred habitat (Pen *et al.* 1993). Black-stripe minnow aestivate in the damp soil/peat substrate when wetlands dry up, and appear again when a pool naturally or artificially fills (Berra *et al.* 1989;

Pen *et al.* 1993; Morgan *et al.* 1998). Black-stripe minnow are often captured in wetlands along with salamanderfish *Lepidogalaxias salamandroides*, which is also an aestivating species and has similar habitat requirements (Jaensch 1992; Morgan *et al.* 2000). Anecdotal evidence suggests the black-stripe minnow use crayfish burrows for aestivation when wetlands dry up (D. Morgan CFFR 2008, pers. comm.; Thompson *et al.* 1999; Bamford *et al.* 2003; McDowall 2006).

Researchers have generally been unsuccessful when trying to find aestivating black-stripe minnow by digging trenches in the substrate of dry pools (Pen *et al.* 1993; Smith *et al.* 2002a). One report shows they were found while digging for salamanderfish, as pools were starting to dry in December/January (Berra *et al.* 1989). Other Galaxiid species, such as the dwarf galaxiid, are known to use crayfish burrows to hide in when disturbed or for aestivation when water levels fall (Beck 1985; Allen *et al.* 2002). Use of crayfish burrows by black-stripe minnow is unknown. It may be an unlikely survival strategy as resident crayfish do not enter a state of torpor, merely burrowing as a way of staying moist and may attack small fish entering burrows (P. Horwitz, CEM ECU 2008, pers. comm.)

Origin and quality of water within the substrate and burrows of black-stripe minnow habitat is unknown. The water may be from the surface expression of a superficial aquifer, or rainfall trapped by an impermeable base forming a perched wetland. Wetlands that rely on groundwater may be impacted by local groundwater extraction or decreases in long-term rainfall. Abstraction by bores may cause drawdown in localised areas, resulting in wetland pools remaining dry for longer periods throughout the dry and early wet season.

How long black-stripe minnows can aestivate for and mortality rates while aestivating are unknown. The effect of groundwater depth below wetlands and substrate type where black-stripe minnows aestivate is also unknown. In addition, it unknown if they <u>need</u> to aestivate to complete their life cycle, or if they undergo any physical changes while aestivating. Given the short (one year) life cycle of the black-stripe minnow, aestivation is a critical stage and must be considered when designing rehabilitation, conservation and management plans.

4.7 Diet

Black-stripe minnows are primarily carnivores and feed in the upper water column and the surface, with their diet thought to follow seasonally available prey (Pusey *et al.* 1996). The main southern population of juveniles and adults (>20 mm TL) regularly consumed calanoid and harpacticoid copepods, flying ants and adult Dipterans, and in summer and autumn Diptera pupae and larvae and diatoms were also taken (Pen *et al.* 1993; Gill *et al.* 1996; Smith *et al.* 2002a). In winter the preflexion to flexion larvae (7–11 mm TL) predominantly fed on rotifers, and postflexion larvae (12–23 mm TL) ate Collembola and Diptera larvae (Gill *et al.* 2003). The diet of the Melaleuca Park population was very similar to the main southern population, except for low quantities of terrestrial insects being eaten (5% of total intake at Melaleuca Park compared to 20–50% in southern populations) (Smith *et al.* 2002a). Black-stripe minnow do not seem to compete with their main co-inhabitant, salamanderfish, in the southern populations as salamanderfish are primarily benthic feeders (Pusey *et al.* 1996; Gill *et al.* 2003).

There are conflicting views on the position of black-stripe minnow in the water column. Research has shown that they are generally found swimming in the metalimnion feeding on terrestrial macroinvertebrates (Pusey *et al.* 1996). However, some laboratory experiments suggest they spend most of their time just above the substrate (Smith *et al.* 2002a). The time of day and season may determine their position in the water column, but has not been investigated.

The aquatic macroinvertebrate community structure has not been surveyed while conducting dietary analyses of black-stripe minnow. Diet studies instead focused on what they ate, not necessarily what was available. Knowing if their diets are limited by what is available may help predict overall health of a population. Was the variation in diet between northern and southern populations due to availability? Knowledge of the black-stripe minnow diet is important for captive breeding programs, assessing suitable habitat for translocation, or conservation and rehabilitation efforts.

4.8 Reproduction

Reproductive behaviour of black-stripe minnow is not fully understood, however parallels may be drawn with the congeneric dwarf galaxiid and mud minnow (McDowall *et al.* 2004). It is thought that the fleshy abdominal keel is used to guide the female onto surfaces such as leaves or rocks to precisely lay her individual eggs (McDowall *et al.* 2004), which are then fertilised by the male, as observed in the dwarf galaxiid (Backhouse 1983). Each female black-stripe minnow lays *ca.* 62 eggs per season, possibly over a period of a couple of weeks (Pen *et al.* 1993). When the larvae hatch they are about 3.5 mm TL and develop their stripes soon after (Gill *et al.* 1994; Morgan *et al.* 1998). Black-stripe minnow become sexually mature when nearly one year old, the following spawning season, and die soon after (Pen *et al.* 1993). Individual black-stripe minnow in aquaria have lived to about eighteen months (M. Bamford, BCE 2008, pers. comm.).

Spawning in the southern populations of black-stripe minnow occur between June and September, which coincide with the early to mid wet seasons (for seasonal descriptions see Table 1 on page 16) (Gill *et al.* 1994; Morgan *et al.* 1998). Spawning peaks during the mid-wet when water temperatures and daylight hours are at a minimum (Pen *et al.* 1993; Gill *et al.* 1994; Morgan *et al.* 1998). The black-stripe minnow population at Melaleuca Park is reported to start spawning a month later than the main southern population, and the Kemerton population may start around August (Smith *et al.* 2002a; Bamford *et al.* 2003).

Since other behaviours of black-stripe minnow differ to the congeneric dwarf galaxiid and mud minnow, such as habitat preference and aestivation practices, direct comparison of reproductive behaviour should not be assumed. Only detailed research can determine the reproductive behaviour of black-stripe minnow. Knowing spawning season timing for black-stripe minnow may improve catch rates of juveniles or overall population abundance, help predict when larvae or juveniles are more prone to predation or the unseasonal drying of a wetland. Knowledge of black-stripe minnow reproductive behaviour is also essential to the success of captive breeding programs. As mentioned previously, captive breeding of black-stripe minnows may be used to reintroduce fish into rehabilitated wetlands or increase fish numbers in marginal populations.

5 Threatening Processes and Conservation Status

Since European settlement in Western Australia up to 80% of wetlands on the SCP have been drained or degraded due to expanding population and agriculture (Balla 1994), and within the SCP from Harvey to Dunsborough 95% of wetlands have been filled or drained for agriculture (Riggert 1966). While the latter figure is over 40 years old, continued urban and rural expansion since that time would have done little to reduce the degradation of wetlands. Agriculture and the subsequent damage to wetlands from infilling, vegetation removal, hard hoofed cattle and insecticide use reduce the suitable habitat and water quality for freshwater fish (Beck 1985; Morgan *et al.* 1998). Further to this, most freshwater organisms are adversely affected by eutrophication caused by excessive amounts of phosphates derived from fertilisers, which can turn waterbodies hypoxic (Thompson *et al.* 1999; Landman *et al.* 2005).

Some threatening processes that may effect black-stripe minnow populations include (Trayler *et al.* 1996; Morgan *et al.* 1998; Smith *et al.* 2002a; Watterson *et al.* 2007):

- some seasonal pools where the black-stripe minnow exist have been excavated when dry, with the soil used for fill, or the dry pools filled in during road maintenance
- the practise of prescribed burning can cause the rich organic substrate in seasonal wetlands to burn for extended periods, killing any fish that may be aestivating within the substrate
- clearing or modification for roads, forestry, dams and other such infrastructure
- the encroachment of urbanization
- mineral and quartzite sand mining under wetlands
- excessive groundwater extraction causing unseasonal or extended dry periods
- predicted climate change: decreasing rainfall, higher mean temperatures and increase in evapotranspiration in south-west Western Australia
- changing the tenure of reserves, when protected areas are no longer protected from agriculture, mining, or other habitat altering activities

Introduced exotic fish species may impact upon native species through competition for food, or aggressive/predatory behaviour that causes displacement, injury or death (Rowe 2007). For example, the mosquitofish (*Gambusia* sp.) prefer shallow still water and may show aggressive behaviour (fin-nipping) toward other species, particularly when water temperature is over 20°C (Morgan *et al.* 2004; Rowe 2007). However, the extent of aggressive behaviour or displacement from a niche is unsure. One report shows 100% mortality of black-stripe minnow caused by aggressive mosquitofish (Griffiths 1972), and with Midgley's gudgeons (*Hypseleotris* sp. 5) there is possible competition for food (Stoffels *et al.* 2003). Other authors disagree about the impact mosquitofish have on native species (Ling 2004; Becker *et al.* 2005). One advantage black-stripe minnow have over introduced species is the ability to aestivate during dry periods. Exotic (and most native) species known to Western Australian wetlands cannot aestivate, therefore die or leave an area that dries. However, exotic species could still have an effect on black-stripe minnow populations as water subsides and population densities increase, by attacking black-stripe minnow's and preventing them from aestivating.

Black-stripe minnow are listed with a number of local, national and international government and non-government agencies as a species of concern as shown in Table 2. To enable black-stripe minnow to survive into the future a number of management options may be considered. Protection of habitat and surrounding areas may be achieved by continuing existing and creating new nature reserves to encompass wetlands and provide substantial buffer zones. Where black-stripe minnow are found in degraded habitats, rehabilitation and a change in land use may be advisable. Breeding programs would allow rehabilitated wetlands to be restocked to widen their geographic range. Further research into distribution and habitat requirements might provide maps so likely habitat could be surveyed and protected if necessary. Physical barriers to prevent exotic species entering neighbouring un-infested waterways or educating the public about the impact of releasing exotic species may also assist black-stripe minnow survival prospects.

Table 2. Conservation status of *Galaxiella* species by local, national and international agencies. Conservation categories are detailed in Appendix 8.1.

	Agency		
Fish species	Department of Environment and Conservation (DEC) (DEC 2008)	Australian Society of Fish Biology (ASFB) (ASFB 2007)	International Union for Conservation of Nature (IUCN) (Wager 2007)
Black-stripe minnow *G. nigrostriata*	Priority 3	Restricted	Lower Risk-near threatened
Mud minnow *G. munda*	Vulnerable	Restricted	Lower Risk-near threatened
Dwarf galaxiid *G. pusilla*	N/A	Potentially threatened	Vulnerable

6 Conclusions and Research Suggestions

There has been much work done on black-stripe minnow over the last four decades, although there are still considerable gaps in the knowledge. Many of the 'gaps' can be related to their habitat requirements, and are linked directly to management and conservation needs. To assist black-stripe minnow survival in the future, the following is a list of suggested areas of research.

Physical description

1. Can the sex of black-stripe minnow be determined from their morphology?
2. Are black-stripe minnow sexually dimorphic?
3. Do the stripes change according to their sexual maturity?

Distribution

4. The past distribution needs verification by examining specimens held in museums or private collections both locally and around the world.
5. Develop a GIS program to locate and/or map preferred habitat type of black-stripe minnow.
6. Survey areas that have been missed in past surveys.

Meta-population?

7. Are all of the populations part of a meta-population?
8. Are southern and the two northern populations genetically divergent? The three populations should be compared and evaluated using mtDNA analysis.
9. Where black-stripe minnow populations are known, is there a wetland where a constant main population survive, amongst other wetlands?
10. Population density at all wetlands need to be estimated/measured.
11. What habitat type within wetlands do black-stripe minnow prefer?

Mechanisms of aestivation

12. Do black-stripe minnow need to aestivate to survive?
13. What percentage of black-stripe minnow survive aestivation?

14. What type of habitat is required for aestivation (substrate type)?
15. How does the depth of groundwater under wetlands affect aestivating black-stripe minnows?
16. Do black-stripe minnow use crayfish burrows?
17. Do black-stripe minnow have a symbiotic relationship with crayfish, or do the fish just use the burrow as a means of gaining access to the cracks (or whatever) in the substrate?

Water quality

18. Do black-stripe minnow have specific water quality requirements?
19. Does gilvin play a role in the positioning of black-stripe minnow in the water column or diurnal patterns? Is there a preferred position in the water column?

Diet

20. What is the feeding preference (diet) of the black stripe minnow?
21. Do black-stripe minnow have diurnal periods of increased activity, such as feeding?

Reproductive behaviour

22. Further research is required into the fertilization and laying of eggs, where and how they are laid, and the number and time period which they are laid.

Interspecific behaviour

23. Do black-stripe minnow live in habitats that dry because of the particular types of food, other fish (symbiotic relationships) or vegetation that is available?
24. Are black-stripe minnow populations affected by mosquitofish? Is there competition for food or position in the water column, aggressive behaviour?

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8

8 Appendices

8.1 Conservation status categories

The black-stripe minnows' status is underlined.

Department of Environment (DEC 2008)

Priority One: Taxa with few, poorly known populations on threatened lands.

Taxa which are known from few specimens or sight records from one or a few localities on lands not under immediate threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, vacant Crown land, water reserves, etc. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Two: Taxa with few, poorly known populations on conservation lands.

Taxa which are known from few specimens or sight records from one or a few localities on lands not under immediate threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, vacant Crown land, water reserves, etc. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Three: Taxa with several, poorly known populations, some on conservation lands.

Taxa which are known from few specimens or sight records from several localities, some of which are on lands not under immediate threat of habitat destruction or degradation. The taxon needs urgent survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Priority Four: Taxa in need of monitoring.

Taxa which are considered to have been adequately surveyed, or for which sufficient knowledge is available, and which are considered not currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on conservation lands.

Priority Five: Taxa that are conservation dependent (i.e. their conservation status is dependent on ongoing active management).

Taxa which are not considered threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

Australian Society for Fish Biology (ASFB 2007)

Extinct: Taxa which are no longer found in the wild or in a domesticated state.

Endangered: Taxa which have suffered a population decline over all or most of their range, whether the causes of this decline are known or not, and which are in danger of extinction in the near future. (Special management measures are required if the taxa are to continue to survive)

Vulnerable: Taxa not presently endangered but which are at risk by having small populations and/or populations which are declining at a rate that would render them endangered in the near future. (Special management measures required to prevent taxa becoming endangered or extinct)

Potentially Threatened: Taxa which could become vulnerable or endangered in the near future because they have a relatively large population in a restricted area; or they have small populations in a few areas; or they have been heavily depleted and are continuing to decline; or they are dependant on specific habitat for survival. (Require monitoring)

Indeterminate: Taxa which are likely to fall into one of the Endangered, Vulnerable or Potentially Threat4ened categories but for which insufficient data are available to make an assessment. (Require investigation)

Restricted: Taxa which are not presently in danger but which occur in restricted areas, or which have suffered a long term reduction in distribution and/or abundance and are now uncommon.

Uncertain Status: Taxa whose taxonomy , distribution and/or abundance are uncertain but which are suspected of being Restricted.

International Union for Conservation of Nature and Natural Resources (Wager 2007)

Extinct (EX): A taxon is Extinct when there is no reasonable doubt that the last individual has died.

Extinct in the wild (EW): A taxon is Extinct in the wild when it is known only to survive in cultivation, in captivity or as a naturalised population (or populations) well outside the past range. A taxon is presumed extinct in the wild when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.

Critically endangered (CR): A taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild in the immediate future, as defined by any of the criteria (A to E) as described below.

Endangered (EN): A taxon is Endangered when it is not Critically Endangered but is facing a very high risk of extinction in the wild in the near future, as defined by any of the criteria (A to E) as described below.

Vulnerable (VU): A taxon is Vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future, as defined by any of the criteria (A to E) as described below.

Lower risk (LR): A taxon is Lower Risk when it has been evaluated, does not satisfy the criteria for any of the categories Critically Endangered, Endangered or Vulnerable. Taxa included in the Lower Risk category can be separated into three subcategories:

Conservation Dependent (cd): Taxa which are the focus of a continuing taxon-specific or habitat-specific conservation programme targeted towards the taxon in question, the cessation of which would result in the taxon qualifying for one of the threatened categories above within a period of five years.

Near Threatened (nt): Taxa which do not qualify for Conservation Dependent, but which are close to qualifying for Vulnerable.

Least Concern (lc): Taxa which do not qualify for Conservation Dependent or Near Threatened.

Data deficient (DD: A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution is lacking. Data Deficient is therefore not a category of threat or Lower Risk. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases great care should be exercised in choosing between DD and threatened status. If the range of a taxon is suspected to be relatively circumscribed, if a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

Not evaluated (NE): A taxon is Not Evaluated when it is has not yet been assessed against the criteria.