

## Black-stripe minnow *Galaxiella nigrostriata* (Shipway 1953) (Pisces: Galaxiidae), a review and discussion

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### Abstract

*Galaxiella nigrostriata* is a small freshwater fish endemic to the southwest of Western Australia. *Galaxiella nigrostriata* are unusual because they aestivate in the sediments of seasonal wetlands when the wetlands dry over summer. Although once thought to be more extensively distributed in coastal wetlands between Moore River and Albany, they are now only found in three remnant populations on the Swan Coastal Plain and wetlands between Augusta and Albany. This review brings together all aspects of *G. nigrostriata*'s life cycle, the most significant findings of research to date and highlights areas lacking in knowledge, most importantly aestivation habits. With the main threats to their conservation being a drying climate, increasing pressure on groundwater resources and competition for land use, research is needed to direct management of this charismatic species, particularly within remnant populations.

**Keywords:** Black-stripe minnow, *Galaxiella nigrostriata*, Galaxiidae, seasonal wetlands, aestivate, Swan Coastal Plain, south-west Western Australia

### Introduction

The Galaxiidae family are freshwater fish thought to have Gondwanan origins and are found below 32° south within cool-temperate regions in the southern hemisphere, namely, South America, southern Africa, New Caledonia, New Zealand and Australia (McDowall & Frankenberg 1981; Allen *et al.* 2002; McDowall 2006). The Galaxiidae consist of 8 genera and *ca.* 56 species, of which 4 genera and 20 species are found in Australia (McDowall 2006). There are only three species in the galaxiid genus *Galaxiella*, and are all located in southern Australia (Allen *et al.* 2002). *Galaxiella nigrostriata* and *G. munda* (mud minnow) inhabit the south-west of WA, and *G. pusilla* (dwarf galaxiid) is found from south-eastern South Australia to southern Victoria and northern Tasmania (Morgan *et al.* 1998; Allen *et al.* 2002). The south-west region of Western Australia (WA) has ten native freshwater fish species, of which eight are endemic (Morgan *et al.* 1998). Of the endemic species three are Galaxiidae, including *Galaxiella nigrostriata* (Morgan *et al.* 1998).

*Galaxiella nigrostriata* is a small endemic freshwater fish that lives in seasonal wetlands in south-west Western Australia, spread between Augusta and Albany and in three remnant populations on the Swan Coastal Plain (SCP) (Morgan *et al.* 1998; Smith *et al.* 2002b; McLure & Horwitz 2009). The three populations on the SCP are believed to be naturally occurring remnants of a greater distribution on the SCP (Morgan *et al.* 1998; Smith *et al.* 2002b), prior to widespread habitat destruction that

followed European colonisation over the last 180 years (Hill *et al.* 1996; Horwitz *et al.* 2009). It is thought that up to 80% of wetlands on the SCP in WA have been drained or otherwise degraded, mostly for urbanisation and agriculture (Seddon 1972; Balla 1994; Davis & Froend 1999). This figure is likely to increase with ongoing urban and rural expansion and predicted ongoing declining rainfall patterns across south-west WA (Watterson *et al.* 2007) continuing to reduce the fisheries value and size, and number of remaining wetlands in this area. Indeed, the reduced distribution of many native freshwater fish species to the relatively pristine areas of the south-west corner of WA is considered to be due to widespread degradation of wetlands on the SCP (Morgan *et al.* 1998; Allen *et al.* 2002). Unfortunately, the sanctuary of national parks where many of the southern *G. nigrostriata* populations remain may also be subject to external pressures (Trayler *et al.* 1996). These conservation issues are not restricted to south-west WA, wetlands in other temperate regions (Brinson & Malvárez 2002; van Diggelen *et al.* 2006), groundwater influenced wetlands (Danielopol *et al.* 2003; Martínez-Santos *et al.* 2008) and wetlands in general throughout Australia and around the world are facing the same ongoing problems (Semlitsch & Bodie 1998; Finlayson & Rea 1999; Baron *et al.* 2002).

This review was undertaken to facilitate further research and management of *G. nigrostriata*. Given their preference for seasonal wetlands and the issues associated with that type of habitat, their future faces many challenges. We intend that the information provided here will give a good starting point for land managers to begin their conservation efforts for this charismatic endemic species.



Figure 1. Adult *Galaxiella nigrostriata*, approximately 30 mm total length. (Courtesy G. Allen)

### Description

Galaxiidae are scaleless fish that have only one dorsal fin, typically have slender cylindrical bodies and maximum lengths range from 40 mm (*G. pusilla*) to 580 mm (*Galaxias argenteus* – New Zealand) (McDowall 1990; Allen *et al.* 2002; McDowall 2006). *Galaxiella*, along with the small monospecific genus *Brachygalaxias* is distinct within the *ca.* 56 species of Galaxiidae for having, among other differences, a lateral longitudinal orange stripe, less than seven pelvic fin rays, a large eye relative to their head size (28–30% of head length) and a fleshy abdominal keel (McDowall & Waters 2004).

*Galaxiella nigrostriata* are small galaxiid fish (Figure 1), maximum total length (TL) is about 48 mm, with an elongate body that is mostly grey-tan with a white ventral surface (Morgan *et al.* 1998; Allen *et al.* 2002). From early larval stages *G. nigrostriata* has dark pigmentation on the dorsal surface from snout to tail and ventrally from the dorsal surface of the gut to tail, with yellow to red pigmentation between (Gill & Neira 1994; McDowall & Waters 2004). The pigmentation becomes more concentrated as the fish mature, turning into two prominent black stripes surrounding a bright yellow to red stripe running laterally between the eye and tail (Morgan *et al.* 1998). The stripes become especially vivid while spawning, between June and September, then fade soon after (Morgan *et al.* 1998; Allen *et al.* 2002). *Galaxiella nigrostriata* become sexually mature when nearly one year old and die soon after spawning (Pen *et al.* 1993), although they have been known to live up to two years in aquaria (M. Bamford, Bamford Consulting Ecologists, 2008, pers. comm.).

### Distribution

Southern populations of *G. nigrostriata* are located between Augusta and Albany, with the majority found on the Scott Coastal Plain, centred near Northcliffe in the D'Entrecasteaux National Park (Figure 2) (Morgan *et al.* 1998; Morgan & Gill 2000). There are three known remnant populations: a population discovered in 2009 at Lake Chandala *ca.* 50 km N of Perth (near Muchea), *ca.* 30 km NNE of Perth at wetland EPP173 in Melaleuca Park and 130 km south of Perth in wetlands within the

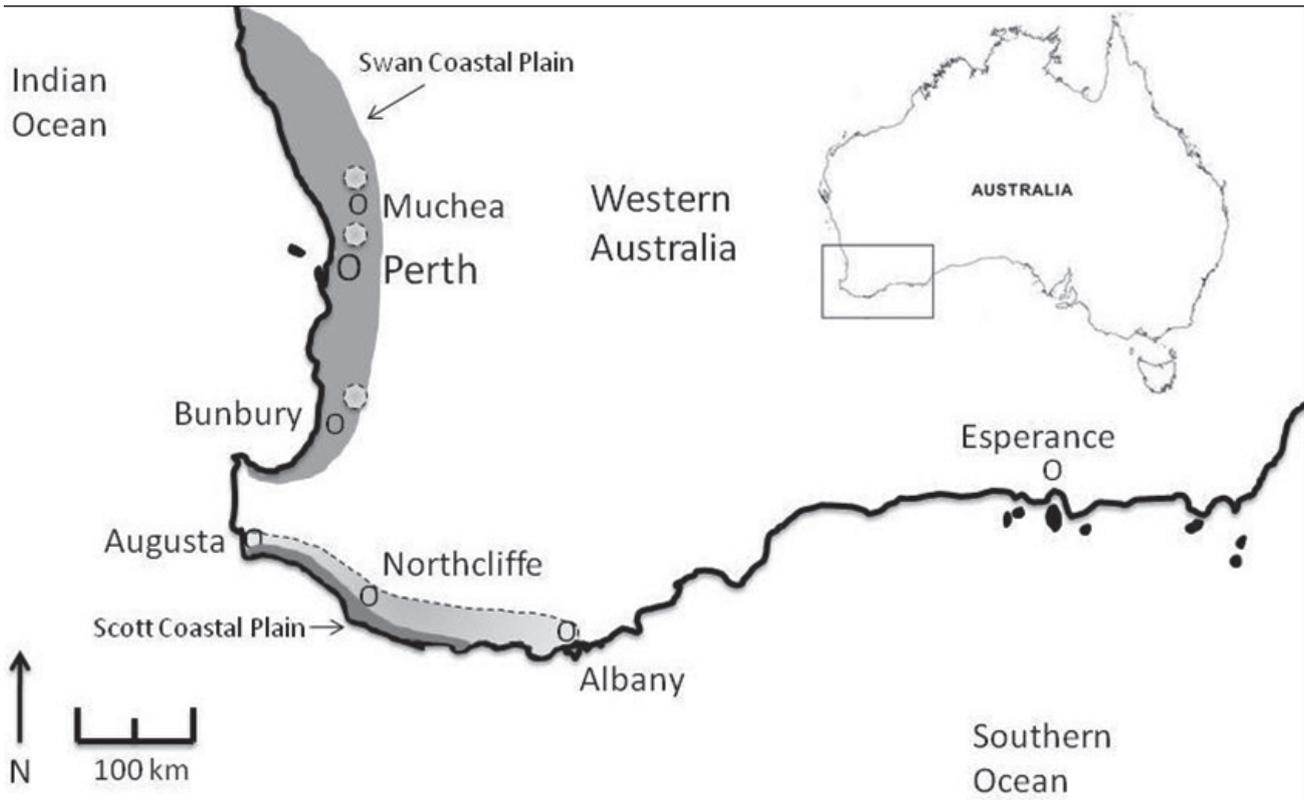
Kemerton Nature Reserve near Bunbury (Morgan *et al.* 1998; Bamford & Bamford 2002; Knott *et al.* 2002; McLure & Horwitz 2009). There was an ambiguous record from 1972 in the Carburnup River, south of Busselton, listed as *Brachygalaxias pusillus* and striped galaxias (Griffiths 1972). It was assumed to be *G. nigrostriata* (Morgan *et al.* 2004), probably due to the names used (see Taxonomy and Nomenclature) and the similarity shown in line drawings of the fish in the report. However, there have been no other records of *G. nigrostriata* in that area and the habitat is more suited to *G. munda*, which are known from there, so the fish may have been misidentified.

The remnant locations are *ca.* 380, 360 and 210 km north of the southern population. The discovery of the Lake Chandala population extends their known distribution further north and suggests other unknown populations may still exist. Coincidentally, papers by Morgan *et al.* (1996, 1998) suggested *G. nigrostriata* had been found near Gingin, *ca.* 80 km north of Perth and *ca.* 30 km north of the recently discovered Lake Chandala population. Unfortunately, as foresighted as it was, that information was entered incorrectly; Morgan *et al.* were referring to records of *G. munda* near Gingin (D. Morgan, Centre for Fish and Fisheries Research, Murdoch University, 2009, pers. comm.).

*Galaxiella nigrostriata* distribution appears to have been incorrectly listed in some publications over the last 30 years as extending east to Esperance. This incorrect distribution is based on Western Australian Museum (WAM) records, from which an entry error for a holotype specimen was listed as collected from Marbelup Creek near Esperance (WAM, 2008, unpublished data). The entry should have been Marbelup Brook, *ca.* 20 km NW of Albany, which is among the eastern-most record. This error has now been rectified in the museum records (S. Morrison, WAM, 2009, pers. comm.).

### Habitat

*Galaxiella nigrostriata* typically inhabit highly tannin stained water *ca.* 300 mm deep, with a pH and temperature range of 3.0–8.0 and 11–30°C respectively (Jaensch 1992; Gill & Morgan 1996; Morgan *et al.* 1998; Allen *et al.* 2002). *Galaxiella nigrostriata* larvae are thought



**Figure 2.** Present population areas of the *G. nigrostriata* in south-west Western Australia shown as light shaded areas. Dark shading shows location of Swan and Scott Coastal Plains.

to prefer open water and as they mature are more likely to be found in areas of macrophytic or riparian vegetation (Morgan *et al.* 1998; D. Galeotti 2008, unpublished data). *Galaxiella nigrostriata* have been recorded in slow-moving streams and lakes (McDowall & Frankenberg 1981; Jaensch 1992; Morgan *et al.* 1998), but are typically found in seasonal wetlands up to 100 km from the coast, with limited connectivity to nearby wetlands or rivers (Pusey & Edward 1990; Morgan & Gill 2000). *Galaxiella nigrostriata* are often found co-habiting with *Lepidogalaxias salamandroides* (salamanderfish), due to similarities in their preferred habitat, *i.e.*, their ability to tolerate seasonal wetlands by aestivating (Jaensch 1992; Morgan & Gill 2000; McDowall 2006).

Wetlands that *G. nigrostriata* inhabit are generally surrounded by fringing and riparian vegetation such as paperbarks (*Melaleuca* sp.) and rushes (*Baumea* sp.) (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 of WA, and *Banksia menziesii* open woodlands where the northern remnant populations exist (Morgan *et al.* 1998; Knott *et al.* 2002). *Galaxiella nigrostriata* have not been found in wetlands surrounded by cleared farmland (Morgan *et al.* 1998), which may underscore an important role of riparian vegetation as has also been found with other members of the Galaxiidae (Hicks & Barrier 1996; Bonnett & Sykes 2002) and other fish species (King & Warburton 2007). Wetlands within the southern

population's main area of distribution generally dry completely around December and remain dry until winter rains begin around June (Pusey & Edward 1990).

### Diet

Pusey & Bradshaw (1996) suggested *G. nigrostriata* are primarily carnivorous and feed in the upper water column and the surface, with their diet following seasonally available prey. Other research showed populations of juveniles and adults (>20 mm TL) recorded near Northcliffe consumed zooplankton, flying ants and adult dipteran (flies) throughout the year, and in summer and autumn dipteran pupae and larvae and diatoms were also taken (however, the benthic algae is likely to be incidental ingestion) (Pen *et al.* 1993; Gill & Morgan 1996; Smith *et al.* 2002b). In winter, preflexion *G. nigrostriata* larvae (7–11 mm TL) predominantly fed on zooplankton, and postflexion larvae (12–23 mm TL) ate Collembola (springtails) and dipteran larvae (Gill & Morgan 2003). The diet of the northern Perth population at Melaleuca Park was very similar to the southern population, except for lower quantities of terrestrial insects being eaten (5% of total intake at Melaleuca Park compared to 20–50% near Northcliffe) (Smith *et al.* 2002b). These diet studies suggest *G. nigrostriata* are opportunist water column feeders with some surface feeding occurring as well, similar to other congeners (Pusey & Bradshaw 1996; Smith *et al.* 2002b; Gill & Morgan 2003) *Galaxiella*

*nigrostriata* do not seem to compete for food with their main co-inhabitant, *L. salamandroides*, in the southern populations as *L. salamandroides* are primarily benthic feeders (Pusey & Bradshaw 1996; Gill & Morgan 2003).

## Reproduction

Reproductive behaviour of *G. nigrostriata* is not fully understood, however parallels may reasonably be drawn with the congeneric *G. munda* and *G. pusilla* (McDowall & Waters 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 & Waters 2004), which are then fertilised by the male, as observed in the *G. pusilla* (Backhouse 1983). Each female *G. nigrostriata* lays ca. 60 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 both males and females develop their stripes soon after (Gill & Neira 1994; Morgan *et al.* 1998).

Spawning in the southern populations of *G. nigrostriata* occur between June and September, from mid-winter to mid-spring (Gill & Neira 1994; Morgan *et al.* 1998). Spawning peaks during mid-winter when water temperatures and daylight hours are at a minimum (Pen *et al.* 1993; Gill & Neira 1994; Morgan *et al.* 1998). *Galaxiella nigrostriata* at Melaleuca Park are reported to begin spawning a month later than the southern populations, and the Kemerton population may start around August (Smith *et al.* 2002b; Bamford & Bamford 2003).

## Aestivation

*Galaxiella nigrostriata* aestivation was explored by Smith *et al.* (2002b) at Melaleuca Park while the wetland was dry, by fencing two drains entering the wetland (using fine mesh). Adult *G. nigrostriata* were present after the wetland had refilled in winter, having survived summer in the dry wetland. Other researchers have artificially flooded small dry wetland pools and found adult *G. nigrostriata* emerging within hours (Berra & Allen 1989b; Morgan *et al.* 1996). *Galaxiella nigrostriata* have also been found in isolated seasonal wetlands which may go years without connecting to neighbouring wetlands (D. Galeotti 2009, unpublished data). Within Galaxiidae, aestivation is limited to *G. nigrostriata* and *L. salamandroides* (south-west WA), possibly *G. munda* (south-west WA) and *G. pusilla* (south-eastern Australia and northern Tasmania), six *Neochanna* spp. (mudfish, in New Zealand, Tasmania and southern Victoria) and *Brachygalaxias bullocki* (red jollytail, in Chile) (McDowall 2006).

Anecdotal observations have suggested *G. nigrostriata* use crayfish burrows to gain access to the substrate for aestivation when wetlands dry (Morgan *et al.* 1998; Thompson & Withers 1999; Bamford & Bamford 2003; McDowall 2006) as they appear physically unable to burrow themselves (Thompson & Withers 1999). Beck (1985) found *G. pusilla* (in South Australia) in the substrate of dry swamps, apparently accessed through *Cherax destructor* (yabby) burrows, and observed the fish fleeing to yabby burrows when approached. However, little research exists to support their use of burrows or

how they may gain access to the substrate, or where they actually aestivate. While digging for *L. salamandroides*, Berra and Allen (1989b) came across *G. nigrostriata* under leaf litter and just below the surface in sandy soils. However, Smith *et al.* (2002b) dug a transect 2 m long by 60 cm deep through a dry wetland in Melaleuca Park known to contain a *G. nigrostriata* population, but did not find any fish. Lento-corral experiments by the authors have shown aestivation occurring in wetland sediments that have no obvious signs of crayfish burrows (unpublished data). Nevertheless, it is also possible *G. nigrostriata* aestivate within damp hollow rushes, tree roots or logs, similar to *Kryptolebias marmoratus* (mangrove killifish) (Taylor *et al.* 2008). Pen *et al.* (1993) suggested *G. nigrostriata* aestivate as a survival mechanism, given the temporary nature of their preferred habitat, although, how long they can survive while aestivating is also unknown.

## Threats

*Galaxiella nigrostriata* are listed with a number of local, national and international organisations: 'Priority 3' (Taxa with several, poorly known populations, some on conservation lands) with the West Australian Department of Environment and Conservation, 'Restricted' with Australian Society of Fish Biology and 'Lower Risk-near threatened' with the International Union for Conservation of Nature (Wager 1996; ASFB 2007; DEC unpublished data 2008).

The main threats likely to affect continued *G. nigrostriata* population survival can be grouped into two types: climate change and habitat modification and destruction. It has been estimated that rainfall in south-west WA will continue to decline, over 40% by 2070 and evapotranspiration will increase (Watterson *et al.* 2007), which will affect wetland hydroperiod through decreased run-off and reduced groundwater recharge. Excessive anthropogenic groundwater extraction can cause unseasonal or extended dry periods in wetlands and decreasing groundwater levels could induce acidification through acid sulphate soils (Smith *et al.* 2002b; Horwitz *et al.* 2008). Wetlands will also be affected by a predicted rise in mean temperatures which will lead to an increase in evapotranspiration in south-west Western Australia (Watterson *et al.* 2007).

A number of land use practices have directly or indirectly caused the loss of up to 80% of wetlands on the SCP, such as filling or draining for agriculture, urbanization and roads, forestry, dams and other such infrastructure, mineral and quartzite sand mining under wetlands (Seddon 1972; Balla 1994; Davis & Froend 1999; Smith *et al.* 2002b). Some seasonal wetland habitats have been excavated when dry with the soil used for fill, or the dry pools filled in during road maintenance, or protected reserves undergo a change in land tenure and are no longer protected from agriculture, mining or other habitat altering activities (Trayler *et al.* 1996; Morgan *et al.* 1998). Furthermore, altered wildfire seasons and prescribed burning practices can cause organic-rich sediments in seasonal wetlands to burn for long periods, killing fish that may be aestivating within the substrate (Trayler *et al.* 1996; Semeniuk & Semeniuk 2005; Horwitz *et al.* 2008). In some areas, an increase of salinity

degrading water quality in rivers and wetlands has been caused by massive historical land clearing (Halse *et al.* 2003).

Introduced exotic fish species may impact upon native species through competition for food, aggressive/predatory behaviour that causes displacement, injury or death and by introducing disease (Becker *et al.* 2005; Rowe 2007; Marina *et al.* 2008). For example, introduced *Gambusia holbrooki* (mosquitofish) similarly prefer the shallow still water of wetlands and may show aggressive behaviour (fin-nipping) toward co-habiting 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 *G. nigrostriata* caused by aggressive *G. holbrooki* (Griffiths 1972), while another study reported native *Hypseleotris* sp. 5 (Midgley's gudgeons) probably competing with *G. holbrooki* for food (Stoffels & Humphries 2003). Other authors disagree about the impact *Gambusia* have on galaxiid species (Ling 2004; Becker *et al.* 2005). One advantage *G. nigrostriata* 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 a deleterious effect by attacking *G. nigrostriata* populations as water subsides, niche habitats in the water column disappear and competition for food and space increase.

## Taxonomy and Nomenclature

The common name black-stripe minnow has been widely used since it was first coined by Shipway in 1953. However, some reports since the mid 1990's have used the name black-striped jollytail (EPA 2005; Coffey Env. 2009; MBS 2009), apparently referring to articles by Bamford *et al.* (*e.g.* Bamford & Bamford 1998). Mike Bamford introduced the jollytail name to replace minnow so they would not be confused with the true minnows (M. Bamford, Bamford Consulting Ecologists 2009, pers. comm.) which belong to the family Cyprinidae and do not necessarily represent only small fish (Berra 2007). More recently an official common name change from black-stripe minnow to black-striped dwarf galaxias has been accepted and published by a conglomeration of government and industry bodies (Yearsley *et al.* 2006).

Due to its similarities with the *G. pusilla*, *G. nigrostriata* was originally described as *Galaxias pusillus* ssp. *nigrostriatus* by Shipway in 1953 from specimens collected near Albany, WA (Shipway 1953). Whitley listed it as a separate species in 1964 and it was declared by Scott in 1971 as *Brachygalaxias nigrostriatus* (Whitley 1964; Scott 1971). McDowall formally identified it as belonging to the new genus *Galaxiella* in 1978 as *Galaxiella nigrostriata* (McDowall 1978). Misidentification has occurred in the past by confusing *G. nigrostriata* with *G. munda* (McDowall & Frankenberg 1981), particularly during the juvenile stage prior to the development of their unique stripes (Allen *et al.* 2002). This confusion led Berra and Allen to publish a paper examining the differences between the two species, the most conspicuous being the origin of the dorsal fin in relation

to the anal fin (Berra & Allen 1989a). It is possible other records are incorrect, as even today researchers have difficulty identifying the two species in the field due to intermediate morphological characters existing in juveniles (D. Galeotti 2009, pers. obs.) and genetic analysis is recommended to confirm their identification (S. Beatty, Centre for Fish and Fisheries Research, Murdoch University, 2009, pers. comm.)

However, little work has been done on the genetics of *G. nigrostriata*. Waters *et al.* (2000) examined phylogenetics of Galaxiidae using mitochondrial DNA (mtDNA) (cytochrome *b* and 16S rRNA) to examine Gondwanan relationships within the family. They suggested *G. munda* is more closely related to *G. pusilla* than *G. nigrostriata*, even though *G. pusilla* occur *ca.* 2,000 km away. It has been suggested that their origins are from the same location, *i.e.*, *Galaxiella* dispersed either from eastern Australian to the west, or vice-versa (Chilcott & Humphries 1996). This may have been possible when more rivers existed 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 therefore been *ca.* 5 Ma, at the end of the Miocene (Unmack 2001)

Smith *et al.* (2002a) used allozyme electrophoresis and morphometric analyses to assess relatedness between populations in Melaleuca Park and two populations near Northcliffe. They determined there was low genetic diversity near Northcliffe (3% polymorphism) while the population at Melaleuca Park was monomorphic, and that isolation had caused minor morphological differences between populations, specifically larger head lengths and shorter caudal peduncle lengths at Melaleuca Park. *Galaxiella nigrostriata*'s whole mitochondrial genome has been mapped and added to Genbank by Miya *et al.* (unpublished data) and is freely available for researchers (Accession # NC\_008448; see Benson *et al.* 2008). To further assess the genetic differences between *G. nigrostriata* populations, it has been suggested mtDNA analysis may provide a more accurate measure than allozyme electrophoresis (D. Morgan, Centre for Fish and Fisheries Research 2009, pers. comm.). The use of mtDNA may allow the path of dispersal to be more accurately mapped, and furthermore, mtDNA analysis may help determine how divergent the known populations are, *i.e.*, if they are genetically separate populations or subspecies. If the populations are genetically identical then deliberate translocations could occur between them to restock diminishing populations or rehabilitated wetlands.

## Discussion

The information contained in this review provides information on many aspects of *G. nigrostriata* required to make informed decisions regarding their conservation management. However, some sections suggest areas that require further research is required, particularly aestivation and genetics. *Galaxiella nigrostriata* distribution appears to have been reduced, as indicated by historical reports that described their range as far as the towns of Esperance to the east and Gingin to the north. Fortunately the reduction is due to data entry

errors and going by the recent discovery at Lake Chandala further populations may still be waiting to be discovered. However, it is unlikely their range will extend further outwards; rather small remnants may possibly be found within their known range boundaries.

Since *G. nigrostriata* spend potentially half of their life cycle in aestivation, it begs the question why is so little known about this life phase, especially with a drying climate and increasing pressure on groundwater resources affecting the hydroperiod of wetlands where they live. Certainly, a greater understanding of aestivation requirements could increase *G. nigrostriata*'s chances of survival in the challenging times ahead (re: climate change). Even though research in this area is lacking, land managers can still be mindful of how their activities may impact wetland ecosystems.

To enable *G. nigrostriata* 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 *G. nigrostriata* are found in degraded habitats, rehabilitation and a change in land use may be required. Reintroductions may allow rehabilitated wetlands to be restocked to widen *G. nigrostriata*'s geographic range. To further assist *G. nigrostriata*'s survival prospects, physical barriers such as bunds may be built to prevent exotic species entering neighbouring un-infested wetlands from permanent rivers or streams (Galeotti *et al.* 2008). Continued effort to raise public awareness about the impact of releasing exotic species into natural habitats will also help, not just *G. nigrostriata* but the survival of many other native species as well.

As genetic analysis techniques become quicker, easier and cheaper, further work in this field could help mitigate species confusion while simultaneously examining population genetic structure. Analysing mitochondrial DNA from specimens at each remnant population and the more widespread southern populations would give the most comprehensive overview of current or past genetic connectivity (McGlashan & Hughes 2001; Davey *et al.* 2003). If northern and southern *G. nigrostriata* populations show little divergence then they may all be managed in similar ways. However, a finding of genetically divergent populations may justify applying a higher conservation status and more intensive management of each sub-population (Ling *et al.* 2001; Cook *et al.* 2007; Phillips *et al.* 2007).

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