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MURRAY-DARLING BASIN AUTHORITY

Native Fish Strategy

Mesoscale movements of small- and medium-sized fish in the Murray-Darling Basin

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M. Hutchison, A. Butcher, J. Kirkwood, D. Mayer, K. Chilcott and S. Backhouse

Queensland Department of Primary Industries and Fisheries



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EXECUTIVE SUMMARY

Modern fisheries management is moving towards an ecosystem approach. The task of sustaining species of economic importance requires an understanding of the environmental needs of these fish and the prey species on which they depend. An aspect of the life cycle of many freshwater fish species is their need to move to different habitats to feed, breed or find refuge from desiccation. Juvenile fish also move to nursery habitats to avoid predators. Understanding the movement requirements of fishes is important for their sustainable management. The specific objectives of this project were to investigate mesoscale movements of Murray-Darling Basin fish species and/or life history stages for which there was little information. This included an investigation into both longitudinal and lateral movements and into possible movement triggers.

A combination of micro-tagging, radiotelemetry, and standardised electrofishing and fyke netting techniques were used to study the movements of a range of fish species in the northern Murray-Darling Basin (MDB). Fyke and mini-fyke nets were used to evaluate direction and magnitude of fish migrations. Electrofishing was used to determine species and size classes that were present but not necessarily migrating.

Despite this study taking place during one of the worst droughts in history, important new information on the movements of many species was still able to be collected. The following are some key findings from the study.

- Carp gudgeons *Hypseleotris* spp., bony bream *Nematalosa erebi*, spangled perch *Leiopotherapon unicolor* and golden perch *Macquaria ambigua* sub-adults and juveniles were more mobile on natural flows than on artificial flow releases. Migrations of these species may be cued by odours in run-off.
- On falling flows there was a tendency for downstream migration by carp gudgeons *Hypseleotris* spp., *N. erebi*, and *L. unicolor* of all sizes, *M. ambigua* (sub-adults and juveniles), dwarf flathead gudgeon *Philypnodon macrostomus* and Hyrtl's tandan *Neosilurus hyrtlii* (juveniles). This may have been to avoid desiccation.
- On rising flows most species of fish tended to move upstream, but there was always a proportion of the population moving downstream.
- Only a small proportion of the Murray-Darling rainbowfish *Melanotaenia fluviatilis* population appeared to move. Of those that did, most headed upstream. In contrast to other species, *M. fluviatilis* were most mobile during artificial flow releases. They may prefer clearer water for movements associated with courtship displays and breeding.
- In most species of fish, adults had more of a tendency to move upstream and juveniles downstream. This trend was very strong in *N. hyrtlii*.
- Most native species displayed diminished movement behaviour during the winter period, corresponding to periods of least flow in the northern Basin. Peak movement occurred in spring for *Hypseleotris* spp., *L. unicolor, N. hyrtlii, Ambassis agassizii* and *M. fluviatilis.* For adults of these species, movement was generally in an upstream direction. We have associated this movement with their reproductive strategy because many fish collected at this time were reproductively ripe.
- Peak movements of juvenile and sub-adult *M. ambigua* and *N. erebi* occurred during autumn. In the northern MDB, such behaviour would be a useful adaptation to enable dispersal to refugia prior to the onset of the winter and early spring dry season.
- During this study the statistical analyses identified a significant link between lunar phase and movement by several native species. The importance of lunar phase in movement behaviour of freshwater fish populations requires further research.
- Lateral migration into lagoons by the endangered olive perchlet *Ambassis agassizi* appears to be for reproduction. Access to lagoon habitats is probably important for this species's long-term survival. Strategies to assist serial connection of lagoon habitats during the reproductive season need to be investigated.

- Hypseleotris spp. as small as 40 mm total length (TL) were recorded moving up to 13 km upstream and more than 5 km downstream. Movements by Hypseleotris spp. were as rapid as 2 km in four days. Other species with evidence for upstream movement further than 10 km include *L. unicolor*, *N. erebi*, *P. macrostomus*, juvenile and sub-adult *M. ambigua*. Downstream movements up to 2 km were recorded for *L. unicolor* and up to 5 km for *N. erebi*. Downstream movements of hundreds of metres were recorded for juvenile and sub-adult *M. ambigua* and *N. hyrtlii*.
- It is very important that managers consider the upstream and downstream movement of small fish when prioritising weir passage investment. In particular, the preponderance of downstream movement for many species dictates that future plunge pool, fishway and spillway design should accommodate small-bodied fish as well as the premier native sport fish and other large-bodied species.

1. BACKGROUND

1.1 The importance of understanding movements by fish

Better understanding fish movements is essential in undertaking activities to protect fish species and determine the range and nature of threats they face.

The Murray-Darling Basin Commission has developed a Native Fish Strategy with the long-term goal of restoring native fish populations to 60% of their pre-European colonisation levels. The strategy's driving actions include rehabilitating fish habitat, protecting fish habitat, managing riverine structures (barriers to migration), controlling alien fish species, protecting threatened fish species and managing fish translocation and stocking (Murray-Darling Basin Commission 2004). The best available knowledge of the ecological requirements (and life history strategies of the native fishes they are intended to help) must guide these actions to be effective. For example, actions will need to take into account movement and habitat access requirements of a range of native fish species.

In many fish populations, some individuals will migrate. The scale of movement will be within a pool, reach, whole of river, or catchment, and researchers often only address questions relevant to small spatial and temporal scales. These studies are less relevant to large spatial, and long temporal-scale, problems for fisheries managers.

A whole-of-river approach is needed to see what is happening. Fausch et al. (2002) have presented a convincing case that a continuous view of the river is needed to understand how processes interacting across scales set the context for stream fishes and their habitats. Ecological studies that focus on fish in one environment only may fail to identify the causal links to a declining population.

The recruitment bottleneck is a good example. This is when habitat for adult fish may be perfectly adequate but access to juvenile habitat or spawning habitat may have been lost or reduced in another part of the riverscape, leading to reduced recruitment. Thus a study focusing on environments where the adults occur could completely miss this crucial causal linkage.

This idea is highlighted in Schlosser's (1991) dynamic landscape model for stream fish ecology. This model comprises a holistic spatial arrangement of spawning, feeding, rearing and refugia habitats and the necessity for movement between habitats for fish to complete their life history. Thus an awareness of fish movements between habitats and reaches, and knowledge of why these movements occur, is fundamental in understanding how to sustain or enhance fish populations in a region.

Some Australian native species are able to complete their entire life history without moving beyond a small home range, e.g. river blackfish *Gadopsis marmoratus*, (Khan et al. 2004); mountain galaxias *Galaxias olidus* (Berra 1973) and two-spined blackfish *Gadopsis bispinosus* (Lintermans 1998). For these species, impediments to passage or migration will have limited direct impact on their sustainability. However, for those species that do make movements, whether between different instream habitats, the river and floodplain habitats, or long-distance movements, impediments to movement can have a major impact.

It is important to know which life history stages move, when they move and why they move. Such information can better inform management decisions, prompting improved fishway operation and design, a better understanding of flow requirements to facilitate movements and access to different habitats, and for developing reach restoration strategies.

Koehn et al. (2003) concluded: "we need to understand the ecology of fish movements better. This includes lesser-known movements, such as lateral movements on and off floodplains. All fish movements need to be considered in relation to the life stage and their evolutionary benefit to populations, and further targeted research on specific aspects of fish migration needs is required to fill important knowledge gaps."

With increasing recognition that rivers and adjacent wetlands require adequate flows to sustain ecological processes and functions (Arthington et al. 2006), information on fish movement requirements helps managers with a range of issues, including:

- Integrating water releases with the temporal requirements of native fish, rather than when fish *might* need them based on some esoteric interpretation of the precautionary principle.
- Guiding investment in fishway infrastructure by highlighting whether fish passage for juveniles or small species is obligatory or facultative. If such movements are essential, then persisting with fishways that only pass large fish would be a sub-optimal use of resources.
- Deciding optimal flows to link habitats at suitable times of the year.

Knowing migration routes can also guide management measures that minimise the risk of trapping or stranding that may lead to major fish kills.

Recent large investment in researching the biology and life history of native fish has documented the habitat requirements of several key species such as Murray cod Maccullochella peelii peelii and golden perch *Macquaria ambigua* (Murray-Darling Basin Commission 2004). This has led to further investment in restoring appropriate habitat, such as:

- adding large woody debris (Crook & Robertson 1999, Crook et al. 2001, Nicol et al. 2004, Bond & Lake 2005)
- reducing impediments to passage by building fishways on key barriers (Close & Aland 2001, Gehrke et al. 2002, Stuart & Berghuis 2002, Baumgartner 2003, Koehn et al. 2003, Koster 2003, Mallen-Cooper 2004, Baumgartner 2006a, Morgan & Beatty 2006)
- re-establishing connectivity between river and floodplain environments (Koehn & Nicol 1998, King et al. 2003), and
- restoring elements of the natural flow regime that trigger key life history stages such as migration and spawning (Koehn et al. 2003). However, there are still key knowledge gaps in the specific biology and habitat requirements of many small native fish species (Treadwell & Hardwick 2003).

The Murray-Darling Basin has about 46 species of native fish (Lintermans 2007), but several of these are predominantly estuarine and confined to the lower freshwater reaches. Within the Queensland region of the Murray-Darling Basin, there are at least 18 species of native fish (Moffat & Voller 2002).

Although adults and sub-adults of some species such as golden perch and Murray cod have some aspects of their movement requirements well documented (Koehn 1996, O'Connor et al. 2005), there are still large knowledge gaps for the majority of native species, particularly small species (Treadwell & Hardwick 2003). Fishway monitoring has provided some information on upstream movements of several, mainly larger, native species (Berghuis & Broadfoot, unpublished report) but there is little information available on downstream (O'Connor et al. 2003, 2004, 2005) or lateral movement requirements, and almost no information on small species or juvenile life stages (Treadwell & Hardwick 2003).

Fisheries managers often question the need to study non-commercial and non-recreational species. Research has demonstrated a trophic link between prey species and many fishery target species (Harris et al. 1992, Pauly & Christensen 1995). This was highlighted by Hutchison et al. (2006) who established a direct link between successful populations of barramundi *Lates calcarifer* and Australian bass *Macquaria novemaculeata* and prey species such as bony bream *N. erebi* and carp gudgeons *Hypseleotris* spp. Consequently, many fisheries managers are now embracing the ecosystem approach to fisheries management (Walters 2000, Stergiou 2002). This includes a thorough understanding of movement requirements through the riverscape by the entire fish assemblage.

1.2 Our current knowledge

The following information summarises the current knowledge of the movement requirements of Murray-Darling Basin native fish species. The summary is drawn from published information only. Several recently completed studies will contribute more knowledge.

Geotriidae

Geotria australis Gray, 1851 Pouched lamprey

Like most other lampreys, *Geotria australis* is an anadromous species that spawns and undergoes larval development in fresh water, but spends most of its adult life at sea. In the freshwater phase of its life,

G. australis is generally found within 60 km of the coast, although it is found along most of the length of the Murray River. It has also been recorded from south-western Australia, New Zealand, Chile and Argentina (Potter 1996a, Allen et al. 2002).

Larval pouched lampreys, or ammocoetes, live in burrows in estuarine soft substrata for an average of about 4.5 years before metamorphosing into the adult form between January and July. The young adults then start migrating to the sea soon afterwards, when freshwater flow is seasonally high. They spend most of their adult life at sea before entering estuarine waters to begin their spawning migration in mid-winter (July). Migrating pre-spawning adults are regularly caught below dams until November, after which the number of adult lampreys captured in freshwater declines. Most upstream migration occurs at night, and pouched lampreys may leave the water to bypass obstacles, particularly on rainy nights during the dark phase of the moon. Laboratory studies indicate that they don't come into spawning condition until the following October or November, 15 to 16 months after starting their upstream migration. Adults usually die after spawning (Bird & Potter 1981, Potter et al. 1986, Potter 1996a).

Mordaciidae

Mordacia mordax (Richardson, 1846) Short-headed lamprey

Mordacia mordax is another anadromous lamprey, with a life history and associated migrations broadly similar to *G. australis*. In its freshwater phases, this species is generally found close to the coast in south-eastern Australia, but has been recorded along virtually the entire length of the Murray River (Potter 1996b, Allen et al. 2002).

Ammocoete larvae of the short-headed lamprey live in soft substrata for an average of three years, before undergoing a slow metamorphosis into the adult form, generally completed in July. These young adults start their downstream migration towards the sea between July and November, with migration occurring later in years with low freshwater flow. Young adult short-headed lampreys do not feed during the freshwater phase of this downstream migration. They spend most of their adult life at sea before returning to freshwater in late winter and spring (August-November) to spawn. As for their downstream migration as young adults, prespawning short-headed lampreys also do not feed in freshwater, and usually die after spawning. During this upstream migration, they actively swim by night and burrow into soft substrata by day (Potter 1970).

Anguillidae

Anguilla australis Richardson, 1841 Short-finned eel

Although generally regarded as a species whose adults spend most of their lives in coastal streams, *Anguilla australis* has been recorded on rare occasions in the inland Murray-Darling (Beumer 1996).

The large scale migrations of this catadromous species are well known. The general pattern is that adult short-finned eels migrate to sea to spawn with the next generation returning to estuaries and fresh water as glass eels and elvers (Allen et al. 2002). However, there may be some variations to this general pattern. Otolith microchemistry analyses from eels captured at sea suggest that some species of short-finned eels have individuals that never enter fresh waters (Tsukamoto et al. 1998, 2002).

Juvenile and adult short-finned eels are capable of moving across damp ground between isolated bodies of water, and can also climb up steep spillways and waterfalls (Beumer 1996). Barriers such as weirs, dams and waterfalls do impede their migrations, although turbulent or high-velocity fishways may be impassable for elvers on their upstream migration (Stuart & Mallen-Cooper 1999, Langdon & Collins 2000). Downstream migration by adults is generally facilitated by floodwaters, which may also trigger active downstream movement (Sloane 1984, Boubee et al. 2001).

Adult short-finned eels are more frequently seen at night, when laboratory studies show that they actively forage for prey (Sagar & Glova 1998, Glova & Jellyman 2000). By day, they tend to be less active and may retreat into soft substrata. A tagging study of adult short-finned eels showed that they generally tended to remain within 400 m of where they were released (Beumer 1979a). Thus, adults appear to spend most of their adult lives within a relatively small home range in still or slowly moving water, over which they forage nightly.

Clupeidae

Nematalosa erebi (Günther, 1868) Bony bream

Nematalosa erebi is one of the most abundant native fish species in the Murray-Darling Basin (Puckridge & Walker 1990, Schiller et al. 1997). They are found in virtually every habitat within the river system, apart from the upper reaches (Merrick & Schmida 1984), probably due to low water temperatures (Lintermans 2007).

Despite its great abundance, little is known about the movements of bony bream. This may be due in part to the near ubiquity of this species (as it is difficult to infer movement from gross changes in abundance), and its tendency to die when caught in nets or handled.

Most of the information we have on the movements of bony bream has been gained from fishway studies. Virtually all upstream passage of bony bream through fishways occurred by day in three separate studies in the Fitzroy, Murray and Burnett Rivers (Russell 1991, Mallen-Cooper et al. 1995, Stuart 1997). Mallen-Cooper et al. (1995) reported that upstream movement of bony bream ceased by night, and any fish still in the fishway at sunset returned to the bottom of the fishway. Almost all of the bony bream that Stuart (1997) reported moving up the Burnett fishway were small (<100 mm) despite the fact that the fishway selectively reduced the abundance of smaller fish. Pusey et al. (2004) also report large congregations of juvenile fish commonly occurring downstream of barriers such as road crossings and culverts. Thus it seems likely that virtually all upstream migrations by bony bream occur when they are smaller than 100 mm. Upstream movement of bony bream may represent colonising movement to compensate for any downstream drift of eggs and larvae (Koehn et al. 2004).

There is some evidence that adult bony bream migrate to particular spawning areas (Puckridge & Walker 1990, Bishop et al. 2001), although the extent of movement made to reach those areas is unknown.

Plotosiidae

Neosilurus hyrtlii Steindachner, 1866 Hyrtl's tandan

Neosilurus hyrtlii is widespread across the northern half of Australia, including the Paroo, Warrego and Condamine Rivers and their tributaries within the northern Murray-Darling (Pollard et al. 1996, Schiller et al. 1997). This species is found across virtually the entire range of freshwater habitats, but has not been recorded from estuarine reaches.

The information we have on the migrations and smaller scale movements of Hyrtl's tandan is derived from studies conducted in tropical streams. Care must be exercised when extrapolating this information to the Murray-Darling as movements may vary between different systems.

Bishop et al. (2001) reported on seasonal and ontogenetic changes in habitat usage by *N. hyrtlii* in the Alligator River, Northern Territory. They reported that juveniles were most abundant in lowland lagoons and sandy creeks. However, adults were abundant across a wider range of habitats and were only recorded from sandy creeks in the dry season. Orr and Milward (1984) reported that adult Hyrtl's tandans moved upstream into small, intermittent tributaries prior to spawning in the Ross River in Townsville, Queensland. In tropical streams, physical changes associated with flooding (such as increasing water level and turbidity or decreasing temperature) may trigger such spawning migrations during wet season floods. (Beumer 1980, Orr & Milward 1984).

Stuart (1997) reported that upstream movements of Hyrtl's tandan through a fishway on the Fitzroy River tended to occur mostly at night, with almost all of the movements occurring in the summer (November to March).

Porochilus cf. rendahli Rendahl's tandan (or allied species)

Several individuals of this species were collected in upstream reaches of Dogwood and Charlie's Creeks (tributaries of the Condamine/Balonne River) by G. Aland in 2003 as part of the Sustainable Rivers Audit (MDBC 2004). Further specimens have been collected in the Balonne River, near St. George in 2005 (Michael Hutchison¹ pers. comm. 2005). The fin ray counts of these specimens differ from those reported for *P. rendahli* from outside the Murray-Darling Basin. Nothing is known about movements of this species.

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Tandanus tandanus Mitchell, 1838 Eel-tailed catfish or tandan

Tandanus tandanus is widespread in coastal streams of eastern Australia north of central New South Wales. It was common throughout most of the Murray-Darling until the late 1970s, but has since undergone a massive decline in abundance. It is now only common in parts of the upper Condamine River in Queensland and impoundments in New South Wales and Victoria (Michael Hutchison¹ pers. comm. 2005, Pollard et al. 1996, Pusey et al. 2004).

Tagging studies have shown that *T. tandanus* adults generally tend to move very little. Reynolds (1983) found that 60% of recaptured *T. tandanus* had not moved from where they had been released in the Murray River in South Australia, and only one fish had moved in excess of 10 km. This individual may have been displaced downstream by a large flood that occurred during this study. In another study in the Tweed River, no recaptured *T. tandanus* had moved more than 50 m from where it had been released in the Tweed River six months previously (Richardson 1984, cited in Pusey et al. 2004). As with all tagging studies, the distribution of recaptures is strongly influenced by the distribution of sampling effort and there is the possibility that tagged fish moved outside the areas re-sampled.

Retropinnidae

Retropinna semoni (Weber, 1895) Australian smelt

Retropinna semoni are reasonably common in the southern basin and western parts of the northern basin (McDowall 1996, Allen et al. 2002). It is predominantly a freshwater species, but can tolerate a wide range of salinities and may migrate between fresh, estuarine and marine environments (McDowall 1996).

Studies of fish movements through fishways, and fish aggregations immediately downstream of barriers, have provided some information on the movements of Australian smelt in fresh water. Beumer and Harrington (1982) reported small aggregations of this species below a weir on the Lerderderg River in Victoria during high flow conditions in mid-winter. Mallen-Cooper et al. (1995) reported that young-of-the-year Australian smelt passed upstream through a fishway at Torrumbarry Weir on the Murray River in the summer months (November to February). This upstream movement occurred only during daylight hours. Attempted upstream migration of juvenile *R. semoni* has also been reported by Pusey et al. (2004) who recorded a very large aggregation of young-of-the-year fish just downstream of a road culvert crossing the Mary River in Queensland in September. Humphries and King (2004) reported large numbers of Australian smelt larvae drifting downstream in the Broken River in October/November 2000, with lower numbers occurring at other times. Thus, adult Australian smelt apparently attempt to move upstream in most seasons, under both high and low flow conditions, to compensate for this downstream larval drift.

Galaxiidae

Galaxias brevipinnis Günther, 1866 Climbing galaxias

Galaxias brevipinnis has a fragmented distribution in south-east Australian coastal rivers. Within the Murray-Darling system, it is found at opposite ends of the Murray River, close to the river mouth in South Australia and near the headwaters in the Snowy Mountains (McDowall & Fulton 1996). This isolated population is now accepted as a translocation via the Snowy River power scheme (Morison & Anderson 1990, Waters et al. 2002).

Many populations of *G. brevipinnis* are diadromous, with newly hatched larvae being swept downstream and into the sea (Koehn & O'Connor 1992, McDowall & Fulton 1996). They return to coastal streams as juveniles, before moving further upstream. Adults and larger juveniles are tenacious upstream migrants, and the species gains its common name of climbing galaxias for its ability to climb damp rock faces and high waterfalls (McDowall & Fulton 1996).

Galaxias fuscus Mack, 1936 Barred galaxias

Galaxias fuscus has a very restricted distribution in the upper reaches of the Goulburn River system in Victoria's central highlands (Allen et al. 2002). Because of this restricted distribution, this endangered species is thought to undergo only local movements (Thorncraft & Harris 2000). There is apparently little else published on the movements of this species.

Galaxias maculatus (Jenyns, 1842) Common galaxias

Galaxias maculatus has a vicariant distribution, occurring in lowland coastal streams in south-eastern and western Australia, Lord Howe Island, New Zealand, Chatham Islands, Patagonia and the Falkland Islands (McDowall & Fulton 1996).

The movements of this catadromous species are relatively well known from research conducted in New Zealand, where *G. maculatus* is the principal component of the whitebait fishery (McDowall & Fulton 1996). Adult *G. maculatus* migrate downstream to spawn in estuaries on new or full moons in autumn. Spawning occurs among terrestrial vegetation that is inundated on high spring tides. Eggs generally hatch about two weeks later, when the terrestrial vegetation is again inundated by a high spring tide. The larvae spend the winter at sea, and re-enter estuaries about 5 to 6 months later as slender transparent juveniles of 40 to 50 mm long ('whitebait'). They move upstream on rising tides and grow to adults in fresh water from spring to autumn. Most adult *G. maculatus* then return to estuaries to spawn at one year of age, after which they usually die (McDowall 1968, McDowall & Eldon 1980, McDowall & Fulton 1996, McDowall et al. 1975, 1994).

Galaxias olidus Günther, 1866 Mountain galaxias

Galaxias olidus occurs in the eastern tributaries of the Murray-Darling from south Queensland to Victoria, and also near the mouth of the Murray River in South Australia (McDowall & Fulton 1996, Allen et al. 2002).

Adults of this non-migratory species have a reported home range of <30 m (Berra 1973). They are known to move short distances to riffle areas for spawning, which peaks in spring but may extend through the summer and even into autumn (O'Connor & Koehn 1991, McDowall & Fulton 1996). Adults and larger juveniles are reportedly capable of climbing damp rock faces of waterfalls (Green 1979). There is little else published on the movements of this species.

Galaxias rostratus Klunzinger, 1872 Flathead galaxias

Galaxias rostratus is largely restricted to the lower Murray-Darling Basin, although McDowall and Fulton (1996) report one isolated record from the upper Darling River. There has been nothing published on the movements of this species.

Atherinidae

Craterocephalus amniculus Crowley & Ivantsoff, 1990 Darling River hardyhead

Craterocephalus amniculus is found in the upper Darling River and several of its northern tributaries, including the Condamine and Macintyre Rivers in southern Queensland and the Peel, Namoi and Cockburn Rivers in northern New South Wales (Crowley & Ivantsoff 1996). There has been nothing published on the movements of this recently described species.

Craterocephalus fluviatilis McCulloch, 1913 Murray hardyhead

Craterocephalus fluviatilis was formerly abundant in the central Murray and lower Darling Rivers, but is now restricted to a few relict populations in small lakes near Swan Hill and Kerang in Victoria (Ivantsoff & Crowley 1996, Allen et al. 2002). Given this restricted distribution, this species must only perform small-scale movements. There has been nothing published on the movements of this species.

Craterocephalus stercusmuscarum fulvus (Günther, 1867) un-specked hardyhead

The subspecies *Craterocephalus stercusmuscarum fulvus* is found throughout most of the Darling River drainage system, and middle reaches of the Murray River, with separate populations in south-east Queensland coastal streams (Ivantsoff & Crowley 1996, Allen et al. 2002, Pusey et al. 2004).

Stuart and Berghuis (1999) and Berghuis (2001) reported small numbers of un-specked hardyheads using fishways on tidal barrages on the Burnett and Mary Rivers. However, this species has not been reported from lower reaches of the Murray River, so does not migrate to tidal waters in the Murray-Darling system. Given this fact, it is possible that those recorded by Stuart and Berghuis (1999) may have been displaced to tidal waters and were returning to the freshwater habitat. Little else has been published on the movements of this species anywhere, and nothing has been published on its movements in the Murray-Darling Basin.

Atherinosoma microstoma (Günther, 1861) Small-mouthed hardyhead

This species is common to estuarine waters of south-eastern Australia and has occasionally been reported from near coastal fresh waters (Ivantsoff & Crowley 1996, Allen et al. 2002). It is unlikely to perform large-scale movements in fresh water and nothing has been published regarding any local-scale movements of this species.

Melanotaeniidae

Melanotaenia fluviatilis (Castelnau, 1878) Murray-Darling rainbowfish

This species is relatively common throughout much of the Murray-Darling Basin, and although it is absent from upper tributaries in the Great Dividing Range, it is common in southern Queensland (Allen 1996a, Allen et al. 2002). There has been nothing published on the movements of this species. The related species, *M. splendida tatei*, has been recorded in the Warrego, Paroo and lower Darling Rivers (Lintermans 2007).

Ambassidae

Ambassis agassizii Steindachner, 1866 Olive perchlet

Ambassis agassizii has been found throughout almost all of the Murray-Darling river system, with the exception of the upper Murray and some of the colder mountain streams of Victoria and southern New South Wales (Allen 1996b). However, it has declined in the southern half of the MDB. There has been nothing published on the movements of this species.

Percichthyidae

Maccullochella macquariensis (Cuvier, 1829) Trout cod

Formerly widespread throughout the southern tributaries of the Murray-Darling river system, the distribution of *Maccullochella macquariensis* has been substantially reduced in recent years. There are now just two substantial self-sustaining populations, one in a stretch of the Murray River between Yarrawonga Weir and Barmah State Forest, and the other in the upper reaches of the Goulburn River system (Harris & Rowland 1996).

Adult wild trout cod show a high degree of fidelity to home snags, and tend to move only short distances from those snags (Koehn 1996, Koehn & Nicol 1998). Hatchery reared *M. macquariensis* tend to be more mobile than wild *M. macquariensis* (Ebner & Thiem 2006). The limited data on this species shows some indication of increased movement in spring, and they moved widely through the river during major flooding in 1993 (Koehn 1996). A proportion of the larval trout cod drift downstream (Koehn & Nicol 1998).

Maccullochella peelii peelii (Mitchell, 1839) Murray cod

Maccullochella peelii peelii is found throughout the Murray-Darling River system apart from within the upper reaches of high latitude tributaries of the Great Dividing Range (Harris & Rowland 1996).

Adult Murray cod are generally considered sedentary and territorial, tending to spend most of the time beneath a particular snag or overhang (Merrick & Schmida 1984, Harris & Rowland 1996). However, Koehn and Nicol (1998) show that adult Murray cod undertake an upstream spawning migration between late winter and early summer, followed by a post-spawning return movement downstream. These authors reported that these migrations could cover up to 120 km each way, and Koehn et al. (2004) stated that about 80% of these migrating fish return to their home site. The greatest amount of movement of adult Murray cod correlated with peak flows (Koehn & Nicol 1998). Larval Murray cod also drift downstream, particularly by night in spring when this species is usually the dominant component of the drifting fish larvae in the Broken River (Humphries & King 2004, Humphries 2005). Thus, the upstream migration of pre-spawning adults may act to compensate for this downstream larval drift. Adult Murray cod have been recorded moving downstream through a fishway on the Murrumbidgee River (Lintermans 2004). Although the scale of these movements is unknown, they may represent a post-spawning return to an adult's normal home range.

Macquaria ambigua (Richardson, 1845) Golden perch

Macquaria ambigua are found throughout the Murray-Darling Basin apart from the highest altitudes (Harris & Rowland 1996). This species is known to migrate large distances, both as a juvenile and an adult, with one individual tagged fish moving 2,300 km upstream (Reynolds 1983). Reynolds reported that these upstream migrations occurred during high flow events in spring and summer, and were apparently triggered by rises in water flow. O'Connor et al. (2004, 2005) reported that over winter, golden perch remained within 5 km of where they were released. Long distance movements generally occurred between September and December. However, Koehn and Nicol (1998) found that golden perch may move up or downstream at any time of the year. Of the fish that O'Connor et al. (2004, 2005) tracked, 26% moved >10 km upstream, 53% moved >10 km downstream and 21% remained within 3 km of the release site from September to December 2000. After December, most golden perch returned to the same area where they had spent the previous winter (O'Connor et al. 2004, 2005).

In contrast to the previous year, O'Connor et al. (2004, 2005) found that only a small proportion of *M. ambigua* undertook long distance movement in 2001. This may have been because there was no increase in flow during spring 2001, and underlines the importance of studying fish movements for several years before attempting to make generalisations.

Reynolds (1983) also found that some tagged golden perch moved upstream, some moved downstream and some remained close to where they were released during both high and low flow periods. Gehrke (1990) found that golden perch larvae introduced into an artificial floodplain and pond environment predominantly moved off the floodplain into the pond, rather than from the pond to the floodplain. Gehrke (1990) attributed this movement pattern to water quality being poorer on the floodplain than in the pond. Mallen-Cooper et al. (1995) recorded movement of small golden perch through fishways in response to small flow events.

Golden perch tend to be most active around dawn and dusk (Harris & Rowland 1996). During high flow events, Reynolds (1983) found that average upstream swimming speeds of golden perch were 2.96 km day⁻¹, equivalent to about 90 km in a month, with some fish averaging 15-20 km day⁻¹. According to Harris and Rowland (1996) this species spawns in floods during spring and summer, and the pelagic eggs are washed downstream, as are the buoyant larvae. Thus, the upstream migration compensates for this downstream flushing of eggs. However, Mallen-Cooper and Stuart (2003) demonstrated that golden perch did not obligate flood spawners and could reproduce successfully in low flow years.

Macquaria australasica Cuvier, 1830 Macquarie perch

This species is found in the middle to upper reaches of the Murray, Murrumbidgee and Lachlan Rivers, and their tributaries (Harris & Rowland 1996, Allen et al. 2002). When present in impoundments, *M. australasica* migrate upstream prior to spawning in October and November, although it is uncertain whether this migration also occurs in riverine populations (Harris & Rowland 1996). Macquarie perch have been recorded moving downstream through a fishway on the Murrumbidgee River, although the scale of these movements is unknown (Lintermans 2004). This downstream movement may be a post-spawning return to a home range, as has been reported for golden perch and Murray cod (Koehn et al. 2004).

Macquaria colonorum (Günther, 1863) Estuary perch

Macquaria colonorum is found in estuarine waters of south-eastern Australia, including within the mouth of the Murray River in South Australia (Harris & Rowland 1996). Adults of this species move to the mouths of estuaries to spawn in winter (Harris & Rowland 1996, Allen et al. 2002). They also move upstream into fresh water at some times.

Gadopsidae

Gadopsis bispinosus Sanger, 1984 Two-spined blackfish

Gadopsis bispinosus has a restricted distribution along the northern edge of the Great Dividing Range in eastern Victoria and south-eastern New South Wales (Jackson et al. 1996). This nocturnal species performs very little movement, with adults tending to remain within a small home range of about 15 m (Sanger 1990, Lintermans 1998).

Gadopsis marmoratus (Richardson, 1848) River blackfish

Gadopsis marmoratus is found in higher altitude tributaries in the Murray-Darling Basin, as well as along most of the length of the Murray River and its Victorian tributaries. This species is not migratory, and tends to move very little throughout its life cycle (Jackson et al. 1996). Adult *G. marmoratus* spawn inside hollow structures, where eggs adhere to the surface and are guarded by the male. Recently hatched fry remain attached to those eggs for about 19 days (Jackson 1978). Adults have small home ranges between 10 to 45 m in length, within which they make only small scale movements (Khan et al. 2004). That study showed that individuals remained within these home ranges for at least seven months, and tended to return within 48 hours if moved 40 m away. There appeared to be little difference in the amount of movement between night and day (Khan et al. 2004), although previous literature reported *G. marmoratus* to be nocturnal (Jackson et al. 1996).

Nannopercidae

Nannoperca australis Günther, 1861 Southern pygmy perch

Nannoperca australis is found throughout Victoria and in southern New South Wales in the Murrumbidgee, Lachlan and Murray Rivers and their tributaries, as well as in northern Tasmania and Bass Strait islands (Kuiter et al. 1996). Nothing has been published on the movements of this species.

Terapontidae

Bidyanus bidyanus (Mitchell, 1838) Silver perch

Bidyanus bidyanus was once very common throughout most of the Murray-Darling river system, but its numbers have declined drastically in recent years (Merrick 1996, Allen et al. 2002).

Silver perch perform long upstream migrations prior to spawning in spring and summer (Merrick 1996). During this migration they form large schools, which frequently accumulate below rapids, barrages and weirs. Allen et al. (2002) attribute the decline in silver perch populations to the proliferation of man-made barriers to these upstream spawning migrations. Mallen-Cooper and Stuart (2003) reported sexual dimorphism in this species and suggested that the larger females move greater distances than the smaller males during spawning. After spawning, the eggs and early larval stages drift back downstream, where constructed barriers may once again impede recruitment of juveniles into existing populations. In unregulated rivers, the pre-spawning upstream migration of silver perch may compensate for the downstream drift of eggs and larvae (Koehn et al. 2004). Outside of these spawning migrations, little is known of the movements of silver perch, although immature fish do move upstream after small rises in water level at any time of the year (Merrick 1996).

Leiopotherapon unicolor (Günther, 1859) Spangled perch

Leiopotherapon unicolor is regarded as Australia's most widespread native freshwater fish, being found throughout most of the continent including the northern Murray-Darling Basin (Merrick 1996, Allen et al. 2002), but is absent from the southern Murray-Darling Basin.

Seasonal migrations of spangled perch have been reported in northern Australia, but the Murray-Darling Basin lacks similar data. In north Queensland coastal streams, this species performs an upstream spawning migration as flooding begins(Beumer 1979b). However, it performs a downstream spawning migration onto the floodplain as the wet season begins in the Alligator River region of the Northern Territory, before returning upstream at the end of the wet season (Bishop et al. 1995). This downstream spawning migration enables spangled perch to use floodplain habitats that are only submerged during the wet season. Lateral movements onto floodplains are facilitated by the ability of this species to move through very shallow water. Spangled perch are rapid swimmers (Bishop et al. 1995) and there are numerous anecdotal reports that suggest active upstream movement in the Murray-Darling Basin.

Bovichtidae

Pseudaphritis urvilii (Valenciennes, 1831) Congolli

Pseudaphritis urvilii is common in coastal and estuarine waters of south eastern Australia and has been reported up to 100 km upstream of the Murray River mouth in South Australia (Andrews 1996). Little is known of the movement patterns of the congolli, apart from the fact that in Victoria it is believed to migrate from fresh water into estuaries to spawn in autumn and winter (Andrews 1996).

Eleotridae

Hypseleotris spp.							
Hypseleotris galii	(Ogilby, 1898)	Fire-tailed gudgeon					
Hypseleotris klunzingeri	(Ogilby, 1898)	Western carp gudgeon					
<i>Hypseleotris</i> sp. 1		Midgley's carp gudgeon					
Hypseleotris sp. 2		Lake's carp gudgeon					
Hypseleotris sp. 3		Murray-Darling carp gudgeon					

Hypseleotris species cannot be reliably separated on the basis of external morphology, so are treated here as one. *Hypseleotris galii* is a coastal species of eastern Australia that has been accidentally translocated to several sites in the northern Murray-Darling Basin. *Hypseleotris klunzingeri* is found throughout the Murray-Darling Basin, and in coastal streams from northern New South Wales to Central Queensland. Midgley's and Lake's carp gudgeons are found throughout most of the Murray-Darling Basin with the exception of the upper Murray and upper Murrumbidgee and their tributaries. The recently discovered Murray-Darling carp gudgeon appears to have a patchy distribution in the Darling River and its tributaries (Larson & Hoese 1996, Allen et al. 2002).

Little is known about the movements of *Hypseleotris* species from any location. Pusey et al. (2004) have reported occasional mass upstream migrations of *H. galii, H. klunzingeri* and *Hypseleotris* sp.1 in south Queensland coastal streams following increases in flow. Stuart and Berguis (1999) have also collected small numbers of *H. klunzingeri* attempting to move upstream through fishways, while Russell (1991) collected two individuals moving downstream through a tidal barrage fishway on the Fitzroy River. The Murray River Fishway Assessment Program has recorded large numbers of *Hypseleotris* moving to barriers in the Murray (Mark Lintermans², pers. comm. 2005).

Determining movement patterns for *Hypseleotris* species is confounded by the difficulty of reliably separating the species.

Mogurnda adspersa (Castelnau, 1878) Purple-spotted gudgeon

Mogurnda adspersa was once found throughout most of the Murray-Darling Basin and the eastern half of Queensland (Andrews 1996, Allen et al. 2002). It is now threatened in the southern half of the MDB. Several authors have speculated on possible movements made by this species (see Pusey et al. 2004), but these speculations lack a base in hard data. A 16-day mark recapture study in north Queensland showed that purple-spotted gudgeons make small scale movements between pools separated by riffles (Boxall et al. 2002). These authors found that males had a slight tendency to move further than females during their April study. Apart from that, nothing substantial has been published on the movements of purple-spotted gudgeons.

Philypnodon grandiceps (Krefft, 1864) Flathead gudgeon

Philypnodon grandiceps is found throughout the Murray-Darling Basin and in coastal streams of eastern and south-eastern Australia (Andrews 1996). Several studies have shown that flathead gudgeons move between fresh and brackish waters. Russell (1991) collected large numbers of this species moving downstream through the Fitzroy River Barrage in September 1986, but not at any other time in his 2.5-year study. Stuart and Berghuis (1999) collected large numbers of flathead gudgeons moving downstream through the Burnett River Barrage in March 1999, but not at any other time during their 1.5-year study. During flow increases, large numbers of this species also accumulate downstream of obstructions to movement, suggesting they were attempting to move upstream (Pusey et al. 2004). Flathead gudgeons comprised more than 95% of the drifting larval fish fauna in the Campaspe River from 1995 to 2001, with the majority of this downstream drift occurring in late spring/early summer (Humphries & King 2004). There has been nothing else substantial published about the movements of these gudgeons.

Philypnodon macrostomus Hoese & Reader, 2006 Dwarf flathead gudgeon

The dwarf flathead gudgeon *Philypnodon macrostomus* has a very restricted distribution within the Murray-Darling Basin, occurring in a few localities in the Murray River in South Australia and New South Wales, the upper reaches of the Macquarie River near Bathurst, and in the lower Condamine River near Condamine, as well as in coastal streams of south-eastern Australia (Larson & Hoese 1996, Allen et al. 2002). Apart from the fact that juveniles and adults are occasionally found in estuaries, there is no information on the movement of this species (Pusey et al. 2004).

² Mark Lintermans, Associate Professor, University of Canberra.

Summary of knowledge gaps

It is apparent that, overall, there is a long way to go before our knowledge of the movements of native fish in the Murray-Darling Basin can be considered adequate for management and conservation purposes. Virtually nothing is known about the movements of a great many species in the Basin, including several of the more common species.

There are significant knowledge gaps even in species that have been well studied. In particular, there are several species for which we know a considerable amount about adult movement but very little about movement during other stages of their life history. This has been partially addressed through recent work on larval drift (Humphries & King 2004, Humphries 2005), but more needs to be done in this area and in the area of juvenile movements. A great example is the Murray cod (*M. peelii peelii*), a species whose adult movements have been well described and modelled (Koehn & Nicol 1998, Koehn et al. 2004). Although we know about the pre-spawning upstream and post-spawning downstream migrations of adults and the downstream drift of eggs and larvae, there has been nothing published on the movements of juveniles. This is a significant gap as these movements include the selection of a home range within which the Murray cod will spend almost all of its adult life.

Another significant knowledge gap is that information on the movements of some species has been derived from studies outside the Murray-Darling Basin. The movement patterns of fish species are influenced by their environment, so that knowledge gained from studies in one river system may not be applicable to another system. For instance, virtually all of our knowledge of the movements of Hyrtl's tandan *N. hyrtlii* comes from studies conducted in the wet/dry tropics (Beumer 1980, Orr & Millward 1984, Bishop et al. 2001). Movement patterns of this species in the Murray-Darling Basin may be completely different due to the great differences in habitat and seasonal cycles between the wet/dry tropics and the Murray-Darling Basin.

By rating the level of our knowledge of different aspects of the movement behaviour for each species on a scale of 1 to 4, we can identify some of the major knowledge gaps (Table 1.1). These ratings must be interpreted with care as they simplify all the complexity of fish movement down to a few numbers. In particular:

- 1. Ratings do not distinguish between movements made at different stages of the fish's life history.
- 2. Ratings include information gained from movement studies outside the Murray-Darling Basin.
- 3. Ratings do not take into account variations within a species. For instance, why do some golden perch *M. ambigua* migrate upstream, some downstream and some stay put in response to increased flow?
- 4. Movements of species that are known not to undergo long distance movements are rated as 1 (well known), dragging their total score down. These species have been marked with an asterisk in the table so that readers can take this factor into account.
- 5. Small scale movements (e.g. within a restricted home range) have been included in mesoscale movements.

The ratings also do not take into account the relative ecological, recreational and conservation significance of each species. With the above limitations in mind, Table 1 does provide a useful overview of our current knowledge gaps. For instance:

- We know considerably more about long-distance migrations than we do about smaller or mesoscale movements of fish in the Murray-Darling Basin (Table 1). Such movements are probably important as they may occupy a greater part of the fish's life history and involve activities such as habitat selection, foraging, spawning and lateral movements onto floodplains and into anabranches, lagoons etc.
- 2. We know considerably less about the triggers for migration than we do about the extent and timing of migration. We know when, where and sometimes even why several species move, but we don't know precisely what triggers those movements. Many species start movements in an apparent response to increased flow, but we don't know whether current velocity, water chemistry, temperature change, season or some other factor (or combination of factors) actually triggers the movement.
- 3. There is little knowledge of the movements of some particularly significant species in terms of abundance, conservation significance and/or recreational value. They include the following:

Common and/or widespread species

- Un-specked hardyhead (C. stercusmuscarum fulvus)
- Murray-Darling rainbowfish (M. fluviatilis)
- Mountain galaxias (G. olidus)

- Flathead gudgeon (*P. grandiceps*)
- Carp gudgeons (*Hypseleotris* spp.)
- Australian smelt (*R. semoni*)
- Spangled perch (*L. unicolor*)
- Bony bream (*N. erebi*)

At-risk species

- Southern pygmy perch (*N. australis*)
- Undescribed tandan (Porochilus cf. rendahli)
- Macquarie perch (*M. australasica*)
- Trout cod (*M. macquariensis*)
- Silver perch (*B. bidyanus*)
- Tandan (*T. tandanus*)
- Agassiz's glassfish (A. agassizii)
- Purple-spotted gudgeon (*M. adspersa*)

Popular angling species

- Estuary perch (*M. colonorum*)
- Macquarie perch (*M. australasica*)
- Trout cod (*M. macquariensis*)
- Silver perch (*B. bidyanus*)
- Tandan (*T. tandanus*)

Table 1.1: Summary of the extent of our current knowledge of large and mesoscale movements of native fish species in the Murray-Darling Basin. 1 = well known or not applicable. 2 = moderately well known. 3 = poorly known. 4 = unknown.

	Level of knowledge					Tatal	
	Large scale movements		Meso	oscale mov	score by		
Species Name	Extent	Timing	Triggers	Extent	Timing	Triggers	species
Ambassis agassizii	4	4	4	4	4	4	24
Anguilla australis	1	1	3	2	2	3	12
Atherinosoma microstoma*	1	1	1	4	4	4	15
Bidyanus bidyanus	2	2	2	4	4	4	18
Craterocephalus amniculus	4	4	4	4	4	4	24
Craterocephalus fluviatilis*	1	1	1	4	4	4	15
Craterocephalus stercusmuscarum	4	4	4	4	4	4	24
Gadopsis bispinosus*	1	1	1	2	3	4	12
Gadopsis marmoratus*	1	1	1	1	2	4	10
Galaxias brevipinnis	2	2	4	3	4	4	19
Galaxias fuscus*	1	1	1	3	4	4	14
Galaxias maculatus	1	1	3	3	3	4	15
Galaxias olidus	4	4	4	3	3	4	22
Galaxias rostratus	4	4	4	4	4	4	24
Geotria australis	1	1	2	3	3	4	14
Hypseleotris galii	3	3	3	4	4	4	21
Hypseleotris klunzingeri	3	3	3	4	4	4	21

* species known to be non-migratory. ** movement information for *N. hyrtlii* only from outside the MDB.

	Level of knowledge					Tatal	
	Large scale movements		Meso	oscale mov	score by		
Species Name	Extent	Timing	Triggers	Extent	Timing	Triggers	species
Hypseleotris sp. 1	3	3	3	4	4	4	21
Hypseleotris sp. 2	3	3	3	4	4	4	21
Hypseleotris sp. 3	3	3	3	4	4	4	21
Leiopotherapon unicolor	3	2	3	4	4	4	20
Maccullochella macquariensis	3	3	3	3	4	4	20
Maccullochella peelii peelii	1	2	3	1	2	3	12
Macquaria ambigua	1	1	1	2	2	3	10
Macquaria australasica	3	3	4	4	4	4	22
Macquaria colonorum	3	2	4	4	4	4	21
Melanotaenia fluviatilis	4	4	4	4	4	4	24
Mogurnda adspersa	4	4	4	3	4	4	23
Mordacia mordax	1	1	3	3	3	4	15
Nannoperca australis	4	4	4	4	4	4	24
Nematalosa erebi	3	3	3	4	3	3	19
Neosilurus hyrtlii**	3	2	3	3	2	3	16
Philypnodon grandiceps	4	3	3	4	4	4	22
Philypnodon macrostomus	4	4	4	4	4	4	24
Porochilus cf. rendahli	4	4	4	4	4	4	24
Pseudaphritis urvilii	3	2	4	4	4	4	21
Retropinna semoni	3	3	4	3	4	4	21
Tandanus tandanus	3	3	4	3	4	4	21
Total score by category	101	97	116	129	136	147	

1.3 Project objectives

The specific objectives of this project were to investigate mesoscale movements of Murray-Darling Basin fish species and/or life history stages for which there is little existing information. This includes an investigation into both longitudinal and lateral movements and into possible movement triggers.

We proposed to address the objectives by studying the mesoscale movements of several common, but less wellknown species (*Hypseleotris* spp., *N. erebi* and *M. fluviatilis*), some rarer species (*T. tandanus, A. agassizii*), and several northern MDB species (*N. hyrtlii, L. unicolour*). We also aimed to collect movement information on the juvenile stages of Murray cod *M. p. peelii* and golden perch *M. ambigua* and, where possible, to opportunistically collect information on the movements of other little-studied species that occur in our selected study sites.

Definition

For the purposes of this project:

Mesoscale movement is defined as a movement beyond at least a single meander (or pool-riffle complex) or a movement between the river channel and its floodplain habitats. The upper bounds of our definition are distances of up to 40 km. Beyond that, we consider movements to be macroscale.

This project did not aim to study microscale movements (e.g. movement from bankside root masses to open water) or microhabitat use. In the context of the Macintyre and Condamine Rivers (our chosen research locations) mesoscale movements are therefore in the order of hundreds of metres. For a small fish like a gudgeon this is a considerable movement in terms of body length.

2. METHODS

This project was run in two phases: a pilot phase and a main phase. The pilot phase was used to select study areas and refine methods used in the main phase of the project. Methods used in both phases are described here. There is partial reporting of the results of the pilot work in this chapter, as these results influenced modifications to the final methodology in the main phase. All work was carried out under animal ethics approval number Bribie 23/10/04.

2.1 Pilot phase

2.1.1 Site selection

We examined aerial photographs, satellite imagery and topographic maps to locate potential areas for studying longitudinal and lateral movements into floodplain lagoons and anabranches. To determine if these areas were likely to have high abundance of native fish species we examined Sustainable Rivers Audit (SRA) pilot sampling data, and Queensland DPI&F long-term monitoring data. We also had discussions with staff in both the Queensland Department of Natural Resources and Mining and from the Cooperative Research Centre for Freshwater Ecology in Goondiwindi. This was followed by ground-truthing to determine whether areas could be easily accessed for sampling. We also had discussions with landholders and staff in regional DPI&F and DNRW offices to negotiate access and determine permanency of river waterholes, floodplain lagoons and the general frequency of connectivity.

During October, November and December 2005, project staff visited several regions in the upper Condamine River (near Warwick), the Macintyre River (near Goondiwindi), and the lower Condamine River (between Chinchilla and the junction of the Condamine and the Balonne Rivers at the confluence of Dogwood Creek) to select suitable research sites. We also visited the lower Dogwood Creek and Charlie's Creek systems (major tributaries of the Condamine-Balonne with lagoon and anabranch systems).

Using this background work we chose two regions for the research project. The first was approximately 40 km west of Goondiwindi on the Macintyre River system, and the second approximately 40 km west of the town of Condamine, on the Condamine River (see Figure 2.1 for a location map).

Both riverscapes were similar in geomorphology. They consisted of a main river channel with floodplain anabranches and floodplain lagoons. There were occasional rock bars across the channel of both systems. Both areas were near the boundary of the transformational and depositional geomorphic zones. The position of both sites in the catchment would generally provide at least three days prior warning of a major flood event from significant upper catchment rainfall. This would enable access prior to a flood arriving, an important consideration for studies of lateral movements. The length of river selected at each location was approximately 40 km. This length encompassed our definition of mesoscale movement.

Both locations contained (according to local knowledge) permanent to semi-permanent lagoons and permanent waterholes in the river channel. The main difference between the selected regions was flow regime. The Macintyre River study reach had a highly regulated flow with frequent releases from upstream water storages. There are three major dams (Pindari, Glen Lyon and Coolmunda) in the mid- to upper Macintyre catchment, all controlled by a single water authority. There are also at least six weirs, including the Goondiwindi and Boggabilla Weirs. In contrast, the Condamine River reach had only natural flows, although these were probably reduced by upstream extraction and capture by weirs upstream, including Louden Weir near Dalby and the Chinchilla Weir. In both regions landholders were extremely generous with access through private property to the river and adjacent wetlands.

Lagoon habitats and some sections of each river were used to pilot research methods as outlined below. In addition, tag retention trials were completed in tanks at the Southern Fisheries Centre, Deception Bay.



Figure 2.1: Location of the Condamine and Macintyre River research reaches. Reaches are denoted by red dots.

2.1.2 Tag retention trials

Five species of fish (Table 2.1) were collected by electrofishing and brought back to Southern Fisheries Centre at Deception Bay for tag retention trials. Three species, bony bream *N. erebi*, carp gudgeons *Hypseleotris* spp. and un-specked hardyheads *C. s. fulvus*, were tagged with Visual Implant Elastomer (VIE) tags. VIE tags were injected as a liquid polymer under the skin with a syringe needle. The liquid polymer sets in situ into an inert non-toxic soft plastic substance. VIE tags come in a range of colours and can be used as batch tags. The number of batches available is a function of tag colour and the number of body locations where the tags are visible after injection. Bony bream *N. erebi* were tagged in clear tissue on the dorsal surface of the head; *Hypseleotris* spp. and *C. s. fulvus* were both tagged under the skin adjacent to the dorsal fin and adjacent to the anal fin.

Spangled perch *L. unicolor* and *N. hyrtlii* were tagged in the gut cavity with Passive Integrated Transponder (PIT) tags. Because each PIT tag contains a unique magnetic code that is activated when the tag is passed over by an electronic reader, these tags are suitable for identifying individual fish.

Prior to tagging, the fish were anaesthetised in clove oil with a concentration of 0.025 to 0.05 mL L⁻¹. They were then measured to fork or total length (depending on tail morphology) and tagged. After tagging, fish recovered in 40L aerated fresh water in Nally bins. Following recovery, fish were transferred to aerated tanks where they were maintained for the duration of the experiment. *Neosilurus hyrtlii, L. unicolor* and *N. erebi* were maintained in 5000L tanks and the other species were kept in 1000L tanks. For each of the species (excluding *N. hyrtlii*) there was an untagged control group to enable evaluation of post-tagging mortality. Numbers of fish tagged and numbers of controls are listed in Table 2.1.

Species	VIE below dorsal fin	VIE adjacent to anal fin	VIE head	Untagged control	PIT tag gut cavity
Nematalosa erebi			57	58	
Hypseleotris spp.	50	50		50	
Craterocephalus stercusmuscarum	38	38		38	
Leiopotherapon unicolor				16	16
Neosilurus hyrtlii					2

Table 2.1: Tagging treatments and number	s of fish tagged at Southern	Fisheries Centre.
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Fish were kept in the tanks from four to six months depending on time of capture (See Table 2.2 for duration of tag trials). Tagged and untagged control fish were maintained in separate tanks. This was to prevent confusion between control fish and fish that lost tags. Fish were fed daily on a diet of commercial pellet and flake foods at a rate of approximately 2% of bodyweight. Tanks were monitored daily for mortalities. Waste was siphoned daily from the bottom of the tanks, and siphoned water was replaced with a fresh water supply.

Species and treatment	Days since tagging
Nematalosa erebi head tag VIE	170
Nematalosa erebi control	170
<i>Hypseleotris</i> spp. anal tag VIE	160
<i>Hypseleotris</i> spp. dorsal tag VIE	160
<i>Hypseleotris</i> spp. control	160
Leiopotherapon unicolour gut cavity PIT	120
Leiopotherapon unicolour control	120
Neosilurus hyrtlii gut cavity PIT	120
Craterocephalus stercusmuscarum anal tag VIE	172
Craterocephalus stercusmuscarum dorsal tag VIE	172
Craterocephalus stercusmuscarum control	172

Table 2.2: Number of days that five trial species of fish were held post-tagging.

2.1.3 Field trials

The riverine research reaches on the Macintyre and Condamine Rivers were broken up into numbered research zones. These were spaced at approximately five to six km intervals in a straight line, but a zone could include up to 15 km of stream length. Some adjacent lagoon systems were also designated as research zones. These zones were designed for use of unique batch tags (see Section 2.2 below and Figures 2.11 and 2.12).

For the pilot work, short-term, mark-recapture trials were conducted in both the Condamine and Macintyre research areas between January and April 2005. In the Macintyre research area, pilot work was restricted to Zone 1 (near Riverview Homestead), Zone 2 (adjacent to Camp David Lagoon), Zone 3 (Camp David Lagoon) and Zone 5 (adjacent to Macintyre Downs Homestead). In the Condamine research area, the pilot work was restricted to Zone 3 (River adjacent to the Karreel lagoons), Zone 4 (Karreel: small lagoon) and Zone 5 (Karreel: large lagoon). A total of 1402 fish were tagged and released in these zones (Table 2.3). VIE tag colour and body location varied according to the zone (Table 2.3). Fish were tagged using both PIT (400) and VIE (1002) tags (Table 2.4).

Fish for tagging studies were collected using a combination of backpack electrofishing, boat electrofishing, fish traps, mini-fyke nets and standard fyke nets. Because the two fyke systems and electrofishing were found to be the most effective sampling methods, they were selected for use in the main phase of the project (see below). However, during very high water temperatures (28–30°C), we noted that electrofished *M. p. peelii* and some spangled perch were having difficulty recovering from electrofishing. Oxygen levels were probably too low to sustain these fish without full gill ventilation. For ethical reasons we concluded it was best to avoid sampling during high water temperatures. This cut short some of our pilot sampling.

Post-capture fish were transported in an aerated fish carrier to a central air conditioned tagging tent (Figure 2.2). Here fish were separated by species and held in 300L tanks until ready for tagging. Just prior to tagging, fish were anaesthetised using clove oil (0.025-0.05 mL L⁻¹), then tagged using automated VIE tagging machines or hand-held PIT taggers. Fish were then allowed to recover in a 300L tank before being transported back to their capture sites for release. Species tagged included *Hypseleotris* spp., *A. agassizii, L. unicolor, B. bidyanus, M. ambigua* juveniles (20 mm–200 mm TL), *M. fluviatilis, N. erebi, N. hyrtlii* and *T. tandanus*. Adult *M. ambigua* and *M. p. peelii* were captured but not tagged. The majority of small fish were tagged with VIE, but *L. unicolor* larger than 50 mm fork length (FL), *M. ambigua* larger than 60 mm total length (TL), *T. tandanus* over 100 mm and *N. hyrtlii* longer than 120 mm TL were PIT tagged in the gut cavity.

Figure 2.2: Tagging tent. Tagged fish were placed into the white chute (centre) which carried them on a flow of recirculating water into the grey recovery tank.



Table 2.3: Zone-specific code for colour and placement of VIE tags used during pilot work on different species of fish. Note *T. tandanus* >100 mm TL, *N. hyrtlii* >120 mm TL, *M. ambigua* >60 mm TL and all *L. unicolor* >50 mm were PIT tagged.

	_	_ .	Spangled perch and	
River	Zone	Bony bream	catfish spp.	All other species
Condamine	Zone 3	Yellow, head, vertical	NA	Yellow, left dorsal
Condamine	Zone 4	Orange, head, vertical	Orange, lower jaw	Orange, left anal
Condamine	Zone 5	Black, head, vertical	Orange lower jaw	Orange, left dorsal
Macintyre	Zone 1	Red, head, vertical	NA	Red, left dorsal
Macintyre	Zone 2	Pink, head, vertical	NA	Pink, left dorsal
Macintyre	Zone 3	NA	NA	Orange, right dorsal
Macintyre	Zone 4	Yellow, head, vertical	NA	Yellow, left dorsal
Macintyre	Zone 5	Green, head, vertical	NA	Green, left dorsal

During April 2005 we used a combination of backpack and boat electrofishing, fykes and mini-fykes to sample the areas where tagged fish had been released. Unfortunately, due to one of the driest summers on record, Macintyre Zone 3 (Camp David Lagoon) had dried out and the fish contained within it had perished. However, some tagged fish were recaptured from the other zones, suggesting that mark recapture of small- to mediumsized species was viable.

		,						i
Species	MZ1	MZ2	MZ3	MZ5	CZ3	CZ4	CZ5	Total Numbers
Ambassis agassizii	1	0	20	0	0	2	1	24
Hypseleotris spp.	1	0	130	1	150	4	170	456
Leiopotherapon unicolor	15	0	0	0	8	241	96	360
Bidyanus bidyanus	1	0	0	0	0	0	0	1
Macquaria ambigua	4	6	0	0	13	0	0	23
Melanotaenia fluviatilis	53	3	2	1	0	0	0	59
Nematalosa erebi	94	44	1	25	52	34	200	450
Neosilurus hyrtlii	0	0	0	0	0	8	4	12
Tandanus tandanus	0	0	0	0	4	1	12	17
Total								1402

Table 2.4: Numbers of fish tagged by zones during pilot work. Condamine Zone (CZ) Macintyre Zone (MZ).

2.2 Main phase

The main phase of this study was developed to include both regular and flood event-driven field sampling trips. These sampling trips had three main aims:

- 1. A mark-recapture study to determine the movements of known individual fish or (in the case of smaller species or life stages) known batches.
- 2. Quantitative or semi-quantitative sampling of fish numbers at regular intervals over a range of habitats to follow movements of fish populations.
- 3. To collect data on environmental parameters that may trigger fish movements.

The third aim was also supplemented by continuous data collected by other agencies and our own data loggers. Radiotelemetry data of *N. erebi* and *L. unicolor* were also used to provide additional information on movements.

2.2.1 Mark-recapture

Field trips were made every three to four months with the sole purpose of collecting, tagging and releasing fish. Fish were collected for tagging using a combination of backpack electrofishing and boat electrofishing.

For the main phase of the project, fish were tagged with VIE and PIT tags. PIT tags were used for robust fish such as *L. unicolor*, catfishes, juvenile *M. peelii peelii* and juvenile *M. ambigua*. Because each PIT tag has a unique code, each one can have a unique release location. Latitude and longitude coordinates were recorded with the aid of a GPS for the release point of every PIT-tagged fish. The locations were recorded in decimal degrees in GD4-94 datum.

Conversely, VIE tags do not have unique codes and can therefore only be used as batch tags. The VIE tagging system was used on small species of fish from about 30 mm total length and upwards (Figure 2.3). For *N. erebi* we used it only on fish larger than 100 mm total length, as tank trials and field-based pilot work suggested post-tagging or post-handling mortality was a problem for smaller *N. erebi*. Juveniles of robust species that were considered too small for PIT tags were tagged with VIE. Batch combinations, for the majority of species, were based on tag colour and four tag positions adjacent to the dorsal or anal fins (right or left dorsal and right or left anal). The only suitable tissue for VIE tags in *N. erebi* is the dorsal area of the head. To increase the number of batches in this area we altered the orientation of the mark: horizontal, vertical, left diagonal, right diagonal (see Figures 2.4 and 2.5). Juveniles of catfish species, and occasionally *L. unicolor*, were tagged in the lower jaw area.



Figure 2.3: VIE-tagged *M. fluviatilis*, showing a yellow tag in the left dorsal position.

Figure 2.4: Inserting a vertical pink VIE tag into the dorsal head region of a *N. erebi* using an automated NMT VIE tagging machine.



Figure 2.5: Alternative VIE head tags for *N. erebi*. A: vertical; B: Horizontal; C: Left diagonal; D: Right diagonal.



Initially, we used only one VIE batch tag per zone in the pilot work. All tagged fish were released near to their point of capture. However, multiple release points in a single zone meant it was not possible to obtain precise movement data for batch-tagged fish. We did not want to release fish far from their capture point, as they could be more susceptible to predation, and movements might just indicate a return to the point of capture. As a compromise, we divided each tagging zone into a number of sub-zones for tagging. Fish were collected from a 300-metre section of river by boat and backpack electrofishing, tagged and then released at a fixed point near the middle of that section. Therefore all tagged fish were released within 150 m of their capture point. Each zone was designated a VIE colour and each sub-zone a different body tagging location. The colours and marks used are detailed in Tables 2.5 and 2.6. This system provided better precision with the recapture data. Figures 2.6 and 2.7 show schematics of the old and new tagging and release systems respectively. Care was taken when selecting batch marks to prevent confusion with the system used in the pilot study.

Figure 2.6: A schematic diagram of the old VIE tag-release system. This involved a number of release sites in a zone with a single batch mark. Fish were released near to where caught.



Figure 2.7: A schematic diagram of the new VIE tag-release system. This has up to four fixed release points per zone, each with a unique colour and body location combination. Fish released at these points come from a 300-m segment of river within the zone.



The tagging process was further improved compared to the pilot phase, with a mobile (rather than fixed) tagging system. This meant all tagging took place near to the zone of capture, reducing handling times and transport stress and increasing the amount of time available for collection and tagging.

Before tagging, fish were held in floating cages in the river or lagoon. They were then transferred to aerated Nally bins or buckets as needed, anaesthetised with 0.025–0.05 mL L⁻¹ clove oil, tagged and placed in an aerated recovery bucket or Nally bin. After recovery, all healthy tagged fish were returned to the river at a fixed release point. When large numbers of fish were captured, we used automated VIE tagging machines from Northwest Marine Technology (NMT) powered by a car battery connected to an inverter. Compressed air from a SCUBA tank (Figure 2.8) was used to move the automated plungers on the syringe needles. When only small numbers of fish were captured, NMT hand taggers were used to inject the VIE tags (Figure 2.9). PIT tags were always injected with hand-held taggers (Figure 2.10).

Figure 2.8: Mobile automated VIE tagging system.





Figure 2.9: Tagging an *A. agassizii* with a VIE tag using a NMT hand tagging unit.

Figure 2.10: Injecting a PIT tag into the abdominal cavity of a juvenile golden perch *Macquaria ambigua*.



Zone and	Bony bream	Spangled perch and catfish spp	All other species
1A	Red. head. vertical	NA	Red. left dorsal
1B	Red, head, horizontal	NA	Red, right dorsal
1C	Red, head, left diagonal	Red, lower right jaw	Red, left anal
1D	Red, head, right diagonal	NA	Red, right anal
2A	Pink, head, vertical	NA	Pink left dorsal
2B	Pink, head, horizontal	NA	Pink, right dorsal
2C	Pink, head, left diagonal	NA	Pink, left anal
2D	Pink, head, right diagonal	NA	Pink, right anal
ЗA	Yellow, head, horizontal	NA	Yellow, right dorsal
3B	Yellow, head, left diagonal	NA	Yellow, left anal
3C	Yellow, head, right diagonal	NA	Yellow, right anal
4	Orange, head, horizontal	Orange, lower left jaw	Orange, left anal
5	Orange, head, vertical	NA	Orange, left dorsal
6A	Green, head, vertical	NA	Green, left dorsal
6B	Green, head, horizontal	NA	Green, right dorsal
6C	Green, head, left diagonal	NA	Green, left anal
6D	Green, head, right diagonal	NA	Green, right anal
7A	Blue, head, vertical	NA	Blue, left dorsal
7B	Blue, head, horizontal	NA	Blue, right dorsal
7C	Blue, head, left diagonal	NA	Blue, left anal
7D	Blue, head, right diagonal	NA	Blue, right anal

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Two study regions were divided into tagging zones, as explained in the pilot phase. However, given the Macintyre Zone 3 (Camp David Lagoon) drying, and limited boat access by boat in other zones due to low water levels, the Macintyre Zones 2, 3 and 4 zones were dropped from the main project phase (see below). These zones were occasionally searched for tagged fish or radiotelemetry searches. Figures 2.11 and 2.12 show all zone boundaries, as well as the fixed release points used for VIE-tagged fish in the Condamine and Macintyre Rivers respectively.

1 and 2 and 3 a

Zone and			
sub-zone	Bony bream	Spangled perch and catfish spp.	All other species
0A	NA	NA	Pink, left anal
0B	NA	NA	Pink, right dorsal
1A	Red, head, horizontal	NA	Red, right dorsal
1B	Red, head, vertical	NA	Red, left dorsal
1C	Red, head, right diagonal	NA	Red, right anal
1D	Red, head, left diagonal	NA	Red, left anal
5A	Yellow, head, left diagonal	NA	Yellow, left anal
5B	Yellow, head, right diagonal	NA	Yellow, right anal
5C	Yellow, head, horizontal	NA	Yellow, right dorsal
5D	Pink, head, right diagonal	NA	Pink, right anal
6	Blue, head, vertical	NA	Blue, left dorsal
7A	Orange, head, vertical	NA	Orange, left dorsal
7B	Orange, head, horizontal	NA	Orange, right dorsal
7C	Orange, head, left diagonal	NA	Orange, left anal
7D	Orange, head, right diagonal	NA	Orange, right anal

Figure 2.11: Condamine tagging zones and release points. Zone boundaries are marked in yellow, and release points are shown as pink dots. Release points within each zone were named alphabetically from upstream to downstream (A, B, C etc.) and can be matched to Table 2.5.



Figure 2.12: Macintyre tagging zones and release points. Zone boundaries are marked in yellow and release points are shown as pink dots. Release points within each zone were named alphabetically from upstream to downstream (A, B, C etc.) and can be matched to Table 2.6. Lagoon zones are circled in yellow.


2.2.2 Radiotelemetry

Between August 2006 and late January 2007 we used radiotelemetry to study movements of spangled perch *L. unicolor* and bony bream *N. erebi.* Radio-tagged *L. unicolor* ranged from 151 mm to 190 mm FL and *N. erebi* were all larger than 228 mm FL. This work was designed to supplement information from PIT and VIE tag recaptures and mini-fyke and fyke net captures of the two species. Radiotelemetry offers the advantage of real-time movement information in relation to prevailing environmental conditions. We believe this is the first time anyone has used radio-telemetry to study these species. The radiotelemetry study was timed to coincide with what is normally the wettest time of the year in the northern Basin.

Nematalosa erebi were collected in the Macintyre River by boat electrofishing. Surgery was conducted adjacent to the river as soon as possible after capture. Fish were sedated in a Nally bin containing clove oil in river water at a concentration of approximately 0.025 mL L⁻¹. Following anaesthesia, fish were transferred to an operating frame with a damp sponge cradle (Figure 2.13). While on the operating frame, fish had their gills irrigated with recirculated aerated water containing anaestheticusing two tubes inserted into the mouth. Surgery began with a small lateral incision made with a scalpel in the abdominal cavity wall just above the pelvic fin (Figure 2.13). An Advanced Telemetry Systems transmitter (F1575) weighing 1.8 g was inserted through the incision. A catheter needle was then used to puncture a small hole towards the distal end of the abdominal cavity. An aerial attached to the transmitter was then threaded though the catheter and out the small hole. Following this, the abdominal wall was sutured internally and externally using dissolving stitches. The wound was then sealed with SuperglueTM and swabbed with an iodine solution. After surgery, the fish was given an intramuscular injection of antibiotic (oxytetracycline) at a rate of 50 mg kg⁻¹ body weight.

To aid recovery from surgery, fish were placed in an aerated Nally bin containing clean water. When fully recovered from anaesthesia they were released into the adjacent river. Radio-tagged bony bream were released at three riverine locations, one in Zone 1 and two in Zone 5. A total of 11 *N. erebi* were released into the Macintyre River.

Leiopotherapon unicolor were collected by boat and backpack electrofishing from the Condamine River and the adjacent large Karreel Lagoon. Surgical procedures to insert radio transmitters were as for *N. erebi*. Post-surgery *L. unicolor* were released either into a riverine weir pool in Zone 1, a river waterhole in Zone 3 or into the large Karreel Lagoon. A total of eight *L. unicolor* were released.

All fish were tracked at four 6-hourly intervals for the first 24 hours post release. Daily fixes were then made over the next two to five days. After that, fish were tracked at intervals of two to three weeks, on foot from the river bank, from boats and, on one occasion, from a light aircraft. The position of the fish was estimated by triangulation with a receiver fitted with a directional loop antenna. Each time a fish was located, the latitude and longitude coordinates of its position was recorded. We recorded details of the type of habitat it was occupying (pool or riffle, open water or near bank, woody debris, undercut bank, overhanging vegetation or bare bank) and stage of flow (see Table 2.7 for full list of parameters recorded). We also noted whether the fish appeared to be stationary or moving.



Figure 2.13: Bony bream undergoing surgery to implant transmitter.

2.2.3 Standardised quantitative sampling

Regular quantitative sampling was conducted at three- to four-month intervals over a two-year period. Sampling at low water levels was avoided during the heat of summer as the high water temperatures (28–30°C) were stressful to fish and could have led to unacceptable levels of post-sampling mortalities. However, the sampling team was on standby to sample major flow or flood events during the summer months.

Quantitative sampling used a combination of boat electrofishing, fykes and mini-fykes. Within each zone, these sampling methods were used at predetermined areas both within and outside tagging sub-zones (see Figures 2.11 and 2.12). In some shallow lagoon sites, backpack electrofishing was used instead of boat electrofishing.

The standardised sampling had several purposes. Differences in catch rates over time between sites could be used to infer movement patterns. Standardised sampling was also used as one means to recapture marked fish, but additional hunting for tagged fish was also carried out (see Section 2.2.5). The key reason for our selected sampling methods was that electrofishing is active, whereas fykes and mini-fykes, being passive, depend on fish to be active for them to be caught. A comparison of electrofishing and fyke net catch data can potentially indicate which species or size classes are moving compared to the range of species or size classes present. If fish were frequently captured in the electrofishing shots, and rarely in the fyke/mini-fyke shots, then this might suggest that fish were "resident" in the area but not migrating. If some were caught using both methods then they might be resident and actively foraging, and if fish were predominantly caught in large numbers in the fyke/mini-fyke nets then they were probably migrating. Furthermore, because fyke nets are directional traps, they can indicate the direction fish are moving.

Fykes and mini-fykes

Fyke nets used in this study had two 5-metre wings, with a 55 cm drop and 12 mm mesh (Figure 2.14). The entrance hoop to the codend was 60 cm high. This was followed by three funnels leading into the codend. Mini-fykes were constructed from five jointed 80 cm square galvanised steel frames. Shade cloth was attached to each of the frames. The two outer frames on each side served as wings, and the middle frame as an entrance funnel. The entrance funnel was attached to a collapsible 3 mm mesh minnow trap (with the distal entrance sewn shut), which served as the codend (Figure 2.15). The mini-fykes could be folded flat, for transport and storage.



Figure 2.14: View of fyke net showing codend with three entrance funnels.



Figure 2.15: View of mini-fyke net showing foldable wings on frames and minnow trap codend.

Fykes and mini-fykes were set in back-to-back pairs, with entrances facing upstream and downstream respectively (Figure 2.16). This was to provide directional movement information. A float was placed in the codend of the fykes to provide an air space for turtles and water rats. The entrance hoop also had 70 mm vertical grills fitted to exclude large turtles. These grills also excluded large carp but had no effect on target species. Fykes and mini-fykes were set in the afternoon and cleared the following morning. Between four and six pairs of fykes and mini-fykes were set in each zone. The number of sets depended on access to areas with suitable bottom topography for setting a fyke. Generally, fykes and mini-fykes were set on opposite banks, so that neither method affected the other. Fyke and mini-fyke pairs were set at least 100 m from the next pair. Fyke sites were generally fixed, but minor adjustments to set locations reflected prevailing water levels.

For each fyke and mini-fyke set, the latitude and longitude coordinates, set and pull times, the depth at the entrance funnel, width of the wings, bottom substrate type, current velocity, habitat type (pool or riffle), stage and type of flow, and whether the codend was upstream or downstream were recorded (Table 2.7 contains a full list of parameters recorded).



Figure 2.16: Back-to-back pairs of fykes and mini-fykes set in the Macintyre River for standardised sampling.

Electrofishing

In each zone there were between four and six standard electrofishing shot sites. Electrofishing sites were fixed, but were selected initially using a stratified random approach, constrained by boat access. Some sites fell within tagging sub-zones, and others were set upstream and downstream of tagging sub-zones.

Boat electrofishing was done using a 12-foot punt fitted with a 2.5KVA generator and 2.5KVA Smith-Root control box. Each standard boat electrofishing shot was completed in a structured fashion (Figure 2.17) over a fixed area of 50 m by 15 m for a defined period of power-on time of approximately 300 seconds (± 5%). To maximise small fish capture , a setting of 120 pulses per second (pps) was used. Voltage was varied according to the prevailing conductivity and temperature conditions. Stunned fish were dip-netted from the water with a 3 mm open-mesh dip net fitted to a fibreglass pole. Given the high turbidity levels it was not possible to see far into the water column. To improve catch rates the netter made continuous blind sweeps in a figure-of-eight movement alternating between the bottom substrate and near the surface. This resulted in captures of large numbers of fish not actually seen by the netter. Fish that were visible to the netter were deliberately targeted between blind sweeps.



Figure 2.17: Structured sampling pattern of a standard boat electrofishing shot. This sampling pattern is carried out over approximately 300 seconds of "power-on time".

In some shallow lagoon habitats, standardised backpack electrofishing was used rather than boat electrofishing. Covering an area approximately 15 m by 50 m, it was done with a Smith-Root LR 24 backpack unit set at 120 pps. Voltages were varied according to the prevailing conductivity and temperature conditions. The stunning range of a backpack unit is generally smaller than that of a boat. Total power-on time for backpack shots was normally about 300 seconds. The two-person team followed a zigzag course across the fixed area. A netter followed close behind the operator of the unit, making blind sweeps behind the anode. Every five metres, netted fish were released into a Nally bin of water set in a tyre inner tube that the netter towed.

For all standardised electrofishing shots, stage of flow, flow type and habitat type were recorded, as were prevailing water temperature, conductivity, stream or lagoon width, maximum depth, date, time of day, power-on time, latitude and longitude of the shot and electrofishing settings (see Table 2.7 for a full list of variables and their categories).

All fish captured in standard electrofishing, fyke and mini-fyke shots were identified and counted. If more than 20 fish of any species were captured, then a sub-sample of the first 20 fish was measured in mm to fork length (FL). A measure of total length (TL) was made for round-tailed species. All target species were checked for tags. If the shot was in a tagging sub-zone, then target species were also tagged with VIE or PIT tags before release.

The majority of fish captured by standardised sampling (fyke or electrofishing) were released unharmed near to where they were caught. VIE-tagged fish were released at fixed release points in tagging sub-zones. Noxious and pest fish species (*Cyprinus carpio, Carassius auratus* and *Gambusia holbrooki*) were euthanised by anaesthetic overdose.

2.2.4 Environmental and other variables

During the project a range of environmental and other variables were collected. These variables were selected as potential triggers or explanatory variables for fish migration, or they were potential covariates that might explain some variation in catch efficiency. Most of these variables were collected as spot samples during standard fyke netting and electrofishing operations. However, some variables were collected using two multiprobe water quality data loggers, one at each site, to obtain data at hourly intervals on water depth, pH, salinity, conductivity, temperature and turbidity. These data loggers were deployed in the Condamine and Macintyre River sites in April 2005.

Some additional flow and water quality information was obtained from Department of Natural Resources and Water (Queensland) and Department of Natural Resources (NSW) gauging stations located adjacent to our research sites. The depth readings from the gauging stations and our own data loggers helped confirm stage of flow information collected during electrofishing and fyke netting operations. Moon phase was obtained from the Australian Bureau of Meteorology. A full listing of variables and their links to any sampling method are shown in Table 2.7.

Variable	Туре	Categories	Linkages to sampling methods	Spot or continuous logging
Water temperature (°C)	Continuous		electrofishing, fykes, mini-fykes	both
Conductivity (µS)	Continuous		electrofishing, fykes, mini-fykes	both
Turbidity (NTU)	Continuous			continuous logging
Oxygen (ppm)	Continuous			continuous logging
Depth (cm)	Continuous			continuous logging
Maximum depth (cm)	Continuous		electrofishing	spot
Set depth	Continuous		fyke, mini-fyke	spot
рН	Continuous			Continuous logging
Stage of flow	Category	Base, Rise, Peak, Fall, No flow river, No flow lagoon, Dry	electrofishing, fykes, mini-fykes	spot (linked to continuous logging of depth)
Flow type 1	Category	Natural, Artificial,	electrofishing, fykes, mini-fykes	spot
Flow type 2	Category	Within bank, overbank, none*	electrofishing, fykes, mini-fykes, telemetry	spot
Current velocity cm s ⁻¹	Continuous		fykes, mini-fykes	spot
River	Category	Condamine, Macintyre	electrofishing, fykes, mini-fykes, telemetry	ΝΑ

Table 2.7: Environmental and other variables collected and their linkages to sampling methods.

Variable	Туре	Categories	Linkages to Spot or continuous sampling methods logging	
Season	Category	Winter, Spring, Summer, Autumn	electrofishing, fykes, mini-fykes	spot
Reach habitat	Category	Pool, Weir pool, Riffle	electrofishing, fykes, mini-fykes, telemetry	spot
Broad habitat	Category	Lagoon, river, anabranch	electrofishing, fykes, mini-fykes, telemetry	spot
Microhabitat	Category	Open water, bank, logs, rocks, overhanging vegetation	telemetry	
Wetted width	Continuous		electrofishing	spot
Latitude-Longitude position	Continuous		electrofishing, fykes, mini-fykes, telemetry, mark-recapture	spot
Time (24 h)	Continuous		electrofishing, telemetry	spot
Set time (24 h)	Continuous		fykes, mini-fykes	spot
Retrieve time (24 h)	Continuous		fykes, mini-fykes	spot
Soak time (h)	Continuous		fykes, mini-fykes	spot
Power-on time (s)	Continuous		electrofishing	spot
Volts	Continuous		electrofishing	spot
Per cent gain	Continuous		electrofishing	spot
Pulses per second	Continuous		electrofishing	spot
Moon phase	Category	New, first quarter, full, last quarter	electrofishing, fykes, mini-fykes	spot
Primary substrate	Category	Silt, rock, clay, sand, mud, gravel	fykes, mini-fykes	spot
Secondary substrate	Category	Silt, rock, clay, sand, mud, gravel, none	fykes, mini-fykes	spot
Gear	category	Fyke upstream codend, fyke downstream codend, mini-fykes upstream codend, mini-fykes downstream codend, boat electrofishing, backpack electrofishing	fykes, mini-fykes electrofishing	spot

2.2.5 Hunting

Some tagged fish were recaptured during standard sampling and also during sampling to collect fish for tagging. To increase the numbers of recaptured tagged fish, more sampling was carried out at sites above and below tagging sub-zones. Hunting for recaptures included both boat-based and backpack electrofishing. Key areas targeted for hunting included below natural barriers and weirs during low flow events, isolated river pools during periods of no flow, and a feeder stream to the large Karreel Lagoon. During backpack electrofishing, catches were examined after every 10 m for tagged fish. For boat electrofishing, catches were checked for tags every 50 m. If a tagged fish was recaptured, it was measured, identified and the tag details recorded. The latitude and longitude of the recapture point was recorded at the mid-point of the area sampled by electrofishing.

2.2.6 Opportunistic use of drought and migration barriers to estimate minimum upstream movement distances

The duration of this project coincided with one of the driest periods on record in the north-eastern Murray-Darling Basin. Substantial sections of the Condamine River dried out completely, providing an opportunity to estimate minimum upstream movement distances by untagged fish. By measuring the distance of dry river bed from the base of Reilly's Weir, Condamine Zone 7 (0.9 km) and Cotswold Weir, Condamine Zone 1 (11 km) to the nearest permanent water downstream, it was possible to estimate the minimum distance fish swam upstream to accumulate at the base of each respective weir during the next flow event. In the case of Reilly's Weir, as the next permanent downstream waterhole was still filling and had not overflowed at the time of sampling, then all upstream migrating fish collected below Reilly's Weir must have been sourced from the same waterhole. Therefore it was possible to estimate maximum (2.3 km) as well as minimum (0.9 km) distances travelled by fish that had accumulated below Reilly's Weir.

While it is acknowledged that fish could have reached the base of the weirs by a downstream movement, it was assumed that the majority of fish accumulating below a weir during a flow were those attempting to move upstream. We assumed fish moving downstream would generally continue away from the weir. This assumption was supported by fyke and mini-fyke data.

Opportunistic sampling below weirs was done by backpack electrofishing, in 10 m by 5 m shots across the base of the weir walls. All fish captured were identified and counted. A sub-sample of 20 fish per species each shot was measured in the same way as for standard shots.

2.2.7 Data analysis

Tag retention trials

Post-handling mortality of tagged and untagged control fish was analysed by chi square analysis to test the null hypothesis of no significant difference. Tag retention or visibility rates were simply recorded as a percentage over time.

Mark-recapture and radiotelemetry data

Distances moved and time-at-large were documented for each recaptured fish. All tagging release and recapture records for VIE- and PIT-tagged fish were entered into an Access database and exported to the GIS program ARCGIS. Distances moved within the rivers or lagoons from the release points to recapture points were calculated in ARCGIS using GD4-94 datum. The same procedures were also used to calculate distances between radiotelemetry fixes for individual fish.

Standard shot data

Generalised linear modelling

Mini-fyke and fyke catch rate data were analysed by generalised linear modelling (GLM, a multivariate regression technique) using the program GenStat[™] 9.2. We restricted GLM analyses to the most common species. Even the common species had numerous shots where they were not recorded. Data with numerous zero values and some extremely high values can present analytical problems. A generalised linear model (GLM) using a Poisson distribution with a logit link function can sometimes be used for data with numerous zero values. We tested such a model for each of the common species, but found residuals were unevenly distributed. Statistical significance levels were therefore unreliable. As an alternative, we tried log transformed data but this did not greatly improve the models. We then used a binomial generalised linear model which treats data as presence-absence data. Essentially, it is an analysis of the proportion of gear capturing fish. Following on from and conditional to the binomial analysis, we used a zero-truncated gamma distribution model to model catch numbers.

Generalised linear modelling means adjusted mean values are estimated from the existing data. It takes into account effects of other variables in the model. By holding some variables constant, the model can predict the mean of effects of selected main or interaction variables. The model can also generate standard errors and confidence limits for these parameters. This is useful in complex data sets for interpreting the individual or combined effects of different variables.

A more accurate calculation of adjusted mean values (and standard errors) was obtained by multiplying the predicted values from the binomial and conditional gamma models. Distribution of residuals in the binomial and gamma generalised linear models were close to normal, therefore deviance was explained and significance levels were considered reliable. Details for modelling zero-inflated fish counts using binomial and gamma models are found in Mayer et al. (2005).

To select the most appropriate variables to include in the model we used a backward stepping procedure. Initial models included as many main and two-way interaction variables as possible. Any that were not significant were discarded. Any aliasing between variables (not all variables were entirely independent) required dropping some and re-running the GLMs as an alternative model. The variables from aliased pairs that explained the greatest amount of deviance were eventually retained.

Binomial and gamma (truncated zero) models were run to select variables to retain in the final models. If a variable or interaction was significant in one of the models, then it was also retained in the other model, even if not significant to that model. This is because the gamma model is conditional to the binomial model and the two models must contain identical variables and interactions when combined to predict adjusted means.

Data was first analysed for combined electrofishing fyke and mini-fyke data, then for fyke and mini-fyke data alone. Variables run in the fyke and mini-fyke only models were kept consistent with the all gear models. Electrofishing shows if a species is present in an area, whether moving or not, and gives some indication of abundance. Fykes and mini-fykes only catch fish that are moving (either foraging or migrating). The combined analysis helped interpret whether fish were moving or not, and whether the movement was migrating or foraging. The fyke and mini-fyke analysis helped interpret which factors were influencing or triggering movement, and movement direction.

For the data analyses by GLM, the term 'gear' was always included, even if not significant, as the direction of movement as indicated by fyke and mini-fyke codends was important to our understanding of the entire data set. For the same reason the interaction of gear with other parameters was often retained. For *Hypseleotris* spp., we included one three-way interaction (gear by hydrography by flow type) because our observations of raw data suggested direction of migration (gear) could be influenced by both flow type and hydrography.

Size composition of catches

The size composition data from fyke, mini-fyke and electrofishing catches were compared across season and stage of flow. This was used in part to explain selectivity of gear, but was also used to determine whether some size classes were moving more than others, and trends by size in direction of movement. If only adult size classes were moving, then a possible reproductive migration could be inferred. We also compared size composition of fish captured in upstream versus downstream codends. This was to determine whether different life history stages migrated in different directions. Size composition data was displayed as length-frequency histograms to enable a visual estimate of potential differences.

The length-frequency data for fyke codends were also compared with that for backpack electrofishing. If upstream codends were not significantly different in size distributions to those captured by electrofishing below weirs, then this would support the hypothesis that fish accumulating below weirs were upstream migrants. The Kolmogorov-Smirnov two-sample test was run in GenStat 9.2 to test the null hypothesis of no significant difference in length frequencies between the different sampling methods. All length-frequency comparisons were broken up by river, season and flow type, and by river and lagoon. This was to ensure that between habitat and between season differences in length-frequency distributions did not mask any underlying patterns.

3. RESULTS AND DISCUSSION

This chapter examines the study in three parts. The first details the results of the pilot phase. The second part gives an overview of the prevailing riverine conditions during its course. This sets the context for the third part, the main phase. The results and discussion for the main phase of the study are presented species by species. A general unifying discussion across all species is presented in Chapter 4.

3.1 Pilot phase

3.1.1 Tag retention trials

As outlined in the previous chapter, VIE and PIT tag retention trials were run for five species of fish: unspecked hardyheads C. stercusmuscarum, bony bream *N. erebi*, carp gudgeons *Hypseleotris* spp., spangled perch *L. unicolor* and Hyrtl's tandan *N. hyrtlii*. Within a week of tagging there were no significant differences in the mortalities of tagged and untagged fish (p>0.05) across all species, or between tagging treatments within species. However, after several months of captivity, C. stercusmuscarum exhibited increased mortalities in the tag treatment tanks compared to the control tanks (Figure 3.1). Given the duration of time between tagging and the onset of increased mortalities, it is not clear whether the increase was related to tagging or other between-tank differences such as disease. For *L. unicolor* and *N. hyrtlii* there were no post-tagging mortalities four months after tagging; and *N. erebi*, the control fish, had higher mortalities than the tagged fish (Table 3.1). Figure 3.1 shows how survival changed over time in tagged and untagged *N. erebi*. Because this species has a reputation as being sensitive to handling, the mortalities probably reflect post-handling rather than post-tagging mortalities. Nevertheless this is an important consideration in any studies involving *N. erebi*, and underlies the need to minimise stress through reducing handling times and using anaesthesia. Tagging/ handling-related mortalities probably did occur during the subsequent first two weeks. Mortalities could be related to other factors such as reluctance of some fish to take artificial feeds.

Tag retention rates were best in PIT-tagged *L. unicolor* (93%) and *N. hyrtlii* (100%) although the latter was a very small sample size and greater numbers needed to be tagged to effectively determine retention rates. Cumulative VIE tag retention rates in the other species ranged from 64% to 88% over periods ranging from four to six months (see Table 3.1). We considered the tag retention rates to be sufficient to provide some movement information, especially if large numbers of fish could be tagged. Post-tagging mortality rates were also considered acceptable. Not all mortalities occurred immediately post-tagging and we believe some mortality may have been related to other causes such as the short life span of some of the small species or other effects relating to captivity.



Figure 3.1: Survival of VIE-tagged and control (untagged) bony bream N. erebi.

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Species and treatment	Days since tagging	% Surviving	% lag retention
Nematalosa erebi head tag VIE	170	74	70
Nematalosa erebi control	170	66	na
<i>Hypseleotris</i> spp. anal tag VIE	160	92	66
<i>Hypseleotris</i> dorsal tag VIE	160	80	64
<i>Hypseleotris</i> spp. control	160	86	na
Leiopotherapon unicolour gut cavity PIT	120	100	93
Leiopotherapon unicolour control	120	100	na
Neosilurus hyrtlii gut cavity PIT	120	100	100
Craterocephalus stercusmuscarum anal tag VIE	172	61	81
Craterocephalus stercusmuscarum dorsal tag VIE	172	66	88
Craterocephalus stercusmuscarum control	172	79	na

Table 3.1: Tag retention and post-tagging survival in various species held at Southern Fisheries Centre, Deception Bay.

3.1.2 Field trials

The 2004-2005 summer was the driest in the Condamine and Macintyre catchments for 107 years. The small lagoon site at Camp David (Macintyre River Zone 3) dried out. When selected as a pilot site, it was thought to be permanent. Consequently some pilot tagging had to be relocated to an adjacent river reach. High temperatures were also a problem during the February 2005 trip to the Condamine region. To minimise stress on fish we restricted sampling to early morning and late afternoon. We also restricted to have a higher post-tagging mortality rate than larger fish.

The majority of post-handling/post-tagging mortalities detected in tank-held *N. erebi* at Southern Fisheries Centre were among fish less than 100 mm TL. Bony bream *N. erebi* smaller than 100 mm TL were numerous in the lagoon sites and to a lesser extent at river sites on the Condamine. We could have substantially increased numbers of fish tagged had we used these, but based on the results of our tank experiments this would have been ethically questionable and wasteful of tagging resources. Restricting tagging to larger *N. erebi* improved post-tagging survival. The shorter than anticipated sampling times and more restricted size range tagged limited the total numbers of *N. erebi* tagged and released during both the pilot and main phases of the study.

Of the 1402 fish tagged and released during the pilot field work (Table 3.2), 118 were recaptured (Table 3.3) by the end of the pilot phase. Most of these were PIT-tagged *L. unicolor* from the two lagoons adjacent to the Condamine River. Only five VIE-tagged fish were recaptured up until April 2005. More recaptures of pilot-phase tagged fish, including VIE-tagged fish, were made during the main phase of the study. VIE-tagged fish recaptured during the pilot phase were *M. fluviatilis* and *N. erebi*. The majority of VIE-tagged fish were *N. erebi* and *Hypseleotris* spp.

Hypseleotris spp. and *N. erebi* were extremely abundant in the Condamine pilot sites, and *Hypseleotris* spp. were common in the Macintyre pilot sites. There are a number of possible explanations for low recaptures of these species, but we suspect that the drought was the primary cause. Many of the *Hypseleotris* that were tagged were released in the Camp David Lagoon site (Macintyre Zone 3). Unfortunately this lagoon dried out between the January tagging trip and the April recapture trip so a large proportion of tagged fish were lost. Summer is normally the wettest time of the year in the northern Basin and we had not anticipated the lagoon site would dry out. Most remaining tagged *Hypseleotris* spp. were released in the large Karreel Lagoon (Condamine Zone 5) adjacent to the Condamine River.

Mark-recapture studies of abundant species rely on tagging large numbers of individuals (Majkowski et al. 1988). We probably needed to tag many more fish to increase recapture rates. This assumption is borne out by the fact that we were able to PIT tag relatively large numbers of *L. unicolor* in the small Karreel Lagoon (Condamine Zone 4). These probably represented a large proportion of the total population at that site. Subsequently in April 2005 we recorded a relatively high recapture rate of *L. unicolor*. This clearly demonstrates the efficacy of tag-recapture experiments, but also demonstrated the need to tag large numbers of fish.

We suspect that high water temperatures (around 30°C) during summer may have increased the risk of posttagging and post-handling mortality after release. This may have contributed to the low recapture rates of VIEtagged fish during the early tagging trips. To reduce risk of poor post-tagging and post-handling survival, we chose to avoid sampling during low water levels in summer for the remainder of the research program.

We made various improvements to our sampling and tagging protocols as a result of our pilot work to increase the numbers of fish tagged per unit time, to reduce stress and improve accuracy. This included using mobile tagging systems, rather than fixed point tagging systems, to reduce both handling times and transport stress. It also included using fixed release points and fixed capture zones for batch-tagged fish to improve accuracy of recorded movements. These changes are detailed in the previous chapter.

River	Number of PIT tags	Number of VIE tags	Total number of fish tagged
Condamine R	376	624	1000
Macintyre R	26	376	402
Total	402	1000	1402

Table 3.2: Total number	of fish tagged in the	pilot field work phase.
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Table 3.3: Total	number of r	ecaptures	durina the	pilot fieldwork	phase.
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River	Number of PIT tags	Number of VIE tags	Total number of recaptured fish
Condamine R	113	2	115
Macintyre R	0	3	3
Total	113	5	118

Due to unprecedented drought conditions in 2005, the small Condamine lagoon dried out several months after the pilot phase was completed. Unfortunately this resulted in the loss of a large number of PIT-tagged fish from the main phase of the study. These losses in conjunction with other effects of the drought had impacts that extended into the main phase of the study.

3.2 Flow conditions during the study

This study took place during one of the driest periods on record in the northern Murray-Darling Basin. Figures 3.2 and 3.3 (below) show local hydrographs for the Condamine and Macintyre Rivers, respectively, as recorded during the course of this study. Two plots are shown for the Condamine River to demonstrate the influence of local run-off. Within the Condamine research area, sections downstream of Zone 3B were strangely influenced by local run-off, mainly from Undulla Creek. Undulla Creek entered the Condamine River just upstream of Zone 1 (Figure 2.11), but water from this creek can back up behind Cotswold Weir and influence water levels upstream to Zone 3B. Areas upstream of 3B received considerably fewer flows and had less connectivity. These flows mainly originated upstream of Chinchilla or from Charlie's Creek below Chinchilla Weir.

An unprecedented dry spell from mid-2006 until February 2007 resulted in many areas of the Condamine River bed drying out. In particular, 11 km of river bed commencing immediately below Cotswold Weir in Condamine Zone 1 dried out completely. A more prolonged lack of flows above Zone 3B resulted in an extended period when much of the river was disconnected. We estimate up to 65% of the river bed was exposed upstream from 3B with large sections of river disconnected for extended periods. The large Karreel Lagoon (Zone 5) contracted to less than 20% of its surface area compared to the start of the study, before storm rain and local run-off restored its levels. Figure 3.4 shows a section of river in Zone 1C which dried out over a period of 12 months. Drying limited opportunities for migration and there were undoubtedly mortalities of tagged fish associated with the desiccation and increased opportunities for predation. Therefore fewer recaptures were to be expected than might have been made under average flow and normal rainfall conditions.

A radiotelemetry study of spangled perch *L. unicolor* and bony bream *N. erebi* was planned for spring 2006 and into summer. Normally, late spring to autumn is when increased rainfall and natural flow events can be anticipated in the Condamine and Macintyre Rivers. However, late 2006 and early 2007 coincided with well below average rainfall and virtually no natural flow events. All flows recorded in this period in the Macintyre River were artificial, originating from upstream dam and weir releases. Flows were almost entirely absent from the Condamine River during the same period.

Figure 3.2: Hydrograph for the Condamine River. Pink plot shows the river height for Cotswold Weir (Condamine Zone 1). The black line at 4.29 metres is the height at which Cotswold Weir overflows. The dark blue plot shows flows recorded just downstream of Chinchilla Weir. These flows influenced all sites on the Condamine. The shaded box represents the period radio-tagged *L. unicolor* were at large, which corresponds to a period of no or limited flow.



Nevertheless those natural flows that did occur in the course of this study (all flows shown on the Condamine hydrograph and several of the flows from spring 2005 to summer 2005-06 in the Macintyre) provided opportunities for tagged fish to move and for movement patterns to be observed in fyke and mini-fyke catches. Artificial flows from upstream dam and weir releases provided connectivity in the Macintyre River and limited desiccation. These flows also provided an opportunity to contrast behaviour of fish between natural and artificial flow events.

Only within-bank flows were recorded during the study period, and only one flow event connected with a lagoon system. This was between Booberoi Lagoon and the Macintyre River in January 2006. The connection, featured in Figure 3.3, was of short duration.

Figure 3.3: Hydrograph for the Macintyre River. Data source from Terrawah, Macintyre Zone 2. Plot shows the river height. The black line at 5.5 metres is the height at which Booberoi Lagoon connected to the river. The shaded box indicates the period at which radio-tagged *N. erebi* were at large. The higher flow spikes (mainly spring 2005 to summer 2005–06) are natural flow events. Most other flows were artificial.



Figure 3.4: Effects of prolonged drought in the Condamine River, Zone 1C.



A: in November 2005, and B: in September 2006. This waterhole had dried out completely by November 2006. (Photo: F. Johnston)

3.3 Main phase

During this study, we spent 115 days in the field, sampling up to 21 sites per river system, depending on water levels. With up to six different gears deployed in any one site, the standard shot database comprises 988 records of individual samples. Catches ranged from 0 to >1200 fish, depending on site, season, flow conditions and gear used. The total catch, for river and individual species, is presented in Table 3.4 along with the average size and 95% confidence interval (c.i.), maxima and minima. The table contains both native and introduced species. Movement by the more abundant species is discussed in detail in the following sections.

River	Species	Total catch	Av. size	95% c.i.	Max	Min
Condamine	Ambassis agassizii	474	39	1	87	11
Condamine	Bidyanus bidyanus	1	228	0	228	228
Condamine	Carassius auratus	111	93	8	195	20
Condamine	Craterocephalus stercusmuscarum fulvus	17	36	2	42	29
Condamine	Cyprinus carpio	39	367	55	650	22
Condamine	Gambusia holbrooki	6590	27	0	51	10
Condamine	Hypseleotris spp.	5129	30	0	52	0
Condamine	Leiopotherapon unicolor	1402	77	2	322	18
Condamine	Maccullochella peelii peelii	27	89	80	957	13
Condamine	Macquaria ambigua	486	105	7	410	12
Condamine	Melanotaenia fluviatilis	179	38	2	74	15
Condamine	Nematalosa erebi	5706	58	1	258	14
Condamine	Neosilurus hyrtlii	125	107	13	280	16
Condamine	Philypnodon macrostomus	225	26	1	41	16
Condamine	Retropinna semoni	370	31	1	58	16
Condamine	Tandanus tandanus	12	168	67	437	57
Macintyre	Ambassis agassizii	93	32	3	58	10
Macintyre	Carassius auratus	8	153	40	253	69
Macintyre	Craterocephalus stercusmuscarum fulvus	17	36	4	56	25
Macintyre	Cyprinus carpio	93	291	36	586	14
Macintyre	Gambusia holbrooki	27	25	2	37	10
Macintyre	Hypseleotris spp.	1043	33	0	49	15
Macintyre	Leiopotherapon unicolor	24	100	20	238	48
Macintyre	Maccullochella peelii peelii	28	273	57	855	91
Macintyre	Macquaria ambigua	71	203	28	374	25
Macintyre	Melanotaenia fluviatilis	650	41	1	72	14
Macintyre	Nematalosa erebi	193	118	11	297	23
Macintyre	Philypnodon grandiceps	1	83	0	83	83
Macintyre	Retropinna semoni	12	33	2	39	27
Macintyre	Tandanus tandanus	1	144	0	144	144

Table 3.4: Seasonal standard shot catch totals for each species by river. Average size (mm), 95% c.i., maxima and minima are also presented.

3.3.1 Carp gudgeons *Hypseleotris* spp.

Generalised Linear Models

Hypseleotris spp. were common in both rivers, with 62% of the catch coming from the Condamine River and 38% from the Macintyre River. Boat electrofishing captured 60%, backpack electrofishing 7.85%, mini-fykes 32% and fykes 0.15% of *Hypseleotris* spp. in both rivers.



All gears

As noted above, most *Hypseleotris* spp. were captured by boat electrofishing and mini-fykes. A generalised linear model, using a binomial distribution with a logit link function for all sampling gear types, explained 56.82% of the deviance in *Hypseleotris* spp. catch rates. The GLM included the terms gear, flow type, season, river, hydrography, substrate and moon phase, and various two-way interactions and one three-way interaction.

Terms identified as significant in the binomial model were gear (p<0.001), flow type (p<0.001), season (p<0.001), hydrography (p<0.001) flow type by season (p<0.001), hydrography by season (p<0.001) and flow type by moon phase (p = 0.045).

A gamma distribution model with a log link function for the same terms and interactions explained 59.14% of the deviance. The gamma analysis is summarised in Table 3.5.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Flow type	1	75.6182	75.6182	84.60	<0.001
Gear	5	92.7894	18.5579	20.76	<0.001
Hydrography	5	54.4028	10.8806	12.17	<0.001
Substrate	5	21.2922	4.2584	4.76	<0.001
Season	2	7.5984	3.7992	4.25	0.015
Moon phase	3	4.8138	1.6046	1.8	0.148
River	1	0.0120	0.0120	0.01	0.908
Flow type.Moon phase	1	15.8944	15.8944	17.78	<0.001
Gear.Season	4	24.7541	6.1885	6.92	<0.001
Hydrography.Season	6	28.0070	4.6678	5.22	<0.001
Gear.Flow type.Hydrography	4	13.5133	3.3783	3.78	0.005
Moon phase.Hydrography	7	22.9513	3.2788	3.67	<0.001
Gear.Hydrography	19	52.9248	2.7855	3.12	<0.001
Gear.Flow type	3	5.7695	1.9232	2.15	0.094
Flow type.Season	1	0.4155	0.4155	0.46	0.496
Residual	325	290.4813	0.8938		
Total	392	711.2379	1.8144		

Table 3.5: Summary of analysis for a conditional gamma distribution GLM (with log link function) of
<i>Hypseleotris</i> spp. catches. Gear includes all six gear types. Significant factors are given in <i>italics</i> .

The significant terms in the "all gears" model do not necessarily relate to movement, just to catch rates. It can be seen in Figure 3.5 (derived from the model) that electrofishing and mini-fykes responded differently to hydrography, although catch rates of all gears were lower under artificial flow conditions. Electrofishing catches of *Hypseleotris* spp. were high during no flow conditions in the river, whereas mini-fyke captures were low during no flow conditions in comparison to most natural flows.

Figure 3.5: Variation under different natural and artificial hydrographical conditions in the catch rates of *Hypseleotris* spp. captured by mini-fykes (upstream and downstream codends) and boat electrofishing. Error bars show one standard error of the mean. Adjusted means were calculated from the binomial x conditional gamma GLMs. Other terms in the model have been held constant. Values should be viewed as trends in the data rather than as predictions of catch.



During natural falling flows, catches in downstream codends peaked, whereas upstream codend captures tended to be higher than downstream codend catches during peak and rising natural flows.

Fykes and mini-fykes

Fykes and mini-fykes rely on fish movement (foraging or migration) to be effective. Significant terms and interactions indicated from modelling, of these data for fyke and mini-fyke only, are more likely to relate to movement than those from a model with all gear types.

A generalised linear model (GLM) with binomial distribution and logit link function was run for fyke and minifyke data only. Fitted terms, including two-way and three-way interactions, were the same as for the all gear GLMs above. The binomial model explained 49.16% of the deviance. Terms and interactions identified as significant in the model were gear (p<0.001), flow type (p<0.001), season (p<0.001), hydrography (p<0.001), flow type by season (p = 0.002), hydrography by season (p<0.001) and flow type by moon phase (p = 0.045). These were the same as the significant terms and interactions in the all gears binomial model.

The corresponding GLM with gamma (zero truncated) distribution and log link function for fyke and mini-fyke data explained 57.05% of the deviance in catch rates of *Hypseleotris* spp. Over 99% of the catch came from mini-fykes. A summary of the analysis is shown in Table 3.6.

The significant terms and interactions identified by the gamma model were similar to those identified in the binomial model although the river was significant in the gamma model but not the binomial. At least one interaction with moon phase was significant in each model.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	3	32.311	10.770	10.3	<0.001
Hydrography	5	50.930	10.186	9.74	<0.001
Season	2	17.768	8.884	8.5	<0.001
Flow type	1	8.766	8.766	8.39	0.004
River	1	4.088	4.088	3.91	0.050
Substrate	4	7.298	1.824	1.75	0.143
Moon phase	3	4.913	1.638	1.57	0.200
Flow type.Moon phase	1	10.757	10.757	10.29	0.002
Hydrography.Season	6	31.134	5.189	4.96	<0.001
Gear.Flow type.Hydrography	2	6.159	3.079	2.95	0.056
Flow type.Season	1	2.917	2.917	2.79	0.097
Moon phase.Hydrography	6	15.206	2.534	2.42	0.029
Gear.Hydrography	10	12.390	1.239	1.19	0.305
Gear.Season	2	1.042	0.521	0.50	0.608
Gear.Flow type	2	4.085	2.042	1.95	0.145
Residual	151	157.861	1.045		
Total	200	367.625	1.838		

Table 3.6: Summary of analysis for a conditional gamma distribution GLM (with log link function) of *Hypseleotris* spp. catches. Gear includes fykes and mini-fykes upstream and downstream codends only. Significant factors are given in *italics*.

Season, and some interactions with season, were among the significant terms. Variation in catch by season is shown in Figure 3.6. Peak catches were recorded in spring. Modelled patterns in mini-fyke catches varied by hydrography in an almost identical pattern to that shown in Figure 3.5, so are not reproduced here. Rising and peak flows had greater catches in upstream codends than no flow situations in the river. On all flows *Hypseleotris* spp. appeared to move both upstream and downstream, but downstream movements only significantly exceeded upstream movements on natural falling flows. Figure 3.5 shows how movement (fyke and mini-fyke catches) varied by flow type and hydrography. It can be seen that more fish tended to move on natural peak, rising and falling flows than on the corresponding artificial flows.

Figure 3.6: Variation in *Hypseleotris* spp. catch rates by gear and season. Error bars show one standard error of the mean. Adjusted means were calculated by the binomial x conditional gamma GLMs. Other terms in the model have been held constant. Values should be viewed as trends in the data rather than as predictions of catch. Catch data is derived from fyke and mini-fyke data only.



Adjusted mean catch rates for moon phase by hydrography (as estimated by the binomial x gamma GLMs) suggest that the new moon on base flows, and the first quarter of the moon on peak and rising flows, increased the chance of captures in fykes and mini-fykes (Table 3.7).

Table 3.7: Adjusted means and standard errors of the mean (S.E.) for catch rates of <i>Hypseleotris</i> spp. by
lunar phase and hydrography. Values calculated by Binomial x conditional gamma GLM for fyke and mini-
fyke data only. Other variables in the model have been held constant.

Hydrography	First q	uarter	Full Moon		Last Quarter		New Moon	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Lagoon no flow	*	*	*	*	0.082	0.059	3.200	1.124
River base	*	*	*	*	0.229	0.117	17.802	7.688
River fall	4.253	1.466	0.198	0.101	6.399	2.631	3.829	1.506
River no flow	0.233	0.234	8.443	2.807	1.563	0.402	1.112	0.379
River peak	6.887	2.669	0.545	0.307	0.768	0.529	2.478	1.387
River rise	9.550	2.631	0.504	0.327	3.741	2.766	0.437	0.290

However, the first quarter and full moon did not correspond with any river base flow or lagoon no flow samples. The data also suggest that the new moon on an artificial flow might also increase catch rates.

Length-frequency data

Natural flows in spring 2005 in the Macintyre River corresponded to high catch rates of *Hypseleotris* spp. in mini-fykes. There was a significant difference in the length-frequency distribution of fish captured in upstream and downstream codends (Kolmogorov-Smirnov two-sample test, p = 0.049). The distribution was more skewed towards larger size-classes for the fish captured in upstream codends (Figure 3.7) compared to downstream codends. The length-frequency distribution of *Hypseleotris* spp. captured by boat electrofishing (n = 89) was not significantly different to the length-frequency distribution captured in the downstream codends (p = 0.094), but was significantly different to length-frequency distribution of *Hypseleotris* spp. captured in upstream codends (p = 0.094), but was significantly different to length-frequency distribution of *Hypseleotris* spp. captured in upstream codends (p = 0.094). There were more large size classes in the upstream sample.

During a falling flow in spring 2005 in the Condamine River, the vast majority of *Hypseleotris* spp. were recorded in downstream codends (Figure 3.8) although no significant difference was recorded in length-frequency distribution of fish (p = 0.392) between codends. The downstream codend captures were not significantly different in length-frequency distribution (p = 0.265) to that of *Hypseleotris* spp. captured by boat electrofishing (n = 42) on the same flow event.

Figure 3.7: Length-frequency comparison of *Hypseleotris* spp. by mini-fyke codend. Fish were captured during a natural flow event in the Macintyre River during spring 2005. Upstream n = 221, Downstream n = 119.



Figure 3.8: Length-frequency comparison of *Hypseleotris* spp. captured moving upstream and downstream by mini-fykes during a falling flow, Condamine River, spring 2005. Upstream n = 5, Downstream n = 42.



During artificial flow conditions in the Macintyre in autumn 2006, spring 2006 and autumn 2007, no significant differences were recorded in length-frequency distributions of *Hypseleotris* spp. captured in either upstream or downstream codends (Kolmogorov-Smirnov two-sample tests, p>0.4) or between captures by boat electrofishing and mini-fykes (p>0.5).

During natural rise and peak flow conditions in the Condamine River throughout autumn 2007, the size distribution of *Hypseleotris* spp. captured in upstream codends of mini-fykes showed a tendency to skew towards larger sizes, when compared to sizes captured in downstream codends (Figure 3.9). However, this was not significant at the 5% level (Kolmogorov-Smirnov two-sample test, p = 0.072).





Recapture data

Recaptures of 29 VIE-tagged *Hypseleotris* spp. are summarised in Table 3.8. Distances moved by recaptured fish ranged from 25 m to more than 10,800 m.

Table 3.8: Recaptures of VIE-tagged *Hypseleotris* spp. in the Macintyre and Condamine Rivers. As fish were batch tagged during the pilot study, there a range of possible times at large for each recapture. Such fish had multiple release points in a zone. Recaptured fish with pilot study batch tags display a range of possible distances moved. For release and recapture zones, see Chapter 2. (L) = lagoon habitat. ds = downstream movement. us = upstream movement. as = across stream movement.

River	Time at large	TL at recapture (mm)	Release zone	Recap zone	Distance moved (m)	Direction moved
Macintyre	1 day	41	1B	1B	425	ds
Macintyre	4 to 5 days	42	5C	5A	2670	US
Macintyre	8 months	49	7C	7C	25	US
Macintyre	4 to 10 months	39	5B	5A	210	US
Macintyre	11½ months	40	4	5A	10,810-13,775	us
Macintyre	4 to 9 months	34	1B	1B	50	US
Macintyre	4 to 11 months	38	1B	1B	90	ds
Condamine	4 days-6 months	-	3	ЗA	110-2700	us
Condamine	4 days-6 months	-	3	3C	320us-2380ds	us or ds
Condamine	2 months	27	6C	6D	390	ds
Condamine	4 to 7 months	34	7A	7B	210	ds
Condamine	10 to 16 months	-	5(L)	5(L)	750ds-750 us	us or ds
Condamine	4 months	21	2B	2B	25	as
Condamine	8 months	33	3A	2B	6100	ds
Condamine	4 to 10 months	33	1A	1A	25	as
Condamine	4 to 9 months	-	7D	7D	25	as
Condamine	4 to 10 months	-	7A	7B	270	ds
Condamine	1 day-10 months	-	7C	7C	25	as
Condamine	7 to 10 months	-	7A	7A	25	as
Condamine	2 to 18 months	41	5(L)	5(L)	120ds-860us	us or ds
Condamine	2 to 12 months	32	7B	7B	210	ds
Condamine	2 to 12months	32	7B	7B	200	ds
Condamine	2 to 12 months	33	7B	7B	200	ds
Condamine	2 to 12 months	34	7B	7B	200	ds
Condamine	1 day-12 months	37	7A	us7A	375	us
Condamine	1 day-12 months	33	7B	7B	260	ds
Condamine	1 day-12 months	31	7A	7B	210	ds
Condamine	1 day-12 months	35	7B	7B	50	ds
Condamine	3- 14 months	41	7A	7B	200	ds

Electrofishing below barriers

During rising and peak flows in the Condamine River in autumn 2007, some *Hypseleotris* spp. were captured below weirs by backpack electrofishing (n = 36). The length-frequency distribution of *Hypseleotris* spp. captured by backpack electrofishing was not significantly different (Kolmogorov-Smirnov two-sample test, p = 0.502) to the length-frequency distribution of *Hypseleotris* spp. captured in upstream codends of mini-fykes (Figure 3.10). During falling flow conditions in the same month, the catch of *Hypseleotris* spp. in upstream codends was low (n = 7), and still not significantly different at the five per cent level in size distribution from the backpack electrofishing catch (n = 69) below weirs (p = 0.062). Downstream codend captures were higher (n = 36) and were not significantly different to backpack captures below barriers in size distribution (p = 0.383).

Figure 3.10: Length-frequency comparison of *Hypseleotris* spp. captured moving upstream by mini-fykes and by backpack electrofishing below barriers in rise and peak but low flow conditions in the Condamine River during autumn 2007. Upstream *n* = 58, Backpack *n* = 39.



On a falling flow in the Condamine River during autumn 2006, the size distribution of *Hypseleotris* spp. captured below a weir by backpack electrofishing and in upstream codends of mini-fykes was not significantly different (p = 0.385). The length-frequency distributions are very similar (Figure 3.11). Note that more fish were captured by mini-fykes moving downstream on the same flow.





Lagoon captures

Hypseleotris spp. were recorded from all lagoons sampled during this study except from Booberoi Lagoon (Zone 8, Macintyre River). This lagoon (dry at the start of the study) connected to the river during the course of the study on a high within-bank flow, but *Hypseleotris* spp. were not recorded post-connection. The other lagoons sampled in the Macintyre catchment did not connect on this event, as these lagoons required a much higher flow to link with the river. The lagoons sampled in the Condamine catchment also required a flood flow to connect to the river.

Discussion

The all gear GLM indicated that electrofishing catch rates of *Hypseleotris* spp. responded differently to hydrography than fyke catch rates. Upstream and downstream codends of mini-fykes also seemed to respond differently to each other during flow events. This provides evidence to suggest mini-fykes were detecting movement behaviour, and catches were not solely related to the prevailing abundance of fish in the surrounding waters.

The fyke and mini-fyke gamma model selected river as a significant factor (p = 0.05) relating to captures by fykes and mini-fykes. This is most likely related to *Hypseleotris* spp. being more abundant (62%) in the Condamine River than in the Macintyre River (38%), rather than differences in migratory behaviour between the two rivers. River was not selected by the binomial model as *Hypseleotris* spp. were sufficiently abundant in both rivers to have a similar presence-absence influence. Other significant factors from the fyke and mini-fyke models probably do relate to movement triggers and cues, and their patterns across both river systems.

The mini-fyke data suggest there was some movement of *Hypseleotris* spp. occurring on most flows within the river. Even though boat electrofishing data showed *Hypseleotris* spp. to be common during no flow periods in the river, captures by mini-fykes were low. This suggests any movement during no flow periods was restricted to localised foraging. Captures in the lagoons during no flow probably also reflect localised foraging. Carp gudgeons *Hypseleotris* spp. were common in the lagoon habitats, but wide shallow edges made them less accessible to boat electrofishing. This may account for lower catch rates by boat electrofishing in lagoons relative to riverine habitats. During most flows *Hypseleotris* spp. were recorded from both upstream and downstream codends, suggesting that they do move in both directions.

On natural falling flows, the number of downstream migrants increased relative to upstream migrants. This is possibly a behavioural response to ensure that fish are able to return to permanent pools within the river and don't become stranded between pools as the flow declines. The downstream movement response on falling flows was across all size classes, and was not significantly different to the population size structure detected by electrofishing. In the northern Murray-Darling Basin, where most rivers are ephemeral, this would be an important behavioural response for survival. Similar observations of downstream fish migrations on falling flows have been made by van der Waal (1996) in Namibia, which is climatically similar to the northern Murray-Darling Basin. Van der Waal suggested downstream movements of some Namibian species are triggered to move to avoid desiccation. Various fish species native to the Murray-Darling Basin in South Australia have also been observed to move downstream out of a draining wetland, back to riverine habitat (Ben Smith³ 2007) to avoid desiccation. In contrast the introduced carp *Cyprinus carpio*, which has not evolved in the ephemeral rivers of the Murray-Darling Basin, moved upstream against the flow into the desiccating wetland.

During natural flow events (other than falling flows) there was some tendency for upstream codends to capture more fish of larger size classes than downstream codends. However, both large and small size classes were recorded in both groups. It may simply be that larger fish are physically more capable of moving upstream, although fish as small as 22 mm were recorded in the upstream group during the tail of a falling flow.

Season was also a significant factor relating to movement of *Hypseleotris* spp. Peak movement was recorded during spring. At this time of the year in the northern Murray-Darling Basin, it has been observed that most of the larger *Hypseleotris* spp. were in spawning condition. There were more fish of large size classes recorded moving upstream in spring, relative to the samples caught by electrofishing, or found in downstream codends of mini-fykes. Upstream movements by large *Hypseleotris* spp. at this time could possibly be related to spawning behaviour. In the Broken River in the southern Murray-Darling Basin, Humphries et al. (2002) recorded *Hypseleotris* spp. larvae from October to April (spring to autumn). It has been hypothesised that upstream movement by spawning condition fish may be to counter downstream displacement or drift of eggs and larvae (Llewellyn 1973, Mallen-Cooper 1999, Mazzoni et al. 2004).

More *Hypseleotris* spp. were recorded moving on natural flow events than on artificial (irrigation) flow events (see Figure 3.5). This observation infers that movement triggers are more than flow. It is possible that odours or chemicals released from soil, vegetation or leaf litter by rainfall enter the river in run-off water, stimulating movement in *Hypseleotris* spp. The position of the study reach in the catchment relative to upstream dams excludes the possibility of temperature differences between natural and artificial flow events being the reason for differences in movement behaviour. Temperature varied little between flow types and was not significant to any models run, explaining less deviance than season. Chemical or olfactory cues have been associated with the migration in a number of fish species. For example, the odour of decaying leaf detritus is highly attractive to migrating elvers of American eels (Sorensen, 1986), lake water is an attractant to sockeye salmon Onchorynchus nerka fry (Bodznick 1978), and larval reef fishes are attracted to lagoon water (Atema et al. 2002).

³ Ben Smith, Fish Biologist. PIRSA, SARDI

Recaptures of tagged *Hypseleotris* spp. show that these small fish are capable of moving large distances upstream (10.8 to 13.7 km). The maximum downstream movement was close to 7 km. Recaptured fish were caught both upstream and downstream of release points. This supports the mini-fyke data observations that movements are in both directions. One problem with batch tag studies is that it is not possible to identify individual fish or to know (except in rare cases) when the movements took place. For example, the fish that moved at least 10.8 km upstream had been at large for approximately 12 months. The movement could have been made gradually over the entire period, or it may have taken place on particular flow events. Nevertheless, VIE is one of the few batchmarking technologies available for tagging very small fish, and does provide more information on distances moved than other available options.

We have some evidence that *Hypseleotris* spp. are capable of rapid mesoscale movements. Early in the study, when only one batch had been tagged, a recapture showed that these small fish could move in excess of two km upstream in just four to five days during rising flow conditions. While there is some evidence that tagged fish will move greater distances immediately after tagging, then resume normal behaviour (Jellyman & Sykes 2003), this recapture coincided with large numbers of *Hypseleotris* spp. being captured in upstream codends of mini-fykes. A 425 m downstream movement was recorded in the Macintyre River on an artificial flow in winter 2005 after one day at large.

Post-drought backpack electrofishing below Cotswold Weir also suggested movements upstream of at least 11 km could take place. The maximum time available with river connectivity for this movement based on flow height records was 20 days. There was one flow event of four days in February 2006, followed by 18 days of flow up until the point the fish were captured on 24 March. Flow continued until 31 March (see Figure 3.2). Evidence supporting that some of the *Hypseleotris* spp. captured below Cotswold Weir were mainly upstream migrants comes from the length-frequency analysis of a sub-sample of 69 fish. The sub-sample was not significantly different in size to fish captured in upstream codends. Furthermore, downstream migrants would not be expected to accumulate below an upstream barrier, but keep moving downstream after negotiating an overtopping weir. Upstream movements of this scale are also supported by the mark-recapture data.

The abundance of *Hypseleotris* spp. was found to be greater below than above a weir on the Edward River (Baumgartner, 2006b). This suggests barriers to *Hypseleotris* spp. movements could affect populations. A Denil fishway tested on the structure was shown to pass *Hypseleotris* spp. of 30 mm and larger (Baumgartner 2006b). This may accommodate many of the breeding individuals, but not necessarily all of the migrating population. During this study *Hypseleotris* spp. were collected as small as 18 mm TL in upstream codends during flowing conditions. The size range of *Hypseleotris* spp. collected by backpack electrofishing immediately below weirs was 19 to 49 mm TL.

The presence of *Hypseleotris* spp. in lagoons suggests that they do enter lagoons on flood events and that some of the population must remain there. *Hypseleotris* spp. are also known from lagoons in other parts of the Murray-Darling Basin (Closs et al.2006). However, a brief within-bank connecting flow to a small lagoon did not result in colonisation by *Hypseleotris* spp. This is despite *Hypseleotris* spp. being one of the more common species in the adjacent river. There are three possibilities to explain this event:

- 1. dispersal by Hypseleotris spp. into lagoons is a random process;
- 2. it occurs only on over-bank flood or sustained connection events; or
- 3. *Hypseleotris* spp. actively entered, then left the small lagoon on the brief connection event before it disconnected from the river.

More research during non-drought conditions is required to answer this question.

Lunar phase interacting with hydrography and also with flow type were identified as significant factors for explaining catch by mini-fykes. Whether moon has an influence on movement, or just 'catchability' by mini-fykes, is still open to question. The model suggested that on a new moon, catches on base flows would increase. This may possibly be related to mini-fykes being less visible during the new moon. Base flows were all recorded in the Macintyre River which was generally less turbid than the Condamine River, so it is possible that light intensity could have had some influence. Experiments designed specifically to look at the influence of lunar phase could be an area for further research. Such work would need to be long term in order to increase the number of moon phase replicates that correspond with different stages of the hydrograph. It also would have to be linked to measures of turbidity to highlight any external influences this might have on lunar phase and catchability.

Various species of fish are known to respond to lunar phase, for example, spawning of barramundi (Toledo et al. 1991, Garcia 1992). Therefore, lunar phase cannot be discounted as something that may contribute to the scale of fish movements, including spawning movements.

3.3.2 Bony bream Nematalosa erebi

Generalised Linear Models

Ninety-seven per cent of captured *N. erebi* came from the Condamine River, with the remainder from the Macintyre River. Boat electrofishing captured 50% of the *N. erebi* during standard shots, backpack electrofishing below barriers captured 35% and the remainder were caught by fykes (14%) and mini-fykes (1%).



All gears

A GLM using a binomial distribution with logit link function was run for data collected using all gear types. The fitted terms in the model were gear, flow type, season, river, hydrography, substrate, moon phase, flow and the following two-way interactions; flow type by season, moon phase by season, gear by hydrography, gear by season, hydrography by season and moon phase by hydrography. The model explained 51.6% of the deviance. Significant terms and interactions in the model were gear (p<0.001), flow type (p<0.001), season (p<0.001), river (p<0.001), hydrography (p<0.001), substrate (p<0.001), gear by hydrography (p = 0.005), and hydrography by season (p = 0.011). Moon phase by hydrography was bordering on significant (p = 0.052) but explained only a small amount of the deviance in the model.

A conditional gamma distribution GLM for data collected using all gear types explained 70.53 % of deviance. A summary of the analysis is presented in Table 3.9. Significant main effects and interactions were similar to those in the binomial model, but with the addition of moon phase and moon phase by hydrography.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Flow type	1	64.9236	64.9236	65.90	<0.001
Gear	5	292.8198	58.5640	59.45	<0.001
Season	2	39.8359	19.9179	20.22	<0.001
River	1	17.5591	17.5591	17.82	<0.001
Substrate	5	35.3032	7.0606	7.17	<0.001
Moon phase	3	20.6194	6.8731	6.98	<0.001
Hydrography	5	17.9393	3.5879	3.64	0.003
Flow type.season	1	11.1107	11.1107	11.28	<0.001
Moon.hydrography	6	18.3985	3.0664	3.11	0.006
Gear.hydrography	20	57.2062	2.8603	2.9	<0.001
Season.hydrography	6	12.1423	2.0237	2.05	0.059
Gear.season	6	7.9287	1.3215	1.34	0.239
Season.moon phase	1	0.7026	0.7026	0.71	0.399
Residual	253	249.2355	0.9851		
Total	315	845.7249	2.6848		

Table 3.9: Summary of analysis for a conditional gamma distribution GLM (with log link function) of *N. erebi* catches. Gear includes all six gear types. Significant factors are given in *italics*.

When using all gear types in the GLM, the resulting significant terms do not necessarily all relate to movement, but do indicate the factors that have probably influenced catch across the gear types. Figure 3.12 shows how fyke catch and boat electrofishing catch varied with hydrography when adjusted for other factors in the models. Peak catches for electrofishing corresponds to one of the lowest catch rates for fykes, whereas one of the higher catch rates by fykes corresponds to one of the lowest electrofishing catch rates. Base flows were only recorded in the Macintyre River and all base flows were artificial in origin (i.e. from upstream dam releases).

Figure 3.12: Variation by hydrography in the catch rates of *N. erebi* by fykes (upstream and downstream codends) and boat electrofishing. Adjusted means were calculated by binomial x conditional gamma GLMs. Error bars show one standard error of the mean. Other terms in the model have been held constant. Values should be viewed as trends in the data rather than as predictions of catch.



Fykes and mini-fykes

A GLM with binomial distribution with a logit link function was run using data derived from fykes and mini-fyke captures only. The model incorporated the same main effects and interactions as the all gear binomial model above. The model explained almost 50% of the deviance. A summary of the analysis is in Table 3.10. A conditional GLM (following the binomial model) of fyke and mini-fyke data using a gamma (truncated zero) distribution and log link function explained nearly 64% of the deviance. The summary of analysis is shown in Table 3.11.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Flow type	1	94.0891	94.0891	94.09	<0.001
Gear	3	99.9467	33.3156	33.32	<0.001
River	1	29.4970	29.4970	29.50	<0.001
Season	2	28.1015	14.0508	14.05	<0.001
Hydrography	5	41.7005	8.3401	8.34	<0.001
Substrate	5	23.5572	4.7114	4.71	<0.001
Moon phase	3	3.3398	1.1133	1.11	0.342
Season.hydrography	6	20.3425	3.3904	3.39	0.002
Season.moon phase	2	3.5468	1.7734	1.77	0.170
Moon phase.hydrography	7	9.7324	1.3903	1.39	0.204
Gear.hydrography	15	22.6856	1.5124	1.51	0.091
Gear.season	6	6.0390	1.0065	1.01	0.419
Flow type.season	1	0.2031	0.2031	0.20	0.652
Residual	705	390.1654	0.5534		
Total	762	772.9467	1.0144		

Table 3.10: Summary of analysis for a binomial distribution GLM (with logit link function) of <i>N. erebi</i>
catches. Gear includes fyke and mini-fyke upstream and downstream codends only. Significant factors
are given in <i>italics</i> .

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Season	2	20.7726	10.3863	15.05	<0.001
Gear	3	27.5015	9.1672	13.28	<0.001
Hydrography	5	30.1848	6.0370	8.75	<0.001
Flow type	1	5.4105	5.4105	7.84	0.006
River	1	2.3731	2.3731	3.44	0.066
Substrate	5	6.3861	1.2772	1.85	0.109
Moon phase	3	2.4307	0.8102	1.17	0.323
Season.moon phase	1	2.0627	2.0627	2.99	0.087
Flow type.season	1	1.8209	1.8209	2.64	0.107
Gear.hydrography	13	22.6024	1.7386	2.52	0.005
Gear.season	4	5.1114	1.2779	1.85	0.124
Season.hydrography	4	4.4405	1.1101	1.61	0.177
Moon phase.hydrography	3	1.5569	0.5190	0.75	0.523
Residual	109	75.2173	0.6901		
Total	155	207.8712	1.3411		

Table 3.11: Summary of analysis for a conditional gamma distribution GLM (with log link function) of *N. erebi* catches. Gear includes fyke and mini-fyke upstream and downstream codends only. Significant factors are given in *italics*.

Fewer interactions were significant in the fyke and mini-fyke only models, compared with the all gear models. In particular, interactions with moon phase are not significant in the fyke and mini-fyke only data.

Mini-fyke captures generally consisted of smaller individuals than fyke captures. The codend entrance ring on mini-fykes prevented the entry of larger individuals, but very small *N. erebi* could pass through fyke meshes. Variation in fyke catch rates by hydrography, as calculated by the combined binomial and gamma models (for fyke and mini-fyke data only), followed the patterns shown in Figure 3.13 above. Of the total fyke and mini-fyke catch, 92.6% (852) of *N. erebi* were fyke caught and 7.4% (68) mini-fyke caught. Trends in mini-fyke captures by hydrography are shown in Figure 3.13.

Figure 3.13: Variation under different hydrographical conditions in the catch rates of *N. erebi* captured by mini-fykes (upstream and downstream codends). Error bars show one standard error of the mean. Adjusted means are calculated from binomial x conditional gamma GLMs. Other terms from the model have been held constant. Values should be viewed as trends in the data rather than as predictions of catch.



Hydrography

Seasonal effects of gear on *N. erebi* catches are shown in Figure 3.14. Significantly more *N. erebi* were caught in fykes and mini-fykes during autumn. Catch rates by fykes and mini-fykes were also higher on natural flows (Figure 3.15).

Figure 3.14: Seasonal variation in the combined fyke and mini-fyke catch of *N. erebi* as calculated by binomial x conditional gamma GLMs. Values are adjusted means. Other terms in the model have been held constant. Error bars show one standard error of the mean. Values should be viewed as trends in the data rather than as predicted catch.



Figure 3.15: Variation in the combined fyke and mini-fyke catch of *N. erebi* by flow type. Adjusted mean values were calculated by binomial x conditional gamma GLMs. Other terms in the model have been held constant. Error bars show one standard error of the mean. Values should be viewed as trends in the data rather than as predicted catch.



Length-frequency data

Bony bream *N. erebi* were less common in the section of Macintyre River used in this study than in the Condamine River. Therefore, the majority of length-frequency comparisons were made using data collected from the Condamine River.

Within the large Karreel Lagoon (Condamine system) where *N. erebi* were abundant, no significant differences were detected between length frequencies of fish captured in upstream codends and downstream codends on all sampling occasions. Figure 3.16 is a typical example (Kolmogorov-Smirnov two-sample test, p = 0.534). Boat electrofishing captures from the lagoon were consistently significantly different in length-frequency distribution to combined captures of both fykes and mini-fykes. Boat electrofishing tended to capture more fish of smaller size classes (e.g. Figure 3.17, p<0.001) or fewer fish from the larger size classes. A similar pattern was observed during no flow and most flow conditions in the Condamine River. There were no significant length-frequency differences between codends, but a greater proportion of smaller size classes captured by boat electrofishing. During artificial flows in the Macintyre River in autumn 2006, almost all *N. erebi* captured in fykes and mini-fykes were found in upstream codends. In this sampling trip, the length-frequency distribution of *N. erebi* captured by boat electrofishing was significantly different to the length-frequency distribution captured in combined fykes and mini-fykes (p<0.001). In contrast to the Condamine River catches, smaller size classes were more prevalent in the fyke and mini-fyke gear than were captured by boat electrofishing (Figure 3.18).

Figure 3.16: Length-frequency comparison of *N. erebi* captured moving upstream and downstream by fykes in Karreel Lagoon, Condamine catchment, spring 2005. Upstream n = 14, Downstream n = 29.



Figure 3.17: Length-frequency comparison of *N. erebi* captured by boat electrofishing and combined fykes and mini-fykes in Karreel Lagoon, Condamine catchment, autumn 2006. Fyke and mini-fyke *n* = 76. Electrofishing *n* = 115.



Figure 3.18: Length-frequency comparison of *N. erebi* captured by boat electrofishing and combined fykes and mini-fykes in the Macintyre River on an artificial flow, autumn 2006. Almost all fish caught in fykes and mini-fykes were heading upstream. Fyke and mini-fyke n = 28. Electrofishing n = 15.



On some, flows significant differences were detected between length frequencies of fish captured in upstream and downstream codends. On these occasions the tendency was for a greater proportion of small size classes to occur in the downstream codends. This occurred on a natural flow in spring 2005 in the Macintyre River (Figure 3.19, p = 0.012) and a falling flow in spring 2005 in the Condamine River (Figure 3.20, p = 0.023). On all other flow events where enough fish were captured for statistical comparisons, there were no significant differences detected in size of fish captured in upstream and downstream codends:

- Condamine rising and peak flows, autumn 2006, p = 0.571;
- Condamine falling flow, autumn 2006, p = 0.278;
- Condamine falling flow, autumn 2007, *p* = 0.362, see Figure 3.20.

Figure 3.19: Length-frequency comparison of *N. erebi* captured moving upstream and downstream by fykes in the Macintyre River, spring 2005. Upstream n = 4. Downstream n = 5.



Figure 3.20: Length-frequency comparison of *N. erebi* captured moving upstream and downstream by combined fykes and mini-fykes in the Condamine River during a falling flow, autumn 2007. Upstream n = 15. Downstream n = 27.



Recapture data

Very few VIE-marked *N. erebi* were recaptured. All recaptured fish were from the Macintyre River, despite the majority of tagged *N. erebi* being released into the Condamine River. The recapture data are summarised in Table 3.12.

Table 3.12: Recaptures of VIE-tagged *N. erebi.* As fish were batch tagged, a range of possible times at large are shown for each recapture. Fish batch tagged during the pilot study had multiple release points in a zone. Recaptured fish with pilot study batch tags display a range of possible distances moved. Release and recapture zones relate to those described in Chapter 2. ds = downstream movement. us = upstream movement.

River	Time at large	FL at recapture mm	Release zone	Recap zone	Distance moved m	Direction moved
Macintyre	3 months	-	1	1B	10-900	ds
Macintyre	3 months	-	1	1B	10-900	ds
Macintyre	1 day to 6 months	240	1B	1B	425-750	ds
Macintyre	2 months	233	5A	5A	120	ds
Macintyre	2-20 months	261	5D	5D	105	us
Macintyre	2-20 months	261	5D	5D	100	us

Radiotelemetry data

Eleven *N. erebi* were released into a slow moving current (< 0.01 m s^{-1}) in the Macintyre River and radio-tracked for between two and 121 days. Over the first 24-hour period, the majority of movement was localised, with both up and downstream movements recorded. Most of these fish appeared to swim in aggregations in large circular movements within the larger pool adjacent to their release site. However, the cumulative movement was generally in a downstream direction (Table 3.13), although several fish did appear to undertake active downstream movement.

Table 3.13: Cumulative 24-hour direction of movement by recently released *N. erebi* tracked by radiotelemetry. Details of release date and size of fish tracked are shown. Negative values indicate downstream and positive values indicate upstream movement.

		24-hr cumulative direction		
Fish radio requency	Release date	of movement (m)	FL (mm)	Wt (g)
48.180	3/08/2006	-703	241	230
48.230	8/09/2006	-295	297	494
48.531	8/09/2006	-270	294	404
48.650	8/09/2006	-270	282	402
48.661	8/09/2006	5	290	430
48.940	8/09/2006	-255	276	372
48.961	3/08/2006	-575	228	222
48.981	14/10/2006	145	287	440
48.990	8/09/2006	-275	263	299
49.090	14/10/2006	-250	278	409
49.240	3/08/2006	115	228	181

Subsequent radio-tracking showed that nearly all *N. erebi* undertook both upstream and downstream movements (Table 3.14) with the largest being nearly one km upstream and 5.2 km downstream. Cumulatively, nearly all fish were found to move downstream. Two fish exhibited normal swimming behaviour for a short period of time (up to two weeks) and then appeared to take up residence on large woody debris or undercut banks within the river channel. We attributed this behaviour to predation by large cod, with the *N. erebi* and transmitters being swallowed whole and the transmitters being subsequently excreted at the site of the predator's refuge. While were able to pinpoint the exact location of one of these transmitters with a magnet on the end of a rope, we were unable to retrieve the tag due to the low visibility and dense tangle of woody debris at this site.

Fish radio frequency	Maximum upstream movement	Maximum downstream movement	Cumulative distance from release point	# days between release and last radio log
48.180	135	545	-1098	74
48.230	905	2500	-1630	121
48.531	230	150	-80	121
48.650	70	115	-235	121
48.661	165	105	165	11
48.940	50	175	-155	37
48.961	10	500	-515	33
48.981	145	180	-35	3
48.990	250	710	-735	37
49.090	0	250	-250	2
49.240	130	5200	-5180	73

Table 3.14: Movement trends for 11 *N. erebi* tracked by radiotelemetry over 2 to 121 days. For cumulative distances, negative values indicate downstream and positive values indicate upstream movement.

Electrofishing below barriers

Large numbers (1800) of aggregating *N. erebi* were captured immediately below weirs in the Condamine River during autumn 2006 by backpack electrofishing. They were also captured at the same locations during flows in autumn 2007, but numbers (207) were lower than in 2006. Prior to the autumn 2007 flows, the Condamine River was reduced to a chain of pools with extensive areas of dry riverbed in between.

Fish captured by backpack electrofishing below barriers in autumn 2006 were not significantly different in size to those captured in upstream codends (Figure 3.21, Kolmogorov-Smirnov two-sample test, p = 0.070), but fish captured in downstream codends (n = 148) were significantly different (smaller) in length-frequency distribution to backpack electrofishing caught fish (p = 0.003).

The size of *N. erebi* captured by backpack electrofishing (n = 48) was not significantly different (p = 0.464) to the size of fish captured in upstream codends (n = 15) on a falling flow in autumn 2007. The size of fish captured in downstream codends (n = 27) was also not significantly different at the five per cent level (p = 0.064) but only marginally so.

Lagoon captures

Bony bream *N. erebi* were common in both Karreel Lagoons (Condamine Zones 4 and 5) and some were also captured in South Callandoon Lagoon (Macintyre Zone 6) before it dried out. None were captured in Camp David Lagoon (Macintyre Zone 3) before it dried out, or in Booberoi Lagoon (Macintyre Zone 8) after it connected briefly to the Macintyre River on a high within-bank flow.

Figure 3.21: Length-frequency comparison of *N. erebi* captured moving upstream by combined fykes and mini-fykes and by backpack electrofishing below barriers in falling flow conditions, Condamine River autumn 2006. Upstream *n* = 91. Backpack *n* = 98.



Discussion

The differing responses of *N. erebi* catch rates in fyke nets and by boat electrofishing to hydrography supports the assumption that the fykes were detecting movement and were not solely related to abundance of *N. erebi*.

Variables and interactions significant to fyke and mini-fyke captures were river, hydrography, gear, season, gear by river, gear by hydrography and hydrography by substrate. Substrate was also a significant main effect in the binomial model. The variable "river" and interactions with "river' can be explained on the basis of *N. erebi* being much more abundant in the Condamine River than in the Macintyre River. River does not necessarily relate to fish movement. The significance of the factor "gear" relates to differences between upstream and downstream catches, as well as differences between mini-fyke and fyke catches, which in turn relate to size of fish moving. This factor can therefore be linked to movement. Movement patterns certainly related to hydrography and the interaction between gear and hydrography provides a good explanation of how *N. erebi* were responding to prevailing hydrographical conditions. As for *Hypseleotris* spp., flow type had a significant effect on movement. Bony bream *N. erebi* were more likely to move on natural than artificial flows. This result may in part be affected by the lower abundance of *N. erebi* compared to the Macintyre, but the models should have been adjusted for this effect when calculating adjusted means. There was also no significant interaction between river and flow type.

The term substrate may not be directly related to migratory behaviour, but it could be related to foraging behaviour. Some substrates may be more attractive to foraging *N. erebi* than others. We observed *N. erebi* flashing over sandy and gravely substrates. Whether this related to feeding behaviour or parasite removal was unclear to us. The adjusted mean estimates from the binomial x gamma model suggest *N. erebi* were captured more frequently in fykes and mini-fykes set on gravel and sand substrates. Substrate may therefore have influenced catch rates. An interaction between hydrography and substrate may have resulted from a combination of foraging or other non-migratory behaviour (substrate) and migratory (hydrography) behaviours contributing to catch rates.

Fyke data indicates *N. erebi* moved both upstream and downstream on all flows. Upstream and downstream movement is also supported by the radiotelemetry observations. Of all flows, the least movement appears to have been on base artificial flows. Base flows were recorded only in the Macintyre where *N. erebi* were in low abundance; this may have dragged base flow values in the model down. Downstream movers tended to exhibit greater numbers than upstream movers, except on peak flows, however differences were not significant. Mallen-Cooper et al. (1995) noted that upstream movement through a fishway ceased at night and that fish turned around and headed back to the base of the fishway. As fyke and mini-fyke sets covered the night period it could be possible that this has skewed movements by *N. erebi* to a downstream direction. This is supported by 24-hour radio-tracking data of large *N. erebi* in the Macintyre River where more fish moved collectively downstream at night than upstream. Although some of these movements were mesoscale by our definition (refer to Section 1.3, Project objectives), all were no more than a few hundred metres, and cannot be termed migratory.

The most pronounced downstream movement by *N. erebi* was on falling flows. As for *Hypseleotris*, this is possibly a behavioural response to avoid desiccation in an ephemeral environment. Downstream movers tended to be smaller or juvenile fish. This explains why mini-fyke captures tended to be dominated by downstream movers on flow events (excluding base flows), whereas fykes detected a more even proportion of upstream movers on some flows. During no flow periods this trend was absent. The greater proportion of small fish in downstream codends may reflect downstream displacement. Upstream movement by adult fish may help counter this effect. However, there was often no difference in size between codends. Electrofishing also tended to capture a greater proportion of small fish than combined fykes and mini-fykes. Many of these small fish were electrofished from the mid-river, or mid-lagoon surface pelagic zone and would not have been caught by fykes or mini-fykes. However, this also suggests that smaller fish were not always migrating or moving on flows in proportion to their population.

Bony bream *N. erebi* were common in the large Karreel Lagoon and must have entered this lagoon from the river at some stage. *Nematalosa erebi* are also known from wetlands in other parts of the Murray-Darling Basin (Closs et al. 2006). Length frequencies of *N. erebi* captured by electrofishing in the large Karreel Lagoon suggested some recruitment was taking place there. Large lagoons may therefore be suitable recruitment areas for *N. erebi*. Booberoi Lagoon, which connected briefly to the Macintyre River during a within-bank

flow event, did not have any *N. erebi* recorded from it post-connection. *Nematalosa erebi* were present in the adjacent river but not in large numbers. There appears to have been no active migration into the lagoon by *N. erebi*.

Large accumulations of *N. erebi* below barriers, as collected in this study using backpack electrofishing and reported by Pusey et al. (2004), tend to focus attention on upstream migration, while those fish moving the opposite direction go unnoticed. Upstream movement by *N. erebi* during daylight hours has been observed in fishways (Russell 1991, Mallen-Cooper et al. 1995, Stuart 1997). Accumulations at weirs probably represent a sample from a long reach of river that has accumulated over many days. Length-frequency analysis of fish captured below weirs and in upstream and downstream codends of fykes supports the notion that *N. erebi* accumulating below weirs are upstream migrants. Upstream migrating fish below Cotswold Weir in autumn 2007 would have travelled at least 11 km to reach the weir. Despite the undoubted importance of upstream movement for a proportion of the *N. erebi* population, the importance of downstream movements should not be underestimated.

There were very few recaptures of *N. erebi* during the course of this study. Those recaptured ranged from 105 m upstream to 900 m downstream from release points. Radio-tagged fish ranged from 905 m upstream to 5180 m downstream from their release points before batteries failed on their respective transmitters. The radiotelemetry work was affected by lack of substantial flow events during the tracking period. Nevertheless *N. erebi* moved distances that can be termed mesoscale. Movements were in the order of hundreds to thousands of metres and were also both upstream and downstream. This substantiates inferences from the fyke data. The limited telemetry data and the data from fish accumulating below weirs do suggest *N. erebi* have the capacity to move long distances.

A problem with radio-tracking small fish is that the transmitters and their batteries have to be small to maintain the minimum recommended (2%) transmitter-to-body- weight ratio (Winter 1983). Smaller fish also require shorter external antennae. Consequently, radio reception range and battery life were greatly reduced compared to studies on larger fish such as cod (Koehn 1996, Koehn & Nicol 1998, Simpson & Mapleston 2002, Ebner & Thiem 2006, Ebner et al. 2006). After a flow event in the Macintyre River when fish moved beyond the range of car or boat-based radio-tracking, it was difficult to pick up tag reception from a light aircraft. Multiple aircraft passes over a known fish location identified the tagged fish in one of the three passes. The problem of "disappearing" fish can be alleviated by having permanent listening stations at key locations.

3.3.3 Spangled perch Leiopotherapon unicolor

Nearly all of the *L. unicolor* captured in this program came from the Condamine River (98%). Backpack electrofishing below barriers accounted for 43% of catches, mini-fykes for 38%, boat electrofishing for 16% with the remainder caught by fykes (3%).



Generalised Linear Models (GLM)

All gears

A GLM that included all gear types with binomial distribution and logit link function was fitted to the standard shot data with the main effects: gear, flow-type, season, river, hydrography, substrate and moon phase. The following two-way interactions were also fitted in the model: flow type by season, gear by river, flow type by hydrography, hydrography by season, flow type by moon phase, gear by hydrography, and gear by season. The model explained 44.91% of the deviance. Significant main effects and interactions were gear (p<0.001), flow type (p<0.001), season (p<0.001), river (p<0.001), hydrography (p<0.001), gear by river (p = 0.030), flow type by hydrography (p<0.001), and flow type by moon phase (p = 0.047).

A conditional GLM with gamma distribution and log link function that followed on from the binomial model explained 83% of the deviance. A summary of the gamma GLM is presented in Table 3.15. Significant main effects were gear, flow type, river, hydrography and substrate. Season by hydrography, gear by hydrography and gear by season were the only significant two-way effects.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	5	196.2119	39.2424	60.42	<0.001
Hydrography	5	30.5939	6.1188	9.42	<0.001
Substrate	4	15.7456	3.9364	6.06	<0.001
River	1	3.8553	3.8553	5.94	0.017
Flow type	1	2.9199	2.9199	4.5	0.036
Season	2	0.7907	0.3954	0.61	0.546
Moon phase	3	0.0282	0.0094	0.01	0.998
Season.hydrography	4	27.9098	6.9775	10.74	<0.001
Gear. hydrography	15	32.9809	2.1987	3.39	<0.001
Gear.river	4	5.6275	1.4069	2.17	0.078
Gear.season	8	11.0263	1.3783	2.12	0.040
Flow type.moon phase	1	0.6664	0.6664	1.03	0.313
Flow type.season	1	0.1223	0.1223	0.19	0.665
Flow type.hydrography#	0	0	*		
Residual	104	67.5440	0.6495		
Total	158	396.0228	2.5065		

Table 3.15: Summary of analysis for a conditional gamma distribution GLM (with log link function) of *L. unicolor* catches. Gear includes all six gear types. # indicates variable not fitted by model due to aliasing. Significant factors are given in *italics*.

Although the GLM using catch data from all gear types does not necessarily reflect movement, there are several significant main effects that can be explained by anomalies in our catch data. However, GLM can account for such anomalies and the resulting standardised means reflect the observed data.

Figure 3.22 shows how boat electrofishing catch and fyke and mini-fyke catch of *L. unicolor* varied across different hydrographical stages. For some conditions the mean electrofishing catch is high relative to fyke and mini-fyke catches, whereas on others, one or more of the fyke and mini-fyke gear types exceeds electrofishing catch. Response of fykes and mini-fykes also differ from each other. Mini-fykes tended to capture more of the smaller size classes (see length-frequency results below).

Figure 3.22: Variation under different hydrographical conditions in the catch rates of *L. unicolor* captured by fykes, mini-fykes (upstream and downstream codends) and boat electrofishing. Error bars show one standard error of the mean. Values are adjusted means calculated from binomial x conditional gamma GLMs. Other terms in the model have been held constant. Values should be viewed as trends in the data rather than as predictions of catch.



Fykes and mini-fykes

A GLM analysis of fyke and mini-fyke catch data, restricted to Condamine River catches only, investigated potential factors that influenced movement. Over 90% of the combined fyke and mini-fyke catch came from mini-fykes. A GLM with a binomial distribution with logit link function explained 36.61% of the deviance in the data. Fitted terms and two-way interactions were the same as for the all gear model above. Flow type (p<0.001), season (p<0.001), river (p<0.012) and hydrography (p<0.001) were the only significant terms identified in the binomial model. The conditional gamma GLM accounted for 91.25% of the deviance and contained some significant main effects and two-way interactions, most of which were different to those in the binomial model. They included gear, gear by river, season by hydrography and gear by season. A summary of the analysis is presented in Table 3.16.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	3	113.5943	37.8648	73.69	<0.001
Season	2	20.8570	10.4285	20.29	<0.001
River	1	5.4614	5.4614	10.63	0.002
Substrate	3	5.3845	1.7948	3.49	0.025
Moon phase	3	3.5526	1.1842	2.30	0.093
Hydrography	5	3.1935	0.6387	1.24	0.310
Flow type	1	0.4967	0.4967	0.97	0.332
Season.hydrography	0	19.7924	9.8962	19.26	<0.001
Gear.river	1	2.7744	2.7744	5.40	0.026
Gear.season	6	11.4009	1.9001	3.70	0.006
Gear.hydrography	7	6.2781	0.8969	1.75	0.129
Flow type.hydrography#	0	0	*		
Flow type.moon#	0	0	*		
Flow type.season#	0	0	*		
Residual	36	18.4987	0.5139		
Total	70	211.2845	3.0183		

Table 3.16: Summary of analysis for a conditional gamma distribution GLM (with log link function) of *L. unicolor* catches. Gear includes fykes and mini-fykes upstream and downstream codends only. *#* indicates variable not fitted by model due to aliasing. Significant factors are given in *italics*.

Catch rates were higher during natural flows (Figure 3.23), although this was not a significant effect in the gamma model due to the low catches in the Macintyre River, the only river with artificial flows. The strong relationship between downstream movement and spring is highlighted in the gear by season catch summary in Table 3.17.

Figure 3.23: Catch rates of *L. unicolor* by flow type. Adjusted mean values were calculated by binomial x conditional gamma GLMs for fyke and mini-fyke gear only. All other variables in the model have been held constant. Error bars show one standard error of the mean. Values should be viewed as trends in the data rather than as predictions of catch.



Table 3.17: Variation in seasonal catch of *L. unicolor* in fyke and mini-fyke, upstream and downstream codend. Values are adjusted means and standard errors of the mean calculated by binomial x conditional gamma GLMs. Other variables in the model have been held constant.

	Fyke downstream		Fyke upstream		Mini-fyke downstream		Mini-fyke upstream	
Season	Adj. mean	S.E.	Adj. mean	S.E.	Adj. mean	S.E.	Adj. mean	S.E.
Winter	0.264	0.163	0.051	0.047	0.053	0.049	0.106	0.097
Spring	0.150	0.0	0.060	0.051	13.638	7.1303	0.091	0.078
Autumn	0.314	0.129	0.1132	0.113	0.685	0.240	0.263	0.086

Length-frequency data

Numbers of *L. unicolor* captured in the Macintyre River were too low for meaningful length-frequency comparisons. Results presented here are for fish captured from the Condamine River during flows when *L. unicolor* were suitably abundant for length-frequency comparisons. Due to drought conditions, periods of flow were limited.

On a falling flow in the Condamine River during spring 2005, all captures of *L. unicolor* except one came from downstream codends. The catch included a large proportion of juveniles. The size distribution was not significantly different (Kolmogorov-Smirnov two-sample test, p = 0.077) to that of *L. unicolor* captured by boat electrofishing during the same flow (Figure 3.24).

Within an abundant lagoon population of *L. unicolor* in Zone 5 (Karreel Lagoon) of the Condamine River, there was no significant difference in size distribution between upstream and downstream codend catches. Figure 3.25 is a typical example (p = 0.424). This was in stark contrast to catches from flowing water. The Karreel lagoon population was isolated from adjacent riverine populations for the entire project, although there were some inflows from overland run-off and along a minor feeder creek. This supports our assumption that these fish were undertaking foraging movement rather than migratory movement.

Boat electrofishing in this lagoon in autumn 2006 tended to capture more small size class fish (Kolmogorov-Smirnov two-sample test, p<0.001) than combined fykes and mini-fykes (Figure 3.26).

Figure 3.24: Length-frequency comparison of *L. unicolor* captured by boat electrofishing and combined fykes and mini-fykes in the Condamine River on a falling flow, spring 2005. Combined mini-fyke and fyke n = 53. Electrofishing n = 10.



Figure 3.25: Length-frequency distributions of *L. unicolor* captured in upstream and downstream codends of fykes and mini-fykes, Karreel Lagoon, autumn 2006. Upstream *n* = 20, Downstream *n* = 27.



Figure 3.26: Length-frequency distributions of *L. unicolor* captured by boat electrofishing and combined fykes and mini-fykes, Karreel Lagoon, autumn 2006. Electrofishing n = 73, Fyke and mini-fyke n = 47.


During a low flow period in autumn 2007, data such as displayed in Figure 3.27 suggests that catches of smaller size classes were proportionally higher in downstream codends than in upstream codends. However, this was not significant at the five per cent level (p = 0.071). During the same period, boat electrofishing captured significantly smaller fish compared to combined fykes and mini-fykes (p<0.001) with no fish being larger than 80 mm.

Figure 3.27: Length-frequency distributions of *L. unicolor* captured in upstream and downstream codends of fykes and mini-fykes combined, during low flows, in the Condamine River, autumn 2007. Upstream n = 10, Downstream n = 24.



Recapture data

Recaptures of VIE-tagged *L. unicolor* are summarised in Table 3.18. This table does not include the fish tagged and recaptured during the pilot phase. Most of the tagged *L. unicolor* were PIT-tagged and are described below.

Table 3.18: Recaptures of VIE-tagged *L. unicolor* in the Macintyre and Condamine Rivers. Release and recapture zones relate to those described in Chapter 2. as = across stream movement.

River	Time at large	FL at recapture mm	Release zone	Recap zone	Distance moved m	Direction moved
Condamine	2½ months	99	1C	1C	25	as

Eighteen PIT-tagged fish were recaptured from the Condamine sites (Table 3.19), mostly from the Karreel Lagoon (Zone 5). This site contracted to about 20% of its bank-full surface area during the prolonged dry spell of 2006. This restricted the movement of many of the *L. unicolor* that were recaptured during this period. There were an additional 106 recaptures of PIT-tagged *L. unicolor* from Zone 4. However, these fish were tagged and recaptured during the pilot phase of the study and had moved less than 50 m. This site subsequently dried out and did not reconnect during the study.

Table 3.19: Recaptures of PIT-tagged *L. unicolor* in the Condamine River. This table excludes recaptured fish from Zone 4. Release and recapture zones relate to those described in Chapter 2. (L) = lagoon habitat. ds = downstream movement. us = upstream movement. as = across stream movement.

River	Time at large	FL (mm) at recapture	Release zone	Recap zone	Distance moved (m)	Direction moved
Condamine	14 months	170	5(L)	5(L)	25	as
Condamine	1 day	125	5(L)	5(L)	660	us
Condamine	2 months	131	5(L)	5(L)	180	us
Condamine	1 day	60	5(L)	5(L)	325	us
Condamine	1 day	65	5(L)	5(L)	330	us
Condamine	4 months	139	5(L)	5(L)	25	as
Condamine	6½ months	148	5(L)	5(L)	370	ds
Condamine	4 months	94	5(L)	5(L)	25	as
Condamine	2 months	105	5(L)	5(L)	135	ds
Condamine	5½ months	187	1D	ds of 1C	950	us
Condamine	3 months	128	5(L)	5(L)	360	us
Condamine	5 days	80	5(L)	5(L)	25	as
Condamine	2 months	96	5(L)	5(L)	120	us
Condamine	2 months	143	1C	1C	25	as
Condamine	2 months	115	1C	1C	25	as
Condamine	2 months	144	1C	1C	25	as
Condamine	2 months	137	1 C	1C	25	ds
Condamine	1 day	96	5(L)	5(L)	120	ds

Radiotelemetry data

Eight *L. unicolor* were radio-tracked in the Condamine River and an adjacent lagoon for up to 138 days. Three were released into a large weir pool (>15 km length when full); three were released into a shorter instream waterhole (about 0.75 km length at base flows); and the other two were released into a large off-stream lagoon (>1.5 km length when full). All fish made some movement during the first 24-hour period (Table 3.20). However, those fish released into the large weir pool made the longest movements compared to all other fish. These three fish made larger movements both during the first 24-hour period, and over the ensuing radio-tracking period, with the largest single movements being 1.4 km. This movement was in both downstream and upstream directions. The maximum cumulative distance moved from the release point was approximately 2 km in both directions (Table 3.21).

Contact was lost with two of the fish released into the weir pool after a small inflow from Undulla Creek (refer to Figure 2.11). One of the two fish released into the large Karreel Lagoon was active when first released, moving more than several hundred metres during nightly foraging. In contrast, the other fish remained within the deeper basin of the lagoon. Both fish frequented these deeper waters as the lagoon surface area contracted. The fish released into the instream waterhole made small scale "investigative" movements during the first 48 hours and then displayed site fidelity associated with large woody debris. These fish did not appear to move far from these woody refuges during the rest of the radio-tracking period.

Table 3.20: Cumulative 24-hour directional movement by radio-tagged *L. unicolor*. Details of release date and size of fish tracked are shown. Negative values indicate downstream movement and positive values indicate upstream movement.

(r) = fish released into a riverine waterhole; (l) = fish released into an off-stream lagoon; and (w) = fish released into a riverine weir pool.

Fish radio frequency	Release date	24-hr cumulative direction of movement	FL (mm)	Wt (g)
48.310(r)	29/08/2006	35	167	72
48.331(l)	23/08/2006	65	165	71
48.860(l)	23/08/2006	0	187	100
48.921(r)	30/08/2006	85	186	103
49.041(w)	29/08/2006	540	151	65
49.061(w)	29/08/2006	-1410	190	108
49.110(w)	29/08/2006	210	167	75
49.150(r)	30/08/2006	80	178	97

Table 3.21: Movement trends of radio-tagged *L. unicolor* over 2 to 4 months. For cumulative distances, negative values indicate downstream movement and positive values indicate upstream movement. (r) = fish released into a riverine waterhole; (l) = fish released into an off-stream lagoon; and (w) = fish released into a riverine weir pool.

Fish radio frequency	Maximum upstream movement	Maximum downstream movement	Cumulative distance from release point	# days between release and last radio log
48.310(r)	40	45	-10	131
48.331(l)	335	345	110	138
48.860(l)	395	400	55	69
48.921(r)	105	30	70	104
49.041(w)	505	30	840	65
49.061(w)	65	1350	-2000	133
49.110(w)	1760	0	2025	63
49.150(r)	180	100	50	131

Electrofishing below barriers

During autumn 2006, on a falling flow, the size distribution of *L. unicolor* captured below barriers by backpack electrofishing (n = 138) was not significantly different (Kolmogorov-Smirnov two-sample test, p = 0.311) to the size distribution of *L. unicolor* captured in upstream codends (n = 6). Backpack electrofishing captures were also not significantly different from the size of *L. unicolor* captured in downstream codends at the five per cent level, but only marginally so (p = 0.065). This sampling event occurred on the tail of the third weir overtopping in as many months.

During falling flows in autumn 2007, the size distribution of *L. unicolor* caught by backpack electrofishing from below barriers (n = 103) was not significantly different (p = 0.119) to *L. unicolor* captured in upstream codends (n = 10), but was significantly different in size (p = 0.012) to fish caught in downstream codends (n = 24) (Figure 3.28). The fish caught below barriers had accumulated over a period of time (about 25 days) when the weir had been overtopped by local run-off. The distance from these barriers to the next downstream permanent waterhole was significant, with one barrier isolated from the nearest downstream pool by 11 km of dry river bed before the autumn 2007 flow. This sampling event occurred during the first major connecting flow event in approximately 11 months.

Figure 3.28: Length-frequency of *L. unicolor* captured moving downstream by combined fykes and minifykes compared to those caught by backpack electrofishing below barriers on a falling flow condition in the Condamine River, autumn 2007.



Lagoon captures

Leiopotherapon unicolor were common in the large and small Karreel Lagoons (Zones 4 and 5) on the Condamine system. They were also captured in South Callandoon Lagoon (Zone 6) and Booberoi Lagoon (Zone 8) on the Macintyre system. The small Karreel Lagoon, South Callandoon Lagoon and Booberoi Lagoon all dried out during the first 12 months of the study. However, during a brief connection period in January 2006, some *L. unicolor* appeared in Booberoi Lagoon. In contrast, the small Karreel Lagoon partially refilled from rainfall and localised run-off six weeks after drying out, but did not connect to the river or the adjacent large Karreel Lagoon. Consequently, no *L. unicolor* were captured after refilling by rainfall.

Combined sampling methods in Karreel Lagoon captured both adult and juvenile size classes in autumn 2006, although electrofishing captured more smaller size classes than the nets (Figure 3.26). The lagoon had not connected to the river during the previous 18 months indicating that some recruitment had occurred in the lagoon.

Discussion

The significant factors influencing fyke and mini-fyke catches in both GLMs included season and river. We feel that the significance of river relates more to abundance than to movement behaviour. It is interesting to note that there were so few *L. unicolor* found in the Macintyre River compared to the Condamine River. Observations from other studies suggest that *L. unicolor* are more numerous in the Goondiwindi and Boggabilla weir pools, upstream of our sites in the Macintyre River. They were numerous in both the small and large Karreel Lagoons in the Condamine system. The smaller size classes in these lagoons suggest that recruitment can occur in still water bodies with adequate persistence. This emphasises the need for managing lateral connectivity.

The boat electrofishing catches of *L. unicolor* were significantly higher from lagoons and still riverine habitats compared to that from the fykes and mini-fykes (Figure 3.22). Conversly net catches in flowing waters were either similar to or exceeded electrofishing catch rates, suggesting movement other than just foraging during flows.

At only 37%, the binomial model explained less deviance than the gamma model (91%). Flow type and hydrography were significant factors in the binomial model, but not in the gamma. However, the two-way interaction between season and hydrography was significant in this model. This has been attributed to the significantly larger catch of *L. unicolor* in downstream mini-fyke codends in spring (Table 3.15), compared to all other seasons and gears. All size classes, including young-of-year, were captured in downstream codends during falling flows in spring. The length frequencies of these fish were not significantly different to boat electrofishing catches, suggesting a whole of population response to falling flows, in common with several other native species.

Like *Hypseleotris* spp. and *N. erebi*, *L. unicolor* appears to be more inclined to move on natural flows (Figure 3.23). However, this was only a significant factor in the binomial model. Although there was a low abundance of *L. unicolor* in the Macintyre River, the models did account for variations in catch, e.g. river, and flow type by river were not significant interactions in either model. The popularity of natural flows for stimulating movement highlights the need for further research into finding the cues that stimulate this migratory behaviour.

Across all flows, *L. unicolor* is a highly mobile species, moving both up and downstream. However, major downstream movements occur in spring, on falling flows, influenced by the higher abundance of young-of-year fish.

Substrate was a significant main effect in the gamma model. Adjusting for other factors in the model, more *L. unicolor* were caught over a sandy substrate. Sandy substrates are confined to riverine habitat only. A considerable number of *L. unicolor* were also caught over silt substrates, but this was mainly from lagoon habitats. As for *N. erebi*, it was suspected that substrate preference may be influenced by foraging behaviour. Length-frequency comparisons between net and electrofishing catches from the lagoons suggest that larger fish forage more widely than smaller fish in these habitats. Movements in excess of 100 m in the lagoon were supported by mark-recapture and radiotelemetry data. The prevalence of *L. unicolor* in lagoon habitats strongly suggests that they actively migrate to these habitats on connecting flows. They were one of only two native species to be recorded in an off-stream lagoon after a brief connecting flow in January 2006. Considering that *L. unicolor* has a relatively low abundance in the adjacent section of the Macintyre River, it can be suggested that this was an active migration.

There have been many reports of aestivation by *L. unicolor*. However, there was no evidence found to support this in lagoons. For example, in January 2005 we PIT-tagged 241 fish in a small ephemeral lagoon (Zone 4) adjacent to the Condamine River. This lagoon dried out by April 2005 and did not receive any inflows of water until July 2005 when local rain partially refilled it. The refilled lagoon was then sampled by backpack electrofishing, seining and fish traps but no fish were found. Given the silt-clay nature of the substrates of this lagoon, it is not surprising that fish were unable to burrow into the substrate and survive. We believe this evidence supports our hypothesis that the *L. unicolor* in this and other lagoons originally recruited from riverine populations during a prior connection. This emphasises the importance of regular connection events for sustaining native fish populations in off-stream aquatic habitats.

There is strong evidence that *L. unicolor* accumulate below barriers during flow events. Sampling below weirs in the Condamine River in autumn 2007 showed that nearly twice the number of fish were moving downstream compared to upstream. Backpack electrofishing caught more large fish than the downstream codend, while upstream codend catches were similar in size range to backpack electrofishing catches. The larger proportion of smaller sized fish in the downstream codends, relative to the backpack-caught fish, supports the theory that adults are more likely to move upstream, while juveniles are commonly downstream movers. The distance from these barriers to the next downstream permanent waterhole was significant, with one barrier isolated from the nearest downstream pool by 11 km of dry river bed before the autumn 2007 flow. This sampling event occurred during the first major connecting flow event in approximately 11 months and these fish had approximately 20 days to move up to the weir.

The majority of *L. unicolor* recaptures were made in the large Karreel Lagoon. Consequently, movement was truncated by the limits of the lagoon water body. The most significant movement recorded from this zone was 660 m after one day by a fish of 125 mm FL. There were other records of movement in excess of 300 m after one day by smaller fish (60 and 65 mm FL) indicating that these are highly mobile fish. There is also a record of one *L. unicolor* moving nearly one km downstream over a 5.5 month period. All of the other riverine recaptures were of a lesser distance moved. This occurred because the extended dry caused significant longitudinal discontinuity and many of the fish were constrained by receding pool size.

Radiotelemetry supported the PIT tagging and fyke data. Movements were detected in both directions. However, movement in excess of one km was confined to those fish released into the large weir pool of Zone 1 on the Condamine River. These fish moved rapidly, with the largest recorded being 1.4 km downstream in a 24-hour period. In the declining riverine waterhole, movement was much more constrained. In this habitat, movement behaviour was consistent with fish showing strong site fidelity to large woody debris. Whether this behaviour stems from duress and conservation of energy, or avoiding predation in a diminishing waterhole, is unclear. The movement behaviour of *L. unicolor* released into an off-stream lagoon habitat was proportional to the declining limits of the lagoon. Our initial plan had been to release these fish into a habitat at a time when normal spring and summer flows would connect lagoon and riverine habitats. However, this did not occur in 2006.

As identified previously (see discussion on *N. erebi*), a problem with radio-tracking small fish is that the transmitters, their batteries and aerial have to be small to maintain the minimum recommended (2%) transmitter-to-body-weight ratio (Winter 1983). Two of the *L. unicolor* released into the weir pool made rapid progress upstream of their release site for several months before "disappearing" after a small inflow of water from Undulla Creek. This flow did not reach the top of the weir, but may have influenced these fish to relocate laterally from the weir pool. This creek has several semi-permanent waterholes upstream of its junction with the weir pool. The problem of "disappearing" fish can be alleviated by having permanent listening stations at key locations.

3.3.4 Murray-Darling rainbowfish Melanotaenia fluviatilis

Seventy-nine per cent of *M. fluviatilis* were captured in the Macintyre River. Boat electrofishing captured 84% of all rainbowfish, mini-fykes accounted for 5.5% and fykes accounted for 9%. The remainder (1.5%) were captured by electrofishing below barriers.



Generalised Linear Models

All gears

A GLM, using a binomial distribution with logit link function, was run for data from all gear types. The model comprised the following fitted variables: gear, flow type, season, river, hydrography, substrate, moon phase; and these two-way interactions: flow type by season, moon phase by season, gear by hydrography and gear by season. The model explained 48.67% of the deviance. A summary of the analysis is shown in Table 3.22. The model had four significant main effects and one significant two-way effect. The term "season" was nearly significant (f = 0.061). This can be explained in part by the large spring catches (40%) of *M. fluviatilis* from the Macintyre River, although in the Condamine River, more were caught in autumn (13%).

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
River	1	51.4857	51.4857	51.49	<0.001
Flow type	1	50.0005	50.0005	50.00	<0.001
Gear	5	212.4691	42.4938	42.49	<0.001
Hydrography	5	66.2190	13.2438	13.24	<0.001
Moon phase	3	10.455	3.485	3.48	0.015
Season	2	5.5807	2.7904	2.79	0.061
Substrate	5	2.2122	0.4424	0.44	0.819
Flow type.season	1	13.2600	13.2600	13.26	<0.001
Gear.season	8	11.2737	1.4092	1.41	0.187
Gear.hydrography	24	29.0641	1.2110	1.21	0.218
Moon phase.season	3	3.2616	1.0872	1.09	0.353
Residual	930	480.1002	0.5162		
Total	988	935.3818	0.9467		

Table 3.22: Summary of analysis for a binomial distribution GLM of rainbowfish captures (with logit link function). Gear includes all gear types. Significant factors are shown in *italics*.

Subsequent to the binomial GLM, a conditional GLM was run with gamma distribution and log link function. This model was slightly more robust, accounting for 52.31% of the deviance, but had only two significant main effects: gear and flow type. A summary of the analysis is in Table 3.23.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Flow type	1	13.1377	13.1377	21.94	<0.001
Gear	5	56.914	11.3829	19.01	<0.001
River	1	0.6712	0.6712	1.12	0.292
Season	2	1.2093	0.6046	1.01	0.367
Moon phase	3	1.8717	0.6239	1.04	0.376
Hydrography	5	2.3135	0.4627	0.77	0.571
Substrate	5	1.6375	0.3275	0.55	0.740
Moon phase.season	1	0.9932	0.9932	1.66	0.200
Gear.season	4	3.7876	0.9469	1.58	0.183
Gear.hydrography	14	6.7338	0.4810	0.80	0.664
Flow type.season	1	0.0199	0.0199	0.03	0.856
Residual	136	81.4284	0.5987		
Total	178	170.7182	0.9591		

Table 3.23: Summary of analysis for conditional gamma GLM (with log link function) for *M. fluviatilis* captures by all gear types. Significant factors are shown in *italics*.

The significance of the effect of gear on catches can be readily understood by examining the variability in catch rates by the different gear types across the spectrum of hydrographical conditions (Figure 3.29). Boat electrofishing catch rates remained consistently higher than all other methods. In part this is influenced by the large catches of *M. fluviatilis* taken from midstream areas that were sampled only by boat electrofishing (84% of total catch). However, upstream codend captures are also consistently above those of downstream codend captures, except during no flow conditions.

Figure 3.29: Catch rates of *M. fluviatilis* by gear and hydrography. Adjusted means were calculated by binomial x conditional gamma GLMs for all gear types. Other factors in the model have been held constant. Error bars show one standard error of the mean.



Fykes and mini-fykes

The binomial model, for fyke and mini-fyke data only, fitted the same main effects as the all gear model. This model, which explained 31.99% of the deviance, is summarised in Table 3.24. All main effects were significant except substrate whereas none of the two-way interactions were significant.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	3	16.3675	5.4558	5.46	<0.001
River	1	42.0926	42.0926	42.09	<0.001
Flow type	1	23.069	23.069	23.06	<0.001
Season	2	9.0397	4.5198	4.52	0.011
Hydrography	5	20.1488	4.0298	4.03	0.001
Moon phase	3	9.8717	3.2906	3.29	0.020
Substrate	5	1.7926	0.3585	0.36	0.877
Flow type.season	1	2.8509	2.8509	2.85	0.091
Gear.season	6	8.6228	1.4371	1.44	0.196
Moon phase.season	2	1.9189	0.9594	0.96	0.383
Gear.hydrography	15	7.9344	0.5290	0.53	0.926
Residual	718	305.5016	0.4225		
Total	762	449.2025	0.5895		

Table 3.24: Summary of GLM analysis of *M. fluviatilis* captures, using a binomial distribution model with a logit link function. Gear includes fyke and mini-fyke codends only. Significant factors are given in *italics*.

A subsequent conditional gamma GLM for the fyke and mini-fyke data explained 37.88% of the deviance, and only one main effect was significant (season, p = 0.042).

From the binomial model, the seasonal catch rates in spring were much higher than all other sampled seasons (Figure 3.30), although sampling in summer was not undertaken due to the effect of high water temperature on post-capture mortality rates.

Figure 3.30: Adjusted mean catch rates of *M. fluviatilis* by season. Catch rates are derived from binomial x conditional gamma GLMs for fyke and mini-fyke data only. Other variables have been held constant by the model. Error bars are one standard error of the mean. Values should be viewed as trends in the data rather than as predictions of catch.



Flow type had an unexpected influence on *M. fluviatilis*, compared to all other native species investigated in this study. These fish were caught more often during artificial flows (71%) than on natural flows (Figure 3.31).

The effect of lunar phase on *M. fluviatilis* catch rates is less distinct (Figure 3.32). This was a significant effect in the binomial, but not the gamma model. Catch rates do appear to decline on the full and new moon, compared to the first and third quarters, but these are not significantly different from at least one other phase of the moon.

Flow had a strong effect on both fyke and mini-fyke catch rates and this followed a similar pattern to that of all gear types. There was a significantly larger catch rate in upstream codends of both gear types (Figure 3.33), is indicative an apparent tendency for upstream, rather than downstream movement by *M. fluviatilis*.

Figure 3.31: Adjusted mean catch rates for *M. fluviatilis* across different flow types. Values were calculated from the binomial x conditional gamma GLMs for fyke and mini-fyke data only. Other variables in the model have been held constant. Error bars show one standard error of the mean. Values should be viewed as trends in the data rather than as predictions of catch.



Figure 3.32: Adjusted mean catch rates for *M. fluviatilis* by moon phase. Values were calculated from the binomial x conditional gamma GLMs for fyke and mini-fyke data only. Other variables in the model have been held constant. Error bars show one standard error of the mean. Values should be viewed as trends in the data rather than as predictions of catch.



Figure 3.33: Adjusted mean catch rates for *M. fluviatilis* by fyke and mini-fyke codend. Values were calculated by binomial x conditional gamma GLMs for fyke and mini-fyke data only. Other variables in the model have been held constant. Error bars show one standard error of the mean. Values should be viewed as trends in the data rather than as predictions of catch.



Length-frequency data

Rainbowfish *M. fluviatilis* were more common in the Macintyre than in the Condamine River with only three out of a possible 52 catch records from the Condamine River having more than ten fish in the catch (Mean = 3, Mode = 1, max = 13, min = 1). Thus, most of the length-frequency analyses were restricted to Macintyre River catches. Generally only the larger size classes were captured in fykes and mini-fykes compared to those captured by electrofishing, which often showed evidence of multiple modes in the catch data (Figure 3.34). Analyses by Kolmogorov-Smirnov two-sample test showed most flow events had significant differences between the size distribution of combined net catch data compared to electrofishing data. For example:

Condamine River

• falling flow, autumn 2006, *p* = 0.039.

Macintyre River

- falling flow, autumn 2006, p = 0.016;
- base flow, autumn 2006 p = 0.008;
- falling flow, spring 2006, *p*<0.001;
- rising and peak flows, late spring 2006, p = 0.005.

Figure 3.34: Length-frequency comparison of *M. fluviatilis* captured by boat electrofishing and combined fykes and mini-fykes in the Macintyre River on a falling flow, early spring 2006. Fyke & mini-fyke n = 15. Electrofishing n = 98.



There were several sampling occasions when no significant differences were detected between size distribution of *M. fluviatilis* captured by boat electrofishing compared to combined nets, e.g. Macintyre River:

- base flow spring 2005, p = 0.450;
- rising and peak flows, spring 2005, p = 0.672,
- falling flow, autumn 2007, p = 0.405;
- falling flow, late spring 2006 p = 0.089.

This tended to occur when small size classes were in low numbers in the electrofishing catch or when combined fyke and mini-fyke captures were very low (Figure 3.35).

Figure 3.35: Length-frequency comparison of *M. fluviatilis* captured by boat electrofishing and combined fykes and mini-fykes in the Macintyre River on natural rising and peak flows, spring 2005. Fyke & mini-fyke n = 30. Electrofishing n = 29.



The majority of *M. fluviatilis* from fykes and mini-fykes were captured in upstream codends. In most cases, too few *M. fluviatilis* were captured in downstream codends for meaningful statistical comparisons of size distributions between fish moving upstream and downstream. On a few occasions when sufficient numbers were captured in downstream codends for statistical comparisons, e.g. on natural rising and peak flows, the length-frequency distribution of *M. fluviatilis* moving downstream had a narrower range than for fish moving upstream (Figure 3.36, Kolmogorov-Smirnov two-sample test, p = 0.023). However, the general situation was for no difference between upstream and downstream catches, e.g. Macintyre River, falling flow, spring 2006, p = 0.467 and base flow, spring 2005, p = 0.460. Downstream movers tended to be larger fish with only *M. fluviatilis* larger than 40 mm captured in the downstream codends.

Figure 3.36: Length-frequency comparison of *M. fluviatilis* captured moving upstream and downstream by combined fykes and mini-fykes in the Macintyre River on natural rising and peak flows, spring 2005. Upstream n = 22. Downstream n = 8.



Recapture data

Most of the VIE-tagged *M. fluviatilis* were from the Macintyre River (92%). Recapture rates were low and give little indication of mesoscale movement. Movement was in both directions (Table 3.25). All recaptures occurred within the same zone and were generally a short distance from the release site. One fish did move upstream through a pool and riffle complex between release and recapture. The recapture date was in spring 2006. The mark date may have been either summer 2005 or autumn/winter 2006.

Table 3.25: Recaptures of VIE-tagged M. fluviatilis in the Macintyre River. Release and recapture zones relate
to those described in Chapter 2. us = upstream movement. ds = downstream movement.

River	Time at large	FL at recapture mm	Release zone	Recap zone	Distance moved m	Direction moved
Macintyre	1 day	-	1B	1B	25	ds
Macintyre	1 day	-	1B	1B	25	us
Macintyre	3 to 9 months	52	7A	7A	25	us
Macintyre	2 to10 months	38	5B	5A	220	us
Macintyre	4 days	-	1D	1D	70	ds

Electrofishing below barriers

Small numbers of *M. fluviatilis* were captured from the Condamine River by backpack electrofishing below two weirs in autumn 2007. These weirs had overflowed after a prolonged dry period. If these fish had moved upstream, then they had moved between 900 m and 2400 m to reach Reilly's Weir and at least 11 km to reach Cotswold Weir. However, while we were able to compare backpack captures with boat electrofishing data, there were insufficient capture data from fyke nets at that time for comparison. The length-frequency of *M. fluviatilis* accumulating below weirs was truncated towards the larger size classes (Figure 3.37) compared to the general river population (as represented by the boat electrofishing catch), but this was not significantly different (p = 0.246) and was probably influenced by the low catch from backpack electrofishing.





Lagoon captures

Both the standard shot and VIE-tag release data demonstrate that *M. fluviatilis* is very uncommon in lagoons. Only one fish was caught in lagoons during the standard shot sampling: by boat electrofishing in the large Karreel Lagoon (Zone 5) adjacent to the Condamine River in autumn of 2005. Another five fish were tagged and released into two ephemeral lagoons adjacent to the Macintyre River. Both sites dried out within three months of releasing fish and were not sampled for the rest of the study. There was no evidence of any *M. fluviatilis* in a small ephemeral lagoon (Zone 8) adjacent to the Macintyre River that did connect to the river in summer 2006. This site subsequently dried out over the next three months and did not reconnect during the rest of the study.

Discussion

The Murray River rainbowfish *M. fluviatilis* is reported to be a schooling species common to the lowland waters of the Murray-Darling Basin (Moffat & Voller 2002, Lintermans 2007). It is common in the lowland reaches of the Macintyre River, but less so in geomorphically similar waters of the Condamine River. Whether this is due to water chemistry factors such as turbidity, or hydrographical factors such as seasonal/non-seasonal flow, is unclear from this study. However, the GLM of all gear types indicate that catch is influenced by various factors including gear type, river, flow type, season, hydrography and lunar phase.

Boat electrofishing was the most effective method of catching *M. fluviatilis*, with schools of fish being captured in over 20% of all boat electrofishing catches where *M. fluviatilis* was present. Most *M. fluviatilis* were caught from the Macintyre River (79%). The reason for their low presence in the section of the Condamine covered in this study is unclear. One explanation could relate to their need for access to backwater macrophytes to complete spawning and recruitment (King et al. 2003). A lack of in-channel macrophytes was noted in this study section of the Condamine River, but as Moffat and Voller (2002) point out, this may be compensated for by the use of snags.

However, during the course of this study, levels in many waterholes in the Condamine River dropped dramatically in a prolonged dry period. This would certainly have diminished recruitment success, but does not explain the lack of larger (adult) fish from the more permanent waterholes and weir pools. Another explanation could relate to the lower turbidity of artificial releases. Irrigation flows in the Macintyre River tended to carry less sediment in suspension which would favour macrophyte productivity. In the Macintyre River, we observed dense stands of Persicaria lapathifolium (smart weed) along the margins of the main channel and this habitat would favour successful recruitment.

Most of the Macintyre River catch of *M. fluviatilis* was taken in spring with strong evidence of recruitment occurring by late spring and autumn. In the southern basin, they are reported to spawn in spring and summer (Backhouse & Frusher 1980) when water temperature exceeds 23°C (Lake 1959). This would occur earlier in the year in the northern basin.

The influence of flow type on *M. fluviatilis* movement is unique compared to all other native species encountered in this study. The catch rates in fykes and mini-fykes were significantly higher during artificial flows, which may have been influenced by the higher abundance of *M. fluviatilis* in the Macintyre River. However, GLM does account for the influence of other factors (e.g. river on flow type) when calculating adjusted mean values.

The significance of artificial flows to movement may be due to the low velocity of irrigation releases, compared to natural flows. Several authors have noted the association of *M. fluviatilis* with slow moving waters (Moffat & Voller 2002, Lintermans 2007). Another reason for higher catches in the fyke and mini-fyke nets (suggesting increased movement) in the Macintyre River could relate to their reproductive strategy. *Melanotaenia fluviatilis* is a highly coloured species with an elaborate courtship display (Lintermans 2007). Lower turbidity could promote greater movement for mate selection.

The influence of hydrography on *M. fluviatilis* movement is complex. They are caught by all gear types predominantly during all stages of flows in the Macintyre River and mainly during falling flows and no flow in the Condamine River. The catch rates of fykes and mini-fykes were higher during base (artificial) flows than all other flows. Only 5% of the total Condamine catch came from fykes and mini-fykes, compared to 18% of the Macintyre River catch. This supports our hypothesis that *M. fluviatilis* is more likely to move in less turbid flowing water. The fyke and mini-fyke catch data also demonstrate a tendency for upstream movement by larger fish with peak movement in spring when *M. fluviatilis* is known to breed. Juveniles were common in boat electrofishing catches, but absent in fyke or mini-fyke catches indicating a lack of movement. These data support our supposition that mesoscale movement by *M. fluviatilis* is related to reproduction.

The mark-recapture data was inconclusive although the largest movement (220 m upstream) coincided with the longest period at large. Electrofishing below barriers in the Condamine River was also inconclusive. There is a possibility of substantial movement by *M. fluviatilis* (1 to 11 km), but fyke and mini-fyke catches were too low to substantiate this. All fish collected below weirs in this study were of adult size (>35 mm TL) which is consistent with upstream codend net catch data from the Macintyre River, suggesting movement had occurred. During other work outside the scope of this study we have observed large aggregations of adult *M. fluviatilis* below Goondiwindi Weir during both artificial (irrigation) and natural flow events.

The absence of *M. fluviatilis* in large numbers from lagoon habitats is contrary to the results of other studies (Closs et al. 2006). Other studies in the area have found *M. fluviatilis* to be common in lagoons adjacent to the Macintyre River (Glenn Wilson⁴, pers. comm. 2005). During this study, we found some evidence of them in lagoons, but not in large numbers. In one brief case of lateral connection, we found no evidence of movement into the lagoon by *M. fluviatilis*, despite being the second most abundant species in the adjacent river. This implies that lateral movement is not obligatory. Dispersal into lagoons might be random and follow large overbank flow events.

3.3.5 Olive perchlet Ambassis agassizii

Over 93% of the *A. agassizii* catch from standard shots came from the Condamine system. The bulk of the catch came from lagoon habitats (90.1%). Within riverine habitats 7.8% of the catch came from the Macintyre River and only 2.1% from the Condamine River. In the Condamine system most of the *A. agassizii* were caught from the large Karreel Lagoon (Zone 5).



Generalised Linear Models

Riverine catches of *A. agassizii* were too low and infrequent in fykes and mini-fykes to run a GLM that would provide insights into movement cues. Fykes and mini-fykes captured a large proportion of the total catch of *A. agassizii*, but most of these were from lagoon habitats. Fykes accounted for 61.4%, mini-fykes 21.9%, boat electrofishing 16% and backpack electrofishing less than 1% of the total *A. agassizii* standard sample catch.

Length-frequency data

Within the riverine habitats catches of *A. agassizii* were too low for any meaningful statistical comparison of length frequencies between codends of fykes and mini-fykes. Electrofishing boat captures were also low but it was possible to compare combined fyke and mini-fyke catch length frequencies with boat electrofishing catch in one instance.

In spring 2005, thirteen *A. agassizii* were captured by combined fykes and mini-fykes in the Macintyre River. Of these, 12 were captured in upstream codends, and their length-frequency distribution is presented in Figure 3.38. In autumn 2007, thirteen fish were caught from the Macintyre River in upstream codends and two in downstream codends. These fish were not significantly different in size distribution to fish captured by boat electrofishing at the same time (p = 0.268, Figure 3.39). All fish captured were from adult size classes.





4 Glenn Wilson, Freshwater Ecology, University of New England.

Figure 3.39: Length-frequency comparison of *A. agassizii* captured by boat electrofishing and combined fykes and mini-fykes in the Macintyre River, autumn 2007. Fyke and mini-fyke *n* = 15, Electrofishing *n* = 7.



Recapture data

There was only one recorded recapture of a VIE-tagged *A. agassizii*. This fish was recorded from Booberoi Lagoon (Zone 8) in the Macintyre system and had moved only 25 m from its release point (Table 3.26).

Table 3.26: Recapture of *A. agassizii* from the Macintyre River system. (L) = lagoon habitat. us = upstream movement.

River	Time at	FL at recapture	Release	Recap	Distance	Direction
	large	(mm)	zone	zone	moved (m)	moved
Macintyre	3 days	57	8A (L)	8A (L)	25	us

Electrofishing below barriers

Captures of A. agassizi were rare in both rivers sampled. Only one *A. agassizii* was captured with backpack electrofishing below Cotswold Weir in Zone 1 of the Condamine River, in autumn 2007. If this fish had moved upstream, then it would have travelled at least 11 km to reach the wall from the next permanent downstream waterhole.

Lagoon captures

Olive perchlets *A. agassizii* were recorded from all lagoon sites sampled in this study. South Callandoon Lagoon (Macintyre Zone 6), Camp David Lagoon (Macintyre Zone 3) and the small Karreel Lagoon (Condamine Zone 4) were all sampled during the pilot work or early in the main phase of the study. Olive perchlets *A. agassizii* were captured from each of these locations for VIE tagging. However, all these lagoons dried in the course of the study and the tagged *A. agassizii* were lost to the study. During the study, a small lagoon (Booberoi Lagoon, Macintyre Zone 8) connected briefly with the Macintyre River during a within-bank flow in January 2006. Post-connection, *A. agassizii* were one of only two native fish species recorded from this lagoon. Fifty-eight *A. agassizii* were captured for tagging (49 during standard shots). Length-frequency distributions of a sub-sample of these fish in early autumn highlight the presence of adult and juvenile size classes (Figure 3.40). Juveniles were absent from river collections (refer to Figures 3.38 and 3.39). Booberoi Lagoon (Zone 8) dried out and all fish in the lagoon were lost.

At times *A. agassizii* were very common in the large Karreel Lagoon (Condamine Zone 5). In winter 2006, a total of 323 *A. agassizii* were captured during standard shots from this lagoon. Length-frequency histograms for spring 2005 catches from this lagoon show, in common with Booberoi Lagoon (Macintyre Zone 8), the presence of juvenile size classes (Figure 3.41) which were absent from adjacent riverine samples.

Figure 3.40: Length-frequency distribution of a sub-sample of *A. agassizii* captured from Booberoi Lagoon in mini-fykes, autumn 2006. *n* = 48.



Figure 3.41: Length-frequency distribution of *A. agassizii* captured by combined fyke and mini-fykes and by boat electrofishing in the large Karreel lagoon, spring 2005. Fyke and mini-fyke *n* = 29, Electrofishing *n* = 9.



Discussion

There were too few *A. agassizii* captured from riverine reaches to make many connections between environmental variables and flow. However, those fish captured in fykes and mini-fykes in the rivers were adult fish and mainly moving in an upstream direction (77%). One fish was captured below Cotswold Weir wall (Condamine Zone 1) and may have moved at least 11 km upstream, but there was no supporting fyke or minifyke evidence from the same sampling trip to support directional movement. Given that so few *A. agassizii* were captured and tagged in the riverine sections, then it is to be expected that there were no recaptures of this species in riverine sites.

The only recaptured *A. agassizii* came from Booberoi Lagoon (Macintyre Zone 8). Various authors have noted the association of *A. agassizii* with wetland/lagoon habitats (Allen 1996b, Moffat & Voller 2002, Closs et al. 2006, Lintermans 2007). Given the rarity of *A. agassizii* in the Macintyre River, and the appearance of this species in relatively large numbers in Booberoi Lagoon after a very brief connection event, migration from the river to the lagoon may be an active behavioural response to lateral connectivity. During non-drought conditions, Booberoi Lagoon might be expected to connect more than once with the river before the end of autumn.

The ability of *A. agassizii* to locate and enter a lagoon on a brief connection event, when more common species like *M. fluviatilis* and *Hypseleotris* spp. did not, suggests that *A. agassizii* may be using olfactory cues to enable them to locate lagoon habitats. This requires further experimental investigation. For example, laboratory-based Y-trough experiments might be able to determine if there is an attraction to lagoon water.

Length-frequency histograms from both the large Karreel Lagoon and Booberoi Lagoon suggest that recruitment of *A. agassizii* occurs in lagoon habitats. Several authors have noted that *A. agassizii* have declined across much of the Murray-Darling Basin (Harris & Gehrke 1997, Morris et al. 2001, Lintermans 2007). In the northern part of the Basin it would appear that access to lagoons may be important for the recruitment of this species. However, prolonged drought and reduced frequency of connection could be putting populations at risk, as the lagoon habitats are drying out before new recruits can be liberated back into the river. The long-term influence of climate change (CSIRO 2007) has been predicted to cause a 10% decline in flow in the Border Rivers Region of the MDB over the next 40 years. This could threaten recruitment opportunities of *A. agassizii* in this area.

Moffat and Voller (2002) reported a reliance of *A. agassizii* on the cover of aquatic vegetation in the northern Basin. Olive perchlets *A. agassizii* in south-eastern Queensland use macrophyte beds for spawning and recruitment (Milton & Arthington 1985). If the same requirements for spawning and recruitment exist in the Murray-Darling Basin, then access to macrophyte habitats may be critical. Post-connection, Booberoi Lagoon had low numbers of carp, clear water and extensive aquatic macrophyte beds – predominantly water primrose Ludwigia peploides and spiny mudgrass Pseudoraphis spinescens (Figure 3.42). This was probably ideal spawning and recruitment habitat for *A. agassizii*.

Figure 3.42: Aquatic macrophytes and clear water in Booberoi Lagoon.



The rise of carp and the associated loss of macrophyte beds in the Murray-Darling Basin may have contributed to the decline of *A. agassizii*. Connections to ephemeral lagoons during spring and summer might offer a chance for *A. agassizii* to spawn and recruit before carp numbers build up in the lagoons and disrupt the lagoon ecosystem. However, for ephemeral lagoon populations of *A. agassizii* to benefit the population as a whole, at least one reconnection event must occur to liberate new recruits back to the river before desiccation of the lagoon.

Further research is needed to investigate the importance of olfactory cues on fish movement, and to investigate how artificial flows can be used to benefit native fish populations. In the case of *A. agassizii* it may be better to combine environmental flows with an irrigation release, or a natural flow event, to increase the total volume of water flowing down the river and create lateral connectivity to some ephemeral lagoons.

3.3.6 Juvenile golden perch Macquaria ambigua

Generalised Linear Models

Eighty-seven per cent of the golden perch *M. ambigua* catch came from the Condamine catchment and 13% from the Macintyre catchment. Only 1% of the catch came from lagoon habitats. Backpack electrofishing captured 11%, fyke netting 24%, mini-fyke netting 14% and boat electrofishing 51% of the total *M. ambigua* standard shot catch.



An all gear binomial GLM with logit link function for captures of *M. ambigua* explained 42.64% of the deviance. A summary of the model including main effects, interactions and levels of significance is presented in Table 3.27. The conditional gamma model with log link function for the same data is presented in Table 3.28. This model explained 43.98% of the deviance. In the binomial model, all main effects excluding moon phase were significant, whereas in the gamma model, substrate and season were not significant. Moon phase was just outside the 5% significance level in the gamma model. The only significant two-way interactions were in the gamma model. These were flow type by moon phase and flow type by season.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Flow type	1	65.4603	65.4603	65.46	<0.001
Hydrography	5	162.2313	32.4463	32.45	<0.001
Gear	5	125.0525	25.0105	25.01	<0.001
River	1	22.0728	22.0728	22.07	<0.001
Season	2	6.2446	3.1223	3.12	0.044
Substrate	5	11.5681	2.3136	2.31	0.041
Moon phase	3	4.0819	1.3606	1.36	0.253
Flow type.season	1	2.8968	2.8968	2.90	0.089
Gear.season	8	9.8274	1.2284	1.23	0.277
Gear.hydrography	24	28.6901	1.1954	1.20	0.232
Flow type.Moon phase	2	1.2776	0.6388	0.64	0.528
Residual	931	591.1029	0.6349		
Total	988	1030.5062	1.0430		

Table 3.27: Summary of analysis for binomial distribution GLM (with logit link function) of *M. ambigua* catches. Gear includes all six gear types. Significant factors are given in *italics*.

Table 3.28: Summary of analysis for conditional gamma distribution GLM (with log link function) of *M. ambigua* catches. Gear includes all six gear types. Significant factors are given in *italics*.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	5	21.5268	4.3054	9.48	<0.001
Flow type	1	2.8256	2.8256	6.22	0.014
River	1	2.4317	2.4317	5.36	0.022
Hydrography	5	5.8584	1.1717	2.58	0.028
Moon phase	3	3.5362	1.1787	2.60	0.054
Season	2	0.5861	0.2931	0.65	0.526
Substrate	5	1.4789	0.2958	0.65	0.661
Flow type.Moon phase	2	6.6328	3.3164	7.30	<0.001
Flow type.season	1	2.8955	2.8955	6.38	0.013
Gear.hydrography	15	9.2429	0.6162	1.36	0.174
Gear.season	8	1.4480	0.1810	0.40	0.920
Residual	164	74.4663	0.4541		
Total	212	132.9293	0.6270		

Figure 3.43 shows the catch rates of fykes, mini-fykes and boat electrofishing under different hydrological conditions. For most riverine conditions (excluding base flows) the electrofishing catch rate was fairly constant, but fyke and mini-fyke catches (particularly mini-fykes) tended to be higher during flow periods (excluding base flows) than during no flow periods. Downstream codend catches were higher than upstream codend catches during falling flows. Base flows were only recorded in the Macintyre River where the abundance of *M. ambigua* tended to be lower compared to the Condamine River.

Figure 3.43: Catch rates of *M. ambigua* by gear and hydrography. Adjusted mean values were calculated from binomial x conditional gamma GLMs. All other variables in the model have been held constant. Error bars represent one standard error of the mean. Results should be viewed as trends in the data rather than predictions.



The corresponding fyke and mini-fyke binomial and conditional gamma GLM for *M. ambigua* are presented in Tables 3.29 and 3.30. The binomial model explained 37.82% of the deviance and the conditional gamma model explained 54.55% of the deviance. Flow type, season and moon phase were all significant in at least one of the two GLM while hydrography and gear were statistically significant in both. Adjusted mean catch rates for season (Figure 3.44), flow type (Figure 3.45), and moon phase (Figure 3.46) were derived from the combined binomial x gamma models. When adjusted for other factors, catch rates were highest during autumn, and autumn differed significantly from winter, but not spring. Catch rates were significantly higher on natural flows. Catches were very low on the full moon and highest during the first quarter of the moon. There was not much difference between the third quarter and new moon. Trends in mini-fyke and fyke catch rates by hydrography are represented by the patterns in Figure 3.43.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Flow type	1	60.0505	60.0505	60.05	<0.001
River	1	27.1844	27.1844	27.18	<0.001
Hydrography	5	79.6985	15.9397	15.94	<0.001
Season	2	10.6328	5.3164	5.32	0.005
Gear	3	8.5334	2.8445	2.84	<0.036
Moon phase	3	5.2176	1.7392	1.74	0.157
Substrate	5	6.7720	1.3544	1.35	0.238
Flow type.season	1	4.1697	4.1697	4.17	0.041
Flow type.Moon phase	2	4.4242	2.2121	2.21	0.109
Gear.hydrography	15	15.4354	1.0290	1.03	0.421
Gear.season	6	6.2886	1.0481	1.05	0.392
Residual	718	375.5378	0.5230		
Total	762	603.9450	0.7926		

Table 3.29: Summary of analysis for binomial distribution GLM (with logit link function) of <i>M. ambigua</i>
catches. Gear includes fyke and mini-fyke upstream and downstream codends only. Significant factors
are given in <i>italics</i> .

Table 3.30: Summary of analysis for conditional gamma distribution GLM (with log link function) of *M. ambigua* catches. Gear includes fyke and mini-fyke upstream and downstream codends only. # indicates variable not fitted by model due to aliasing. Significant factors are given in *italics*.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	3	5.9591	1.9864	5.94	<0.001
Hydrography	5	8.2870	1.6574	4.96	<0.001
Moon phase	3	3.6907	1.2302	3.68	0.016
Flow type	1	1.2112	1.2112	3.62	0.061
Season	2	1.2209	0.6104	1.83	0.169
Substrate	5	0.7663	0.1533	0.46	0.806
River#	0	0	*		
Gear.hydrography	9	4.3318	0.4813	1.44	0.189
Gear.season	6	1.3834	0.2306	0.69	0.658
Flow type.season	1	0.0230	0.0230	0.07	0.794
Flow type.Moon phase#	0	0	*		
Residual	164	22.3926	0.3342		
Total	212	49.2659	0.4830		

Figure 3.44: Adjusted mean catch rates of *M. ambigua* by season as calculated by binomial x gamma GLMs for fyke and mini-fyke data. Error bars show one standard error of the mean. Other variables in the model have been held constant. Values should be viewed as trends in the data rather than as predictions of catch.



Figure 3.45: Adjusted mean catch rates of *M. ambigua* by flow type as calculated by binomial x gamma GLMs for fyke and mini-fyke data. Error bars show one standard error of the mean. Other variables in the model have been held constant. Values should be viewed as trends in the data rather than as predictions of catch.





Figure 3.46: Adjusted mean catch rates of *M. ambigua* by moon phase as calculated by binomial x gamma GLMs for fyke and mini-fyke data. Error bars show one standard error of the mean. Other variables in the model have been held constant. Values should be viewed as trends in the data rather than as predictions of catch.



Length-frequency data

Catch rates of *M. ambigua* from the Macintyre River were too low for meaningful length-frequency analyses. Some Condamine samples had sufficient captures for length-frequency comparisons. In most flow conditions in the Condamine River there were no significant differences between the size distribution of *M. ambigua* captured in upstream codends and downstream codends of fykes and mini-fykes (Table 3.31). One exception was during a falling flow in the Condamine River during spring 2005 (p = 0.01), when fish moving downstream tended to be smaller, but the sample size was small (Figure 3.47).

There were also no significant differences in the size distribution of *M. ambigua* captured by combined minifykes and fykes compared to boat electrofishing in most situations (Table 3.32). There were two exceptions where boat electrofishing and combined fyke-mini-fyke captures had different size distributions. The first was for no flow conditions in spring 2005 (p<0.001) when smaller size classes were under-represented in the fyke and mini-fyke catches compared to the electrofishing results (Figure 3.48). The second was for falling flows during autumn 2006, when smaller size classes were more strongly represented in the combined fyke and mini-fyke catch (Figure 3.49), than in the boat electrofishing catch (p = 0.006).

Sample	Kolmogorov-Smirnov two-sample test probability and sample size
Condamine, no flow, spring 2005	p = 0.509 upstream $n = 12$ downstream $n = 11$
Condamine, falling flow, aut 2006	p = 0.409 upstream $n = 15$ downstream $n = 62$
Condamine, no flow, winter 2006	p = 0.766 upstream $n = 8$ downstream $n = 12$
Condamine, rising/peak flows aut 2006	p = 0.317 upstream $n = 8$ downstream $n = 11$
Condamine, falling flow aut 2007	p = 0.301 upstream $n = 6$ downstream $n = 10$

Table 3.31: Probability of no significant difference between the length-frequency distributions of *M. ambigua* captured in upstream and downstream codends on various flow events in the Condamine River.

Figure 3.47: Length-frequency comparison of *M. ambigua* captured in upstream and downstream codends of combined fykes and mini-fykes during a falling flow, Condamine River, spring 2005. Upstream n = 10, Downstream n = 4.



Table 3.32: Probability of no significant difference between the length-frequency distributions of*M. ambigua* captured by combined fykes and mini-fykes and by boat electrofishing on various flow eventsin the Condamine River.

Sample	Kolmogorov-Smirnov two-sample test probability and sample size
Condamine, falling flow, spring 2005	<i>p</i> = 0.232 fyke & m-fyke <i>n</i> = 14 boat e.f. <i>n</i> = 22
Condamine, rising/peak flows aut 2006	<i>p</i> = 0.440 fyke & m-fyke <i>n</i> = 18 boat e.f. <i>n</i> = 26
Condamine, no flow winter 2006	<i>p</i> = 0.198 fyke & m-fyke <i>n</i> = 20 boat e.f. <i>n</i> = 25
Condamine, falling flow aut 2007	<i>p</i> = 0.368 fyke & m-fyke <i>n</i> = 16 boat e.f. <i>n</i> = 16
Condamine, no flow aut 2007	<i>p</i> = 0.319 fyke & m-fyke <i>n</i> = 4 boat e.f. <i>n</i> = 14

Figure 3.48: Length-frequency comparison of *M. ambigua* captured by combined fykes and mini-fykes and by boat electrofishing during no flow conditions, Condamine River, spring 2005. Fyke & mini-fyke n = 23, Electrofishing n = 52.



Figure 3.49: Length-frequency comparison of *M. ambigua* captured by combined fykes and mini-fykes and by boat electrofishing during a falling flow, Condamine River, autumn 2006. Fyke & mini-fyke *n* = 77, Electrofishing *n* = 31.



Recapture data

Recaptures of VIE-tagged and PIT-tagged *M. ambigua* are summarised in Tables 3.33 and 3.34. Juvenile and sub-adult *M. ambigua* (<200 mm TL) were targeted for tagging, and most had grown by time of recapture. All recaptured golden perch had moved downstream. Distances ranged from 55 m to 1 km. There were no inflows of water into the Condamine River Zone 7 during the period that the recaptured VIE-tagged fish was at large. The PIT-tagged fish from the Macintyre River was recaptured twice, once 100 m downstream from its release point, and a second time a further 110 m downstream from the second release point (total movement 210 m ds).

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River	Time at	FL at	Release	Recap	Distance	Direction
	large	recapture mm	zone	zone	moved m	moved
Condamine	3 to 5 months	55	7A	7A	150	Ds

Table 3.34: PIT-tagged <i>M. ambigua</i> recaptures in the Macintyre and Condamine Rivers
ds = downstream movement

River	Time at large	TL at recapture mm	Release zone	Recap zone	Distance moved m	Direction moved
Macintyre	2 months	234	1D	1D	100	ds
Macintyre	2 months	234	1D	1D	(+110) 210	ds
Condamine	1 day	120	7C	7C	210	ds
Condamine	7 months	189	1A	1C	800	ds
Condamine	9½ months	175	7C	7C	55	ds
Condamine	12 months	266	1B	ds 1C	345	ds
Condamine	7 months	140	1B	1D	1000	ds

Electrofishing below barriers

There is evidence that *M. ambigua* accumulate below weirs during flows in the Condamine River. Twentysix juvenile *M. ambigua* (54 to 87 mm TL) were captured by backpack electrofishing below Cotswold Weir (Condamine River Zone 1) during a falling flow, representing a potential upstream movement of 11 km. During the same flow only six *M. ambigua* were captured in upstream codends (Figure 3.50). Their size distribution was not significantly different to the backpack-caught fish (p = 0.236). However, upstream and downstream codend catches were not significantly different. Another three juvenile *M. ambigua* (<40 mm TL) were caught below Reilly's Weir on a rising, but minor flow that topped the weir on the previous day. These fish may have moved 0.9 km to 2.4 km upstream. Figure 3.50: Length frequencies of *M. ambigua* captured below Cotswold Weir, Condamine River on a falling flow, autumn 2007, compared to length frequencies of *M. ambigua* captured in upstream codends on the same flow. Backpack *n* = 26, Upstream *n* = 6.



Lagoon captures

Golden perch were rare or absent in lagoons sampled, with only five captured during standard shots in the large Karreel Lagoon over three years. None were recorded from the other lagoons sampled. In contrast, golden perch were reasonably common in the Condamine River.

Discussion

The electrofishing catch of *M. ambigua* was consistent across all riverine hydrographical conditions, excluding base flows (Figure 3.43). Artificial base flows were only recorded in the Macintyre River, so this may have influenced the lower adjusted mean value for that hydrographical condition. During no flow conditions in the river, fyke and mini-fyke catch rates were low, but one or more of the mini-fyke or fyke codends showed increased catch rates during all flows except artificial base flows (Figure 3.43). This suggests that fykes and mini-fykes were detecting movement in different directions.

Hydrography was one of the significant factors identified by the binomial and gamma GLMs for mini-fyke and fyke only data. In common with most other species in this study, there was a tendency for more *M. ambigua* to be caught in downstream codends in both fykes and mini-fykes on falling flows. The trend was not quite as marked in this species, with a reasonable proportion of fish captured moving the opposite direction. As for other species we hypothesise that the downstream movement of a falling flow is a response to avoid desiccation.

However, being a larger bodied species than most others studied, the swimming abilities of golden perch may enable some individuals to move upstream rapidly enough to reach refugia before becoming stranded by a falling flow. On peak flows there was a tendency for more fish to be captured in downstream codends of mini-fykes, and in downstream codends of fykes on rising flows, possibly indicating different movement behaviours for different size ranges of *M. ambigua*. However, this was not a strong trend for all hydrographical conditions in riverine habitats because low numbers of *M. ambigua* were captured in codends of both gears.

The tendency for more juvenile and sub-adult *M. ambigua* to move downstream rather than upstream is also supported by the recapture data. All tagged fish were recaptured downstream of their release point. Downstream migratory behaviour has previously been reported for adult *M. ambigua* (Reynolds 1983, Koehn & Nicol 1998, O'Connor et al. 2004, 2005, 2006). The latter found more than half of the *M. ambigua* tracked by them moved over 10 km downstream.

Season was a significant factor identified by the binomial GLM. Adjusted mean values (as calculated by the binomial x gamma models) for fyke and mini-fyke captures of golden perch suggest less movement in winter, with increased movement in spring and autumn. Due to drought conditions and high summer water temperatures, the study could not evaluate movements in summer, but our results are consistent with findings for adult golden perch by O'Connor et al. (2004, 2005). They reported reduced movement in winter with long distance movements performed between September and December.

In contrast, Koehn and Nicol (1998) reported movement at any time of the year. We do not dispute that movement may occur at any time of the year, but we suggest movement is more frequent in the warmer months in juvenile and sub-adult *M. ambigua*. Peak movement during autumn flows (Figure 3.44) in the northern Basin could be a useful behavioural adaptation to enable dispersal to refugia prior to the onset of the winter and early spring dry season.

Consistent with the results for *Hypseleotris* spp., *N. erebi* and *L. unicolor*, there was a tendency for more movement on natural flows compared to releases from upstream dams. This raises the question of difference between natural and artificial flows, and how fish differentiate between the two. Is it magnitude, timing or chemical cues that drive these native fish to differentiate between natural and artificial flows?

Environmental flows may serve a number of purposes, including maintaining pool refugia and access to critical habitats for breeding or juvenile recruitment. However, if fish are to gain maximum benefit from environmental flows, there is a need to better understand how to manage these flows. Further research is needed to investigate the importance of olfactory cues on fish movement. For example, it may be favourable to link environmental flows to natural rainfall events, such that some natural run-off and the associated odours that cue movement are incorporated into the flow release.

Moon phase has emerged as a significant factor explaining catch of *M. ambigua* in fykes and mini-fykes. After adjusting for other factors the binomial x gamma GLMs suggested peak catches in fykes and mini-fykes corresponded with the first quarter of the moon and low catches were associated with the full moon. Whether this was a function of improved avoidance of fykes during moonlit conditions or an actual lunar effect on movement behaviour is unclear. In the Condamine River, it would be expected that prevailing high turbidity levels should have countered any gear avoidance effect of moon on gear efficiency.

As discussed earlier in this chapter, moon phase has been linked to behaviours of other fish species, but the literature reports mainly of marine and estuarine environments. Moon phase is worthy of further investigation to separate movement behaviour effects of the moon from gear avoidance effects. In sub-adult *M. ambigua* such a study may be achievable using radiotelemetry.

Generally there was no significant difference in the size of *M. ambigua* moving upstream or downstream. When there was a difference, it was related to a greater proportion of smaller individuals in downstream codends. We conclude that all size classes make movements in both directions, but small (25 mm TL) juveniles might get displaced downstream on occasions. Although the fyke and mini-fyke catches show *M. ambigua* move both directions, there is a tendency for more fish to move downstream. The VIE and PIT tag recaptures support this. Some of the PIT-tagged fish had moved from the Cotswold Weir pool to sites downstream of the weir. The longest of these downstream movements was 1000 m. These PIT-tagged fish were not recaptured at the base of the weir, but in pools further downstream. If these fish did want to make a return migration upstream, then they would not be able to pass upstream of the weir wall except during over-bank flood flows.

Long-distance upstream migration by adult *M. ambigua* has been highlighted by Reynolds (1983). The fyke and mini-fyke data from this study suggest that a proportion of the juvenile and sub-adult population of *M. ambigua* also move upstream. Mallen-Cooper et al. (1995) has recorded small *M. ambigua* moving upstream through a fishway in response to small flow events. We suggest that the *M. ambigua* collected accumulating below Cotswold Weir were also attempting to move upstream. As the river was completely dry for 11 km below the weir prior to the autumn 2007 flow, this is evidence that juvenile *M. ambigua* between 50 and 90 mm (TL) can make substantial upstream movements. The capture of three *M. ambigua* < 40 mm (TL) below Reilly's Weir suggests that these smaller fish are capable of upstream movements of between 0.9 km and 2.4 km within two days.

The absence of *M. ambigua* from most lagoon sites suggests that lateral movements are not obligatory. We suggest *M. ambigua* probably reach lagoon sites by random dispersal during flood events.

3.3.7 Dwarf flathead gudgeon Philypnodon macrostomus

All of the *P. macrostomus* in this study were captured from riverine habitats. Backpack electrofishing captured 7% below weirs during falling flows. Minifykes accounted for 30% of the catch of which most came from the upstream codend (96%). Boat electrofishing accounted for 63% of the total catch.



Generalised Linear Models

During this study *P. macrostomus* were collected only from the Condamine River therefore the terms "river" and "flow type" were excluded from the GLMs. A binomial GLM for captures of *P. macrostomus*, run for all gear types, included the following main effects and interactions: gear, season, hydrography, substrate, moon phase, gear by hydrography and gear by season. Of these, gear, season, hydrography and moon phase were all significant. The model, summarised in Table 3.35, explained 57.06% of the deviance. A corresponding conditional gamma GLM for all gear types explained 71.49% of the deviance. Significant factors, summarised in Table 3.36, were consistent with the binomial model. As both models are all gear models, significant factors do not necessarily relate to movement behaviour because the majority of the catch (63%) was taken by boat electrofishing which infers presence or absence, rather than directional movement.

Captures of *P. macrostomus* varied significantly (*p*<0.001) between different gears and hydrography in the Condamine River. Peak catches were associated with falling flows in the downstream codends of mini-fykes (Figure 3.51). Higher catch rates by boat electrofishing also occurred on falling flows. However, they also occurred during a no flow periods. There were no catches of *P. macrostomus* in any fyke gear during this study.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	5	96.7473	19.3495	19.35	<0.001
Hydrography	4	34.6546	8.6636	8.66	<0.001
Season	2	11.9216	5.9608	5.96	0.003
Moon phase	3	8.4658	2.8219	2.82	0.037
Substrate	5	6.1115	1.2223	1.22	0.296
Gear.season	8	9.5617	1.1952	1.20	0.297
Gear.hydrography	19	17.3890	0.9152	0.92	0.564
Residual	493	139.1049	0.2822		
Total	539	323.9563	0.6010		

Table 3.35: Summary of analysis of binomial distribution GLM (with logit link function) of *P. macrostomus* catches. Gear includes all six gear types. Significant factors are given in *italics*.

Table 3.36: Summary of analysis of conditional gamma distribution GLM (with log link function) of *P. macrostomus* catches. Gear includes all six gear types. Significant factors are given in *italics*.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	3	15.9083	5.3028	9.43	<0.001
Hydrography	2	8.2320	4.1160	7.32	0.002
Moon phase	3	9.3060	3.1020	5.52	0.004
Season	2	3.9264	1.9632	3.49	0.043
Substrate	3	2.9446	0.9815	1.75	0.178
Gear.season	1	1.3801	1.3801	2.45	0.127
Gear.hydrography	2	2.0614	1.0307	1.83	0.177
Residual	31	17.4328	0.5623		
Total	47	61.1915	1.3019		

Figure 3.51: Adjusted mean capture rates of *P. macrostomus* by mini-fykes and boat electrofishing during different hydrological conditions in the Condamine River. Values were calculated from the binomial x conditional gamma GLMs for all gear types. Other variables in the model have been held constant. Error bars represent one standard error of the mean. Values should be viewed as trends in the data rather than as predictions of catch.



Captures of *P. macrostomus* by net gears were too infrequent to run a gamma GLM restricted to only fyke and mini-fyke data. However, the binomial GLM was significant, explaining 32.92% of the deviance. The terms of the model included Gear, Moon, Hydrography, Substrate and Season. As with the all gear GLM, in the fyke and mini-fyke model, hydrography was the only significant variable (Table 3.37), although gear by hydrography was nearly significant (p = 0.058). The failure of the gamma GLM has restricted our ability to produce any binomial by gamma catch predictions.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Hydrography	5	26.6999	5.3400	5.34	<0.001
Substrate	5	6.5650	1.3130	1.31	0.255
Season	2	2.5108	1.2554	1.26	0.285
Moon phase	3	3.9097	1.3032	1.30	0.271
Gear	3	1.0645	0.3548	0.35	0.786
Gear.hydrography	15	24.4149	1.6277	1.63	0.058
Gear.season	6	7.2871	1.2145	1.21	0.295
Residual	723	147.6389	0.2042		
Total	762	220.0909	0.2888		

Table 3.37: Summary of analysis of binomial distribution GLM (with logit link function) of *P. macrostomus* catches. Gear includes fyke and mini-fyke data only. Significant factors are given in *italics*.

Length-frequency data

Philypnodon macrostomus were not recorded from the Macintyre River and captured only occasionally in the Condamine River. There were only a few occasions when sufficient numbers were captured to analyse length frequencies. In spring 2005, during no flow conditions a range of size classes were captured by boat electrofishing (Figure 3.52) but only one fish was captured in mini-fykes. During a falling flow in spring 2005, *P. macrostomus* were captured in downstream codends of mini-fykes. These fish were significantly smaller than fish captured by boat electrofishing in the same reach at the same time (*p*<0.001, see Figure 3.53).

Figure 3.52: Length-frequency histogram of *P. macrostomus* captured by boat electrofishing and mini-fykes during no flow conditions, Condamine River, spring 2005. Electrofishing *n* = 55, Mini-fyke *n* = 1.



Figure 3.53: Length-frequency histogram of *P. macrostomus* captured by boat electrofishing and mini-fykes during a falling flow, Condamine River, spring 2005. Electrofishing *n* = 21, Mini-fyke *n* = 52.



Recapture data

Very few *P. macrostomus* were tagged (26). Most captured fish were too small for tagging and none of the tagged fish were recaptured.

Electrofishing below barriers

In autumn 2007, a small number of *P. macrostomus* were captured by backpack electrofishing below Cotswold Weir. These fish had proportionally fewer small size classes (p = 0.023) than fish captured from pools in the same reach by boat electrofishing (Figure 3.54). Only four *P. macrostomus* were captured at the same time in mini-fykes. All were in downstream codends and all were between 21 and 28°mm total length, whereas the backpack-caught fish ranged from 21 to 36 mm, with a modal length of 32 mm.

Figure 3.54: Length-frequency histogram of *P. macrostomus* captured by boat electrofishing in river pools and by backpack electrofishing below Cotswold Weir during a falling flow, Condamine River, autumn 2007. Boat n = 43, Backpack n = 15.



Lagoon captures

No P. macrostomus were captured in lagoons during the course of this study.

Discussion

Most of the *P. macrostomus* catch from mini-fykes came from a falling flow during late spring 2005, and consisted of individuals from 15 to 29 mm (TL). All were caught in downstream codends. The peak electrofishing catch of *P. macrostomus* occurred on the same sampling trip, although the electrofishing catch rate was lower than the mini-fyke catch rate. *P. macrostomus* are reported to spawn in late winter to early spring (Llewellyn 1971, 1983) and it would appear there was good recruitment during spring 2005 leading to increased catches. The length-frequency distribution of *P. macrostomus* in the downstream codends was comprised of a significantly greater proportion of smaller sizes than that of *P. macrostomus* captured by boat electrofishing. This suggests either downstream displacement of smaller individuals by the flow, or an active downstream migration by smaller individuals on a falling flow. Most of the other species covered by this study also showed a tendency for downstream movement on falling flows. As we have discussed previously, the possibility of downstream movement on falling flows being an adaptive movement to avoid desiccation is common to several other species covered in this report.

During all other flows (including no flow periods) there were very few or no *P. macrostomus* captured in minifykes. Electrofishing catch rates exceeded mini-fyke catch rates during no flow periods. This indicates that although *P. macrostomus* were present, they were not moving.

There is no evidence for upstream movement by *P. macrostomus* from the mini-fyke data although 15 were captured immediately below Cotswold Weir (Condamine Zone 1) in autumn 2007. This is evidence supporting an upstream movement of 11 km. The significantly larger size of these fish, compared to fish captured by boat electrofishing in adjacent sites, and the tendency for downstream codend fish to be smaller in size, supports the hypothesis that these individuals were adults undertaking an upstream mesoscale migration. Fish captured in downstream mini-fyke codends in spring were smaller in size than the general population caught by boat electrofishing at the same time, suggesting that downstream movement in spring is likely to consist primarily of smaller individuals. Further research is needed to ascertain whether this is a juvenile recruitment-related movement, or downstream displacement.

3.3.8 Hyrtl's tandan Neosilurus hyrtlii

Hyrtl's tandan *N. hyrtlii* were caught only in the Condamine River system, predominantly by mini-fykes (84.8%) during standard shots. Only 2.4% were captured by boat electrofishing, 4.8% by fykes and 8% by backpack electrofishing. This species was patchily distributed in the Condamine River, with all riverine captures (85.6%) coming from Zones 1 and 7, during standard shots. The remainder of the catch (14.4%) came from the large Karreel Lagoon (Zone 5).



Generalised Linear Models

Captures of Neosilurus hyrtlii were too infrequent for analysis by GLM.

Length-frequency data

Captures of *Neosilurus hyrtlii* were generally too low for length-frequency analyses. However, in spring 2005 on a falling flow in the Condamine River, sufficient numbers were captured for a length-frequency comparison of fish from upstream and downstream codends. There was a significant difference between the two groups (Kolmogorov-Smirnov two-sample test p<0.001). Mostly juvenile fish (mean = 25 mm TL, 95% c.i. = 2 mm) were caught in downstream codends, and adult fish (mean = 187 mm TL, 95% c.i. = 8 mm) were captured in upstream codends (Figure 3.55).

Figure 3.55: Length-frequency comparison of *N. hyrtlii* captured moving upstream and downstream by combined fykes and mini-fykes, on a falling flow, Condamine River, spring 2005. Upstream n = 21, Downstream n = 45.



Recapture data

Excluding recaptures in the small Karreel Lagoon (Condamine Zone 4) during the pilot study, only one tagged *N. hyrtlii* was recaptured during this study (Table 3.38).

	Table 3.38: Recar	oture of PIT-tagged /	N. hyrtlii in the	Condamine River.	ds = downstream movement
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River	Time at	TL at recapture	Release	Recap	Distance moved	Direction
	large	mm	zone	zone	m	moved
Condamine	6 months	161	1C	ds 1C	190	ds

Electrofishing below barriers

One *N. hyrtlii* was captured by backpack electrofishing below Cotswold Weir in autumn 2007 and five were captured in the same way below the same weir in autumn 2006. All were juveniles (66 to 109 mm TL).

Lagoon captures

Neosilurus hyrtlii were captured in both the large and small Karreel Lagoons. Eighteen were captured from the large Karreel Lagoon (Condamine Zone 5) during standard shots and some more were collected there for tagging. Eight *N. hyrtlii* were captured from the small Karreel Lagoon (Condamine Zone 4) for tagging during the pilot study.

Discussion

Hyrtl's tandan *N. hyrtlii* is a benthic species which rarely floats following electrofishing. As the waters of the Condamine River were highly turbid, this probably explains why few *N. hyrtlii* were captured by boat electrofishing compared to mini-fykes. The relatively high catch of this species by mini-fykes does suggest some movement or foraging activity was taking place. However, the rarity of this species and its patchy distribution made it difficult to identify any meaningful patterns using statistical methods. The one exception was during a falling flow in spring 2005.

There was a very distinct separation in the size of fish moving upstream from those moving downstream. Upstream migrants were all adult fish whereas downstream migrants were predominantly juveniles. Some species of fish may migrate upstream for breeding, to counter the downstream drift of eggs and larvae (Reynolds 1983, Mazzoni et al. 2004). Upstream spawning migration by *N. hyrtlii* has been reported in the Ross River in Queensland (Orr & Milward 1984). In the Fitzroy River, Central Queensland, upstream movements by *N. hyrtlii* through a fishway have been reported to take place in summer and early autumn (Stuart 1997). It is possible that the small *N. hyrtlii* captured in mini-fyke downstream codends were being displaced downstream by the current. They do not appear to be strong swimmers, compared to native Perciformes. *Neosilurus hyrtlii* captured below the weir in autumn 2006 were of intermediate size between the upstream migrating adults and the downstream moving juveniles captured in mini-fyke nets in spring 2005. We suggest that these fish (66-109 mm TL) represent the recruitment pulse captured moving downstream in spring which, by autumn 2006, had grown to be capable of moving back upstream.

Hyrtl's tandan *N. hyrtlii* were present in both lagoons studied in the Condamine system. Therefore some lateral movement by this species must occur during connection events. Given that *N. hyrtlii* are not common in the adjacent river, it is possible that they may actively move into the lagoon habitats. However, some *N. hyrtlii* captured in the lagoons were juveniles, and as there had been no recent lateral connection we conclude that some recruitment of *N. hyrtlii* takes place in lagoon habitats. Juvenile *N. hyrtlii* are reported to be common in lagoons in the Alligator River catchment, Northern Territory (Bishop et al. 2001). The large catch of juveniles in the Condamine River during spring 2005 shows that recruitment also takes place in riverine habitats. Therefore lateral movement into lagoon systems is probably not obligatory for survival of this species in the northern Murray-Darling Basin, but may still be beneficial.

3.3.9 Other species: Australian smelt *Retropinna semoni*, silver perch *Bidyanus bidyanus*, juvenile Murray cod *Maccullochella peelii peelii*, eel-tailed catfish *Tandanus tandanus* and un-specked hardyhead *Craterocephalus stercusmuscarum fulvus*

Generalised Linear Models

Overall, 344 Australian smelt *Retropinna semoni* were caught during standard seasonal sampling in the Condamine River and a further 16 in the Macintyre River. This was sufficient to run binomial and conditional gamma GLMs for the Condamine River data. However, there were insufficient captures to run meaningful models for fyke and mini-fyke only, and insufficient captures of the remaining species to justify any statistical analyses. The all gear binomial and conditional gamma models for *R. semoni* are shown in Tables 3.39 and 3.40. The binomial model explained 64.41% of the deviance and the conditional gamma model explained 49.63% of the deviance. Gear and moon phase were significant to both models. It can be seen that the passive sampling technique of mini-fykes caught far fewer fish than the active technique of boat electrofishing (Figure 3.56).

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	5	180.4856	36.0971	36.10	<0.001
Hydrography	4	40.1240	10.0310	10.03	<0.001
Season	2	10.2931	5.1465	5.15	0.006
Moon phase	3	9.4054	3.1351	3.14	0.024
Substrate	5	5.8103	1.1621	1.16	0.325
Gear.Hydrography	19	7.4065	0.3898	0.39	0.992
Gear.Season	8	13.2244	1.6530	1.65	0.104
Hydrography.Season	3	10.6886	3.5629	3.56	0.014
Gear.Moon phase	13	2.9657	0.2281	0.23	0.998
Moon phase.Hydrography	3	2.0104	0.6701	0.67	0.570
Moon phase.Season#	0	0	*		
Gear.Substrate	12	1.3583	0.1132	0.11	1.000
Hydrography.Substrate	10	2.5680	0.2568	0.26	0.990
Substrate.Season	7	3.1937	0.4568	0.46	0.866
Moon phase.substrate	9	0.0001	0.0000	0.00	1.000
Residual	436	159.9914	0.3670		
Total	539	449.5289	0.8340		

Table 3.39: Summary of analysis of binomial distribution GLM (with logit link function) of *R. semoni* catches. Gear includes all six gear types. Significant factors are given in *italics*. # indicates variable could not be fitted due to aliasing.

Table 3.40: Summary of analysis of conditional gamma distribution GLM (with log link function) of *R. semoni* catches. Gear includes all six gear types. Significant factors are given in *italics*. *#* indicates variable could not be fitted due to aliasing.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx F pr.
Gear	4	17.7873	4.4468	5.77	<0.001
Moon phase	3	11.3533	3.7844	4.91	0.004
Season	2	3.6524	1.8262	2.37	0.103
Hydrography	4	2.6632	0.6658	0.86	0.491
Substrate	4	0.8670	0.2167	0.28	0.889
Gear.Moon phase	3	1.1859	0.3953	0.51	0.675
Gear.Season	1	0.4410	0.4410	0.57	0.453
Season. Moon phase#	0	0	*		
Gear.Hydrography	1	0.3141	0.3141	0.41	0.526
Moon phase.Hydrography	2	3.9502	1.9751	2.56	0.086
Season. Hydrography#	0	0	*		
Gear.Substrate#	0	0	*		
Moon phase.Substrate	1	0.0000	0.0000	0.00	*
Substrate.Season#	0	0	*		
Hydrography.Substrate#	0	0	*		
Residual	54	41.5905	0.7702		
Total	78	83.8048	1.0744		

Figure 3.56: Adjusted mean catch rates of *R. semoni* by mini-fykes and electrofishing as calculated by the binomial x gamma GLMs. All other variables in the model have been held constant. Error bars show one standard error of the mean. Values should be viewed as trends in the data rather than as predictions of catch.



Length-frequency data

Captures of smelt *Retropinna semoni*, silver perch *B. bidyanus*, Murray cod juveniles and sub-adults *M. p. peelii*, eel-tailed catfish *T. tandanus* and un-specked hardyhead *C. s. fulvus* were not frequent enough in fykes or mini-fykes to merit any length-frequency analyses for the different rivers and different flow events that could be related to movement patterns.

Recapture data

There were few recaptures of tagged *B. bidyanus*, juvenile *M. p. peelii* and *T. tandanus*. Of these three species, *M. p. peelii* had the greatest number of individuals tagged and *B. bidyanus* the least. Distances moved by recaptured fish of these species are shown in Tables 3.41 to 3.43.

Table 3.41: Recapture of PIT-tagged *B. bidyanus* in the Macintyre River.

ds = downstream movement.

River	Time at	FL at recapture	Release	Recap	Distance moved	Direction
	large	mm	zone	zone	m	moved
Macintyre	2 months	57	1A	1B	1065	ds

Table 3.42: Recaptures of PIT-tagged *M. p. peelii* in the Macintyre River.

us = upstream movement. as = across-stream movement.

River	Time at large	TL at recapture mm	Release zone	Recap zone	Distance moved m	Direction moved
Macintyre	10 months	163	5D	5D	110	us
Macintyre	9 months	159	5C	5C	25	as

Table 3.43: Recapture of PIT-tagged *T. tandanus* in the Condamine River.

as = across-stream movement.

River	Time at	TL at recapture	Release	Recap	Distance moved	Direction
	large	mm	zone	zone	m	moved
Condamine	6 months	428	3C	3C	25	as

Electrofishing below barriers

Only one juvenile Murray cod *M. p. peelii* (67 mm TL) was captured by backpack electrofishing below a weir. Four *T. tandanus* were captured below Cotswold Weir on a falling flow in autumn 2006. Three of these were juveniles (57, 62 and 70 mm TL) and the other was an adult (306 mm TL). In autumn 2007, one *R. semoni* (41 mm FL) was captured below Reilly's Weir and four were captured below Cotswold Weir (37 to 56 mm FL). These were all in the larger size range for their population. No *B. bidyanus* or *C. s. fulvus* were captured below weirs.

Lagoon captures

Smelt *R. semoni* and catfish *T. tandanus* were captured in lagoons. Thirteen *R. semoni* were recorded during standard surveys in the large Karreel Lagoon. Two *T. tandanus* were captured in the large Karreel Lagoon, but in no other lagoon sites during this study. However, we have observed numerous eel-tailed catfish in a lagoon in the middle Condamine, near Cecil Plains. Eel-tailed catfish *T. tandanus* were also rare in riverine sites in both study areas. Un-specked hardyheads *C. s. fulvus* were not captured in any lagoons during standard surveys in this study, but two were captured for tagging in South Callandoon Lagoon (Macintyre Zone 6) before it dried out. During an unrelated study, we also observed *C. s. fulvus* in Caliguel Lagoon which is in the Condamine catchment approximately 40 km upstream of our study reach. Silver perch *B. bidyanus* and *M. p. peelii* juveniles (and adults) were not captured in any lagoon sites.

Discussion

The very low catch rates of *R. semoni* by mini-fyke shots compared to boat electrofishing shots suggests that this species is probably not mobile. Recent genetic evidence from Murray River populations of *R. semoni* (Ryan Woods⁵ pers. comm. 2007) also supports the hypothesis that *R. semoni* does not move long distances.

For *T. tandanus*, juvenile *M. p. peelii*, *B. bidyanus* and *C. s. fulvus*, catch rates were too low to draw any firm conclusions about their movement behaviour. We can say that *B. bidyanus* can move at least one km, and we recaptured this fish on the same snag from where it was collected. This suggests adult *B. bidyanus* display site fidelity. Juvenile *M. p. peelii* and *T. tandanus* recaptures were close to release locations so nothing can be concluded about longitudinal movement of these species.

We know that *C. s. fulvus, T. tandanus* and *R. semoni* occur in lagoons in the study area therefore some lateral movement must take place. All three species have been recorded from lagoon habitats in other parts of the Basin (Closs et al. 2006). In a review of fish in wetlands in the Murray-Darling basin, Closs et al. were uncertain as to whether these three species occurred in wetlands in the northern Basin. We can confirm that they do. However, given the rarity of all three species in the adjacent river system, it is difficult to conclude whether this movement to lagoons is likely to be active or random.

To gain more information on the movement requirements of juvenile *M. p. peelii*, *T. tandanus*, *C. s. fulvus* and *B. bidyanus* it would be necessary to select sites where these species are more common. For example, the upper Condamine or mid to upper Macintyre system may be suitable sites for all these species excluding *B. bidyanus*. Upstream of Goondiwindi, *C. s. fulvus* become common and *M. p. peelii* are in high densities above Goondiwindi in the Dumaresq River and the Macintyre Brook. Eel-tailed catfish *T. tandanus* are common in the mid-to-upper Condamine River where carp are less abundant. Studies on *B. bidyanus* should probably concentrate on the middle Murray system.

⁵ Ryan Woods, Australian Rivers Institute, Griffith University

4. A SYNTHESIS OF IDEAS, RECOMMENDATIONS AND CONCLUSIONS

4.1 Flow conditions

During this study, rainfall in the Condamine and Border Rivers catchments was severely deficient (BOM 2007). This altered the catchment hydrodynamics dramatically and reduced opportunities for scientific study of fish movement within these catchments. Longitudinal connectivity in the Condamine River was restricted for much of the study period, especially between April 2006 and February 2007 when water inflows were negligible. Longitudinal connectivity in the Macintyre River was maintained by artificial releases from upstream impoundments. The level of lateral connectivity was greatly affected with only one such event recorded during the study period, in the Macintyre River.

The drought affected recapture rates of our tagged fish by increasing mortality rates (predation and desiccation) and reducing movement opportunities. In spite of this impact, the use of multiple methods and known distances of dry river bed has allowed us to obtain new and meaningful data on movements of lesser studied native fish in the Murray-Darling Basin. We have identified a number of general trends in fish movement behaviour across species.

4.2 General trends

Downstream movement on falling flows

Most species examined in this study were found to have moved both up and downstream on most stages of the hydrograph. However, there was a distinct trend by several species to move downstream during a falling flow. These included *Hypseleotris* spp., *N. erebi*, *L. unicolor*, *M. ambigua*, *P. macrostomus* and juvenile *N. hyrtlii*. For *Hypseleotris* spp., *N. erebi* and *L. unicolor*, this behaviour was across all size classes. For *M. ambigua*, the tendency was for more juveniles and sub-adults to move downstream than upstream. We suspect that downstream migration on a falling flow is a desiccation avoidance adaptation to longitudinal disconnection and diminished hydrological persistence. Similar downstream behaviour has been observed in ephemeral rivers in southern Africa (van der Waal 1996). Artificial attenuation of the falling flow associated with upstream water harvesting could lead to stranding of more fish than would otherwise occur.

Increased movement on natural flows

There appears to be a distinct trend for several species to undertake significantly more movement during natural flows, compared to artificial releases. In particular, *Hypseleotris* spp., *N. erebi, L. unicolor* and *M. ambigua* were more mobile during natural flows. This behaviour may be stimulated by chemical cues (Sorensen 1986, McCleave & Jellyman 2002) such as those associated with rewetted soils (Baldwin & Mitchell 2000). In contrast, *M. fluviatilis* is more mobile during artificial flows. We speculate that this movement, occurring primarily in spring, is associated with their reproductive strategy. They are known to rely on elaborate visual courtship displays (Lintermans 2007) that would be facilitated by the less turbid artificial flows in the Macintyre River.

Seasonal influence on movement

Most native species moved less during the winter period, corresponding to periods of least flow in the northern Basin. Peak movement occurred in spring for *Hypseleotris* spp., *L. unicolor*, *N. hyrtlii*, *A. agassizii* and *M. fluviatilis*. For adults of these species, movement was generally upstream. We have associated this movement with their reproductive strategy because many fish collected at this time were reproductively ripe. Upstream movement before spawning has been suggested as a strategy to counter downstream displacement of eggs and larvae (Llewellyn 1973, Mallen-Cooper 1999, Mazzoni et al. 2004).

We also observed an increase in catches of juveniles of *Hypseleotris* spp., *L. unicolor*, *N. hyrtlii* and *P. macrostomus* moving in a downstream direction during spring, suggesting recent recruitment. This movement may have been active, but the possibility of downstream displacement cannot be discounted even though flow rates were generally low.

Peak catches of juvenile and sub-adult *M. ambigua* and *N. erebi* occurred during autumn. In the northern MDB, such behaviour would be a useful adaptation to enable dispersal to refugia before the onset of the winter and early spring dry season.

Longitudinal movement

Mesoscale longitudinal movement was observed for *Hypseleotris* spp., *N. erebi, L. unicolor, M. ambigua, M. fluviatilis, P. macrostomus* and *N. hyrtlii*. Radiotelemetry and tag recapture data demonstrated upstream and downstream longitudinal mesoscale movement in excess of 2 km by *N. erebi* and *L. unicolor*, and in excess of 10 km by *Hypseleotris* spp. (tag recaptures only). Captures below weirs after rewetting supported upstream movements in excess of 11 km by *Hypseleotris* spp., *N. erebi, L. unicolor, M. ambigua, M. fluviatilis*, and *P. macrostomus*. Only a small proportion of adult-sized *M. fluviatilis* appear to undertake mesoscale movement. Tag recapture data for *M. ambigua, N. hyrtlii* and *M. fluviatilis* demonstrated mesoscale movements in the order of hundreds of metres.

Lateral mesoscale movement and the importance of lagoons

Several fish species were found in lagoon environments at the start of this study. These included *Hypseleotris* spp., *N. erebi, L. unicolor, M. ambigua, M. fluviatilis, C. s. fulvus, R. semoni, T. tandanus, N. hyrtlii, A. agassizii* and *L. unicolor*. Closs et al. (2006) report these species in lagoon habitats in other parts of the MDB. Most of the lagoons sampled in this study required minor or major flood heights to connect. We found no evidence of connection to these sites during this study with the exception of Booberoi Lagoon (Zone 8) that connected on a within-bank flow. We suggest that most of the lagoon-inhabiting species were not active migrants; rather they were opportunistic, randomly dispersing migrants. This hypothesis needs to be tested during a flood event.

In contrast, lateral movement was observed for *A. agassizii* and *L. unicolor* following a brief connection event in the Macintyre River. Both of these species were not common in the adjacent river. However, more common riverine species such as *M. fluviatilis* and *Hypseleotris* spp. were not found in the lagoon. This suggests that movement into the lagoon was an active process by *A. agassizii* and *L. unicolor*.

The cues that have triggered this movement are unknown and the brief hydrological persistence of the lagoon connection has impeded further research in this area.

Baldwin and Mitchell (2000) have identified several chemicals that are released into the water on rewetting of soils and leaf litter (carbon, nitrogen, phosphorus). Sorensen (1986) identified chemical olfaction as a migratory cue in freshwater eels. We hypothesise that chemicals liberated from rewetted lagoon sediments stimulate *A. agassizii* and *L. unicolor* to move laterally into these lagoon habitats. The rewetting of soils is known to result in an initial flush of available P and N, coupled with increased bacterial activity (Baldwin & Mitchell 2000). This also liberates C, N and P from leaf litter and may stimulate aquatic plant productivity.

Lagoon habitats offer several advantages to small native freshwater fish. Piscivory is a dominant factor in both stream and lake systems of North America (Jackson et al. 2001). Within small lakes, impacts of predators may exclude other species, but our study found large piscivorous fish were absent from lagoon habitats. We did find five sub-adult *M. ambigua* in the large Karreel Lagoon early in the study, but these fish were not found in the following 18 months of sampling. Closs et al. (2006) report cod species to be absent from lagoons in the MDB, and we found none in our study.

The presence of the introduced piscivorous Perca fluviatilis in lagoons in the southern MDB (Closs et al. 2006) may have disadvantaged small native fish populations such as *A. agassizii* in these habitats.

Floodplain sites away from the main river channel can account for high recruitment levels and species diversity in the Border Rivers region (Wilson & Wright 2005). Spangled perch *L. unicolor* are known to spawn in lagoon habitats of the Northern Territory (Morris et al. 2001). We found evidence of recruitment by *L. unicolor*, *Hypseleotris* spp., *N. erebi*, *T. tandanus* and *N. hyrtlii* in lagoon habitats in the northern Murray-Darling Basin during this study. Wilson and Wright (2005) noted that recruitment abundances were much higher in autumn following recent flooding, and fish abundance was higher in satellite floodplain sites. They suggest lagoons are critical to population replenishment of many species.
Connections to ephemeral lagoons during spring and summer might offer a chance for *A. agassizii* spawning and recruitment. *Ambassis agassizii* are known to utilise aquatic macrophytes for spawning substrates (Lintermans 2007) and we have evidence of recruitment of *A. agassizii* in newly inundated lagoon habitats with abundant macrophyte cover. However, hydrological persistence and reconnection is also an important factor governing the population benefits of exploiting lagoon habitats (Puckridge et al. 2000, DeAngelis et al. 2005).

Floods tend to occur in clusters associated with La Niña episodes, and Puckridge et al. (2000) have attributed a recruitment advantage to native fish over the exotic Gambusia holbrookii during serial floods. Evidence from our study suggests that inundated lagoon habitats that have established extensive macrophyte populations offer recruitment advantages to *A. agassizii*, provided that *C. cyprio* do not degrade that habitat. However, without reconnection to disperse the accrued benefits to other populations within the river system, the advantage is lost.

Climate change may impact on the frequency and duration of serial connection events. Recent modelling of climate has predicted a 10% reduction of flows in the Border Rivers (CSIRO 2007). This could have implications for recruitment success and the status of *A. agassizii* populations in the northern MDB.

Lunar influence on movement

During this study the statistical analyses identified a significant link between lunar phase and movement by several native species. In *Hypseleotris* spp. there was a significant interaction between hydrography and lunar phase that suggested increased movement on base flows during the new moon. We postulate that base flows may have been less turbid and *Hypseleotris* spp. may have preferred to move during periods of less illumination as a predator-avoidance strategy. Alternatively, increased mini-fyke catches of *Hypseleotris* spp. could have resulted from increased gear efficiency in low light.

Two species, *M. ambigua* and *M. fluviatilis*, had peak catches on the first quarter of the moon (after adjusting for other factors). The reason for this is unknown. Various fish species are known to have their behaviour influenced by lunar phase (Toledo et al. 1991, Garcia 1992). This is an area that has received little attention in Australian freshwater species.

4.3 Future management and research recommendations

This study has highlighted that small native fish in the northern Murray-Darling Basin, and probably elsewhere in the basin, travel both up and downstream.

Management recommendations

- 1. We feel it is very important that managers consider the egress of small fish when prioritising weir passage investment. In particular, the preponderance of downstream movement amongst many species dictates that future plunge pool, fishway and spillway design need to accommodate small-bodied fish as well as the premier native sport fish and other large-bodied species.
- 2. There is a need for fisheries managers to negotiate with water managers on different methods of delivering water to increase lateral connectivity. The potential benefit of delivering impounded water less frequently or more strategically, and in larger volumes to replicate natural flows, needs to be understood by fisheries managers. The concept of flexible delivery needs to be promoted to water managers. Increasing volume does not necessarily mean increased volume of release from upstream storages. Increased flow delivery may be achieved by combining environmental flow releases with natural flow events or irrigation releases.

The importance of lateral connectivity has been highlighted in this study. In particular, it may be an important resource for sustaining populations of several threatened native fish species in the northern Basin.

Research

- 1. We believe that an otolith microchemistry study would determine a direct linkage between lateral connection and recruitment in lagoons.
- 2. There is a need to establish which species are active off-stream exploiters. This could be achieved by establishing active choice using Y-trough experiments.
- 3. The reasons for active or obligate lateral migration needs to be established. Three possible reasons are for feeding, reproduction, or predator avoidance. These could be investigated by a study of lagoon fish assemblages through several cycles of connectivity.
- 4. We concur with Puckridge et al. (2000) and reiterate the need to investigate lagoon hydrological persistence and its ecological impacts on threatened/endangered native fish populations in the northern MDB.
- 5. We also feel that a study on the alteration of off-stream linkages, e.g. modified sill heights, would benefit our understanding of the impacts that agriculture and land modification has had on serial hydrological persistence in these wetlands. It would give fisheries managers a more robust position to negotiate with water managers for environmental flow access. This work has been done for some regions in the northern MDB, e.g. lower Macintyre River.
- 6. Most of the current study was completed during a severe drought. Further work is required during average or above average rainfall conditions to better understand the role of lateral connectivity for northern MDB fish assemblages.

Environmental flows may serve a number of purposes, including maintaining pool refugia and access to critical habitats for breeding or juvenile recruitment. This research has highlighted the impacts of different-sourced flows on driving movement of small native fish in the northern MDB. This raises the question of what is different between natural and artificial flows, and how fish differentiate between the two. If fish are to gain maximum benefit from environmental flows, we need to better understand how to manage these flows.

7. Further research is needed to investigate the importance of olfactory cues on fish movement. For example, it may be better to link environmental flows to natural rainfall events, so that some natural run-off and the associated odours that cue movement are incorporated into the flow release. In the case of *A. agassizii*, it may be better to combine environmental flows with an irrigation release, or a natural flow event, to increase the total volume of water flowing down the river and create lateral connectivity to some ephemeral lagoons.

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