Ecology of Freshwater Fish 2008: 17: 146–154
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ECOLOGY OF
FRESHWATER FISH

Diurnal and nocturnal movements of river blackfish (*Gadopsis marmoratus*) in a south-eastern Australian upland stream

Koster WM, Crook DA. Diurnal and nocturnal movements of river blackfish (*Gadopsis marmoratus*) in a south-eastern Australian upland stream.
Ecology of Freshwater Fish 2008: 17: 146–154. © 2007 The Authors. Journal compilation © 2007 Blackwell Munksgaard

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Abstract – We used radio-telemetry to investigate the movement patterns of river blackfish [*Gadopsis marmoratus* (Richardson)] in Armstrong Creek, south-eastern Australia between August and October 2005. Movements of 11 fish were monitored 2–3 times per week during daylight over 48 days and diel movements of six fish monitored hourly for three consecutive days and nights. Most river blackfish displayed little or no movement during the day and were confined to distinct positions in the stream. However, fish moved over significantly larger ranges and moved amongst mesohabitats at night, which would not have been detected using daylight tracking data only. River blackfish most often were located within pools, but they also commonly used riffle and run habitats. We also found that several fish used inundated riparian areas during a flood and two fish made rapid, large movements coinciding with the elevated flows. This study has revealed previously undocumented aspects of the movements and behaviour of river blackfish. The study has also shown the potential for different conclusions regarding the extent of movement by a species depending on the temporal scale and the timing of observations.

Key words: *Gadopsis marmoratus;* diel movement; habitat use

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Accepted for publication August 24, 2007

Introduction

Studies of animal movements provide valuable insights into the processes that influence a species' presence and abundance, and are increasingly recognised as an important tool in the management and conservation of species (Baker 1982; Lucas & Baras 2001). Over the past two decades, particularly with the advancement of telemetric methods, considerable progress has been made in understanding the movements of freshwater fishes (Gowan et al. 1994; Lucas & Baras 2000). Telemetric methods have commonly been used to provide detailed information on the short-term movements of fish, including variations in movement patterns over diel periods (e.g. Matthews 1996; Harvey & Nakamoto 1999; David & Closs 2001). Miniaturisation of transmitters and the development of improved transmitter attachment and implantation techniques have also allowed longer-term studies of the movements of relatively small fish, thus providing critical information on movements at temporal scales of up to several years (e.g. Eiler 1995; Harvey & Nakamoto 1999; Irving & Modde 2000).

River blackfish [*Gadopsis marmoratus* (Richardson)] occur in fresh waters of south-eastern Australia. The spawning period for the species is October–December (Cadwallader & Backhouse 1983; Koehn & O'Connor 1990). Two distinct forms of river blackfish, a northern and southern form have been identified (Sanger 1986) and a recent taxonomic work suggests that these may represent distinct species (Miller et al. 2004). The southern form [approximately <600 mm total length (TL)] grows much larger than the northern form (approximately <300 mm TL) (Cadwallader & Backhouse 1983) and is a popular angling species (Jackson et al. 1996). A decline since European

doi: 10.1111/j.1600-0633.2007.00269.x

settlement in the range and abundance of river blackfish has been attributed primarily to stream siltation and removal of woody debris (Lake 1971; Jackson et al. 1996). Consequently, there has been a recent emphasis in stream rehabilitation programmes to conserve or restore suitable habitat conditions for river blackfish populations. For example, environmental flow recommendations specifically aimed at restoring flow patterns suitable for sustaining river blackfish populations have been established, and woody debris introductions have been undertaken to provide physical habitat for the species (Coleman 2006). Although such efforts are likely beneficial to river blackfish populations, considerable gaps in our knowledge of basic aspects of the species' life history currently hinder the development and implementation of targeted management strategies for the species.

Although movements of river blackfish have been examined in several previous studies, there has been little detailed investigation of their long-term or diel movements. Koehn (1986) reported the preliminary results of a mark-recapture study conducted over a 2-year period in Armstrong Creek in southern Victoria, describing river blackfish (southern form) movements as limited and estimating a home range of 25–30 m. Similarly, Khan et al. (2004) conducted a radio-telemetry and mark-recapture study in Birch Creek in northern Victoria, between late spring and early summer (November–December) and mid-spring to late autumn (October–May) respectively, and reported that river blackfish (northern form) also displayed little movement and had a small home range (10–26 m). Distances moved between day and night were also examined but were not significantly different (Khan et al. 2004). Movements of the only other member of the genus, the two-spined blackfish (*Gadopsis bispinosus*), have been investigated using mark-recapture techniques in the Cotter River in the Australian Capital Territory, between late spring and late autumn (November–May), and were similarly described as relatively sedentary with a home range of approximately 15 m (Lintermans 1998).

The current study was undertaken to investigate the movement of river blackfish using radio-telemetry at two temporal scales: (i) 2–3 times per week during daylight over 48 days and (ii) hourly for three consecutive days and nights. The results of the study are discussed with regard to the general ecology of river blackfish and implications for management and conservation of the species.

Study area

The study was conducted in Armstrong Creek, a second order tributary of the Yarra River, ~100 km east of Melbourne in south-eastern Australia (Fig. 1). Streamflows in Armstrong Creek are partially regulated through small diversion weirs located on the

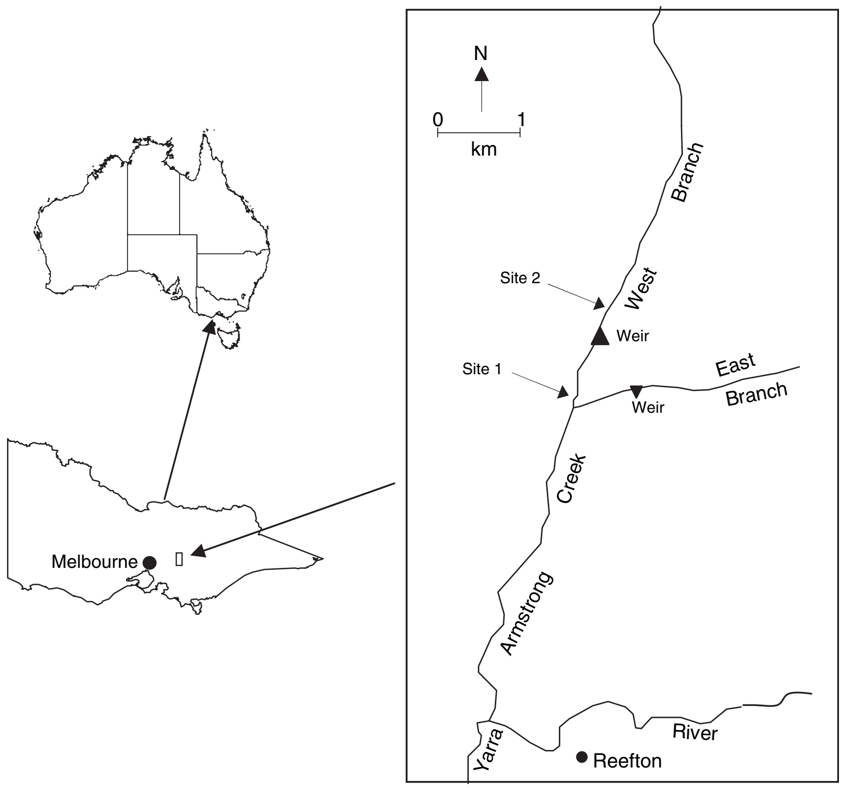

Fig. 1. Location of Armstrong Creek in south-eastern Australia.

eastern and western branches of the creek that supply water for use in Melbourne. Both weirs act as barriers to fish movement. The upper reaches of each creek flow through largely forested catchment. Two study sites were selected (mean stream width 4–5 m), one 250 m downstream and one 150 m upstream of the diversion weir on the west branch (Fig. 1). The weir on the west branch at full supply level retains approximately 20 Ml. Daily discharge records were obtained from a gauging station on the west branch weir and water temperature was recorded *in situ* during each tracking event. The study was conducted between late winter (August) and mid-spring (October). Water temperatures gradually increased over this period from about 8 to 13 °C. A high discharge event (maximum flow ~470 Ml·day^{-1}) occurred in late August–early September (Figs 2 and 3). Apart from this event, discharge was generally much lower and more stable downstream of the weir (median flow ~5 Ml·day^{-1}) compared with upstream of the weir (median flow ~95 Ml·day^{-1}) because of flow regulation (Figs 2 and 3). This downstream site was previously used for studies of fish movement and habitat use (Koehn 1986; Koehn et al. 1994) and the effects of sedimentation on fish and macroinvertebrates (Doeg & Koehn 1994).

Materials and methods

Fish collection and radio-tagging

Seven river blackfish (southern form) were collected downstream and six upstream of the west branch weir (mean TL 260 ± 40 mm SD, mean weight 182 ± 90 g SD) by backpack electrofishing on 18 August 2005. Radio-transmitters with an internal coil antenna and a battery life of ~60 days [model 1040; Advanced Telemetry Systems (ATS), Isanti, MN, USA; frequency: 150 MHz; dimensions: 24 × 10 × 7 mm; weight: 2 g in air] were implanted into the body cavity of the fish through an incision of approximately 10 mm, adjacent to the pectoral fin extending toward

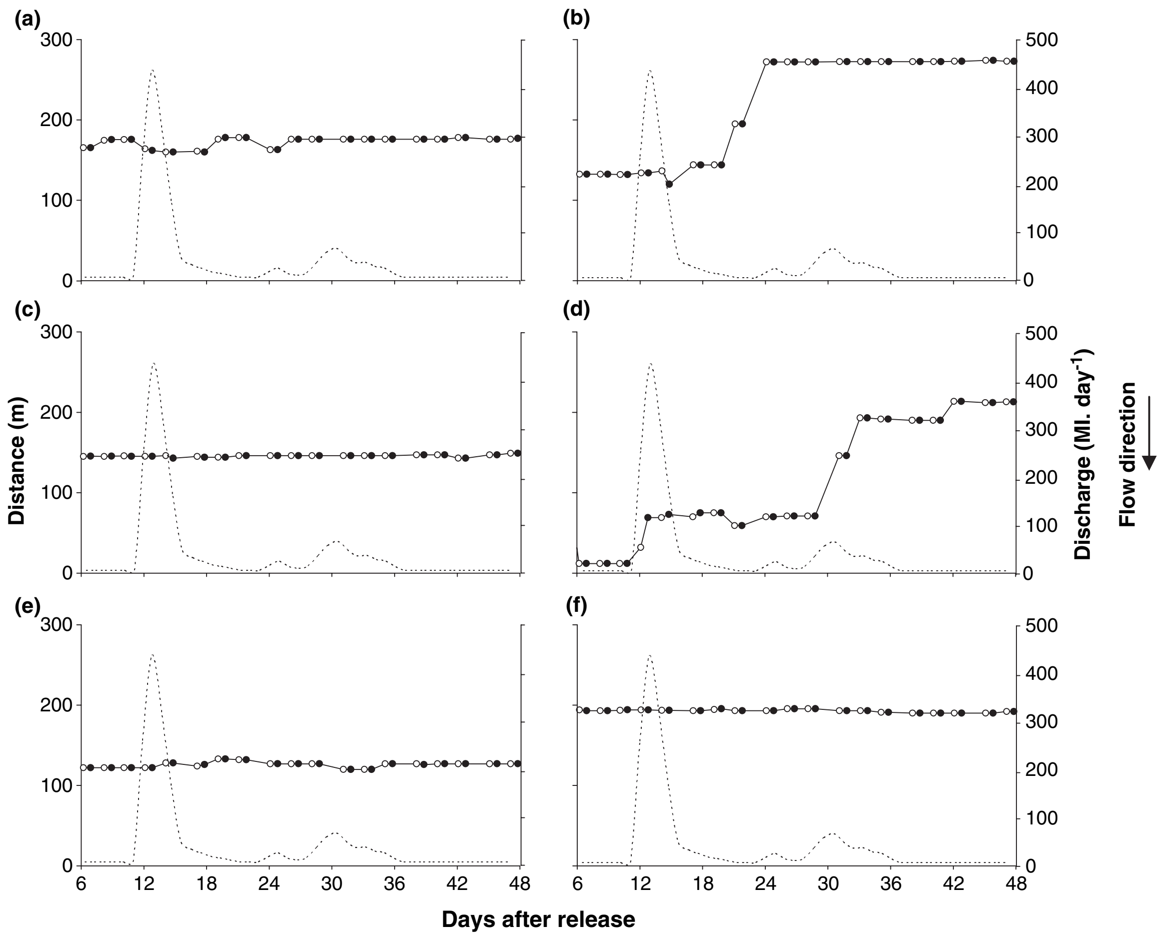

Fig. 2. Daily discharge (Ml·day^{-1}) (···) and distances (m) moved by six radio-tagged river blackfish in Armstrong Creek downstream of the west branch weir over the study period during the morning (○) and afternoon (•). Zero on the left *y*-axis refers to a ford crossing downstream of the radio-tagged fish that was used as a reference point for the location of fish.

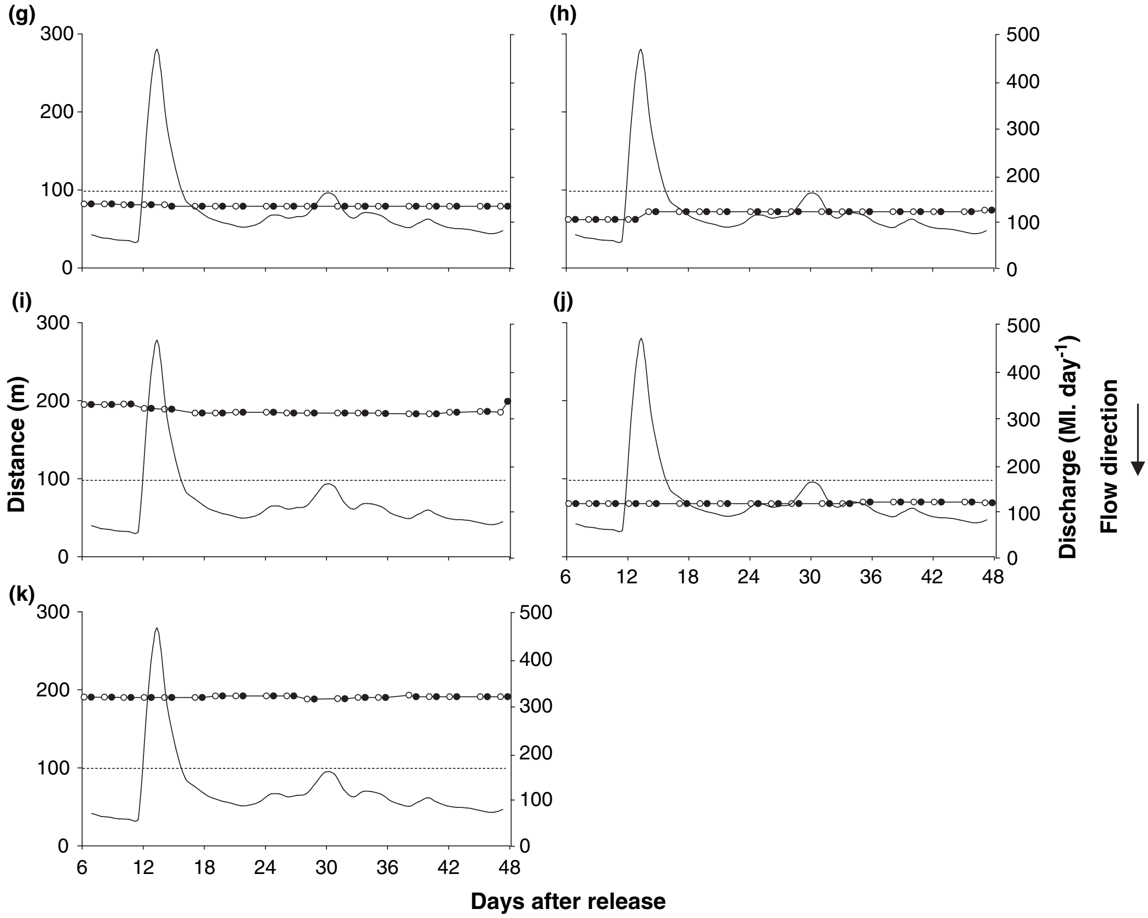

Fig. 3. Daily discharge (Ml·day^{-1}) (–) and distances (m) moved by five radio-tagged river blackfish in Armstrong Creek upstream of the west branch weir over the study period during the morning (○) and afternoon (•). Zero on the left *y*-axis refers to the west branch weir wall downstream of the radio-tagged fish that was used as a reference point for the location of fish. Dotted line denotes the junction of Armstrong Creek and the weir pool.

the anus. The incision was not closed with sutures, as trials indicated much higher survival and tag retention rates with unclosed incisions, than with suturing (unpublished data). The transmitter weight to fish body weight ratio did not exceed 2% and observations of six tagged fish held in aquaria for 6 weeks showed no apparent effects of the transmitter implantation method upon behaviour (i.e. swimming, feeding and condition). Each fish was released near its point of capture immediately after recovery from the transmitter implantation procedure.

Fish monitoring

Data were collected for five of the six river blackfish tagged upstream and six of the seven fish tagged downstream of the weir. Despite extensive searches, we were unable to locate the remaining two radio-tagged river blackfish and assume that the transmitters had failed before any data could be collected. Tracking began 6 days after implantation of the transmitters. Movements of each river blackfish were recorded during daylight on two or three occasions per week from late winter to mid-spring (24 August to 5 October, 2005). River blackfish were located in the morning (09:00–11:00 hours) and afternoon (14:00–16:00 hours) of each day by triangulation with a handheld, three-element Yagi antenna and an ATS receiver. Because of battery life limitations, the fish were only able to be tracked for 48 days. At the downstream site, a ford crossing downstream of the radio-tagged fish was used as a reference point for the location of fish. At the upstream site, the west branch weir wall downstream of the radio-tagged fish was used as a reference point. The distance of each river blackfish from the relevant reference point was recorded to the nearest 1 m. At each site, markers were placed at 5 m intervals on the bank to assist with the location of fish relative to the reference points.

In addition, radio-tagged river blackfish downstream of the weir were tracked hourly for 71 consecutive hours from 3 to 6 October 2005 to examine diel movements. Mesohabitats for each fish location were recorded using the categories riffle, run or pool (after Anderson et al. 1989). Smaller-scale habitat features (undercut bank, woody debris or open channel) for each fish location were also recorded when possible. However, smaller-scale habitats for each fish location could not always be accurately determined at night. After the tracking was completed, mesohabitat composition was measured along a 200 m section of stream encompassing the most upstream and downstream diel movements.

Results

Daylight movement

Most of the 11 radio-tracked river blackfish remained within a short (<30 m) length of stream for the duration of the study (Figs 2 and 3). River blackfish rarely moved from their location within the same day, although some individuals were occasionally found to have moved to new locations between days (Figs 2 and 3). Two fish were occasionally located in close proximity (<5 m) to each other, although usually only for a few days before one of the individuals moved to another location. By the end of the study, the locations of all river blackfish did not overlap at all (Figs 2 and 3).

A high-discharge event (maximum flow ~470 $\text{Ml}\cdot\text{day}^{-1}$) in late August–early September (Fig. 2) (2 weeks after transmitter implantation) resulted in short-term inundation of floodplain habitats downstream of the weir. During this event four river blackfish moved out of the river channel and onto inundated floodplain habitats. Three of these fish were positioned within 10 m of their previous location within the main channel. Two of these individuals returned to their previous location once the discharge had dropped below bankfull several days later, while the remaining individual undertook a series of upstream movements before positioning itself in a new location in the creek 140 m upstream of its preflood position (Fig. 2b).

One river blackfish located on the floodplain was positioned 30 m upstream from its location prior to the flood in the morning, and a further 35 m upstream by the same afternoon of the first day of the flood (Fig. 2d). This fish returned to the creek as flood waters subsided and remained in this location for several weeks, before undertaking a series of upstream movements to a new location in the creek (200 m upstream of its preflood position) coinciding with a smaller increase in discharge (4 weeks after transmitter implantation) (Fig. 2).

Three river blackfish tagged and released above the weir had moved downstream from their capture location and were located in the weir pool 50–100 m downstream at the commencement of tracking (Fig. 3g, h and j). These fish then undertook minimal movements and all remained in the weir pool throughout the remaining study period. All three of these river blackfish were located on the western side of the weir pool in close proximity to the old course of the creek channel.

Diel movement and habitat use

During the three diel periods of hourly radio-tracking, five of the six river blackfish were inactive during daylight hours, but became more mobile around sunset (Fig. 4). These fish continued to move throughout the night, before returning, at about sunrise, to the same area that they previously occupied during daylight hours (Fig. 4). For five of the six river blackfish, the rate of movement ($\text{m}\cdot\text{h}^{-1}$) was significantly greater at night than during the day (Mann–Whitney *U*-test: $P < 0.001$). The single river blackfish that did not exhibit a detectable diel pattern of movement (Mann–Whitney *U*-test: $P > 0.05$) stayed within a highly restricted area throughout the three diel periods (Fig. 4c). The distances moved by each of the six river blackfish varied considerably: the largest total linear range over the 3 days was 25 m and the smallest was 5 m (Fig. 4, Table 1). However, the distances moved and the areas of stream used were extremely consistent for each individual over the 3 days and nights (Fig. 4). Fish length did not significantly influence the total distance moved or total linear range of the tagged fish (Pearson correlation: $P > 0.05$). The areas of stream occupied by individual river blackfish did not overlap during the three diel periods (Fig. 4).

Runs (43%) comprised the largest proportion of available mesohabitat, followed by riffles (34%) and pools (23%). Although pools comprised the least habitat, river blackfish were positioned within pools more often than other mesohabitats during both the day (50% of observations) and night (59% of observations) (Table 2). During the day, river blackfish did not move between mesohabitats (Table 2). In contrast, at night, four of the six river blackfish moved between two or more mesohabitats (Fig. 4, Table 2). At the smaller scales, four river blackfish were located exclusively in undercut banks and two fish amongst woody debris during the day. Although the small-scale habitats used by river blackfish could not be accurately determined at night, it was apparent that most fish were moving often between habitats, including the open channel.

Discussion

The results of this study provide a demonstration of the importance of the temporal scale and timing of monitoring for understanding patterns of fish movement. Measurement of the movements of river

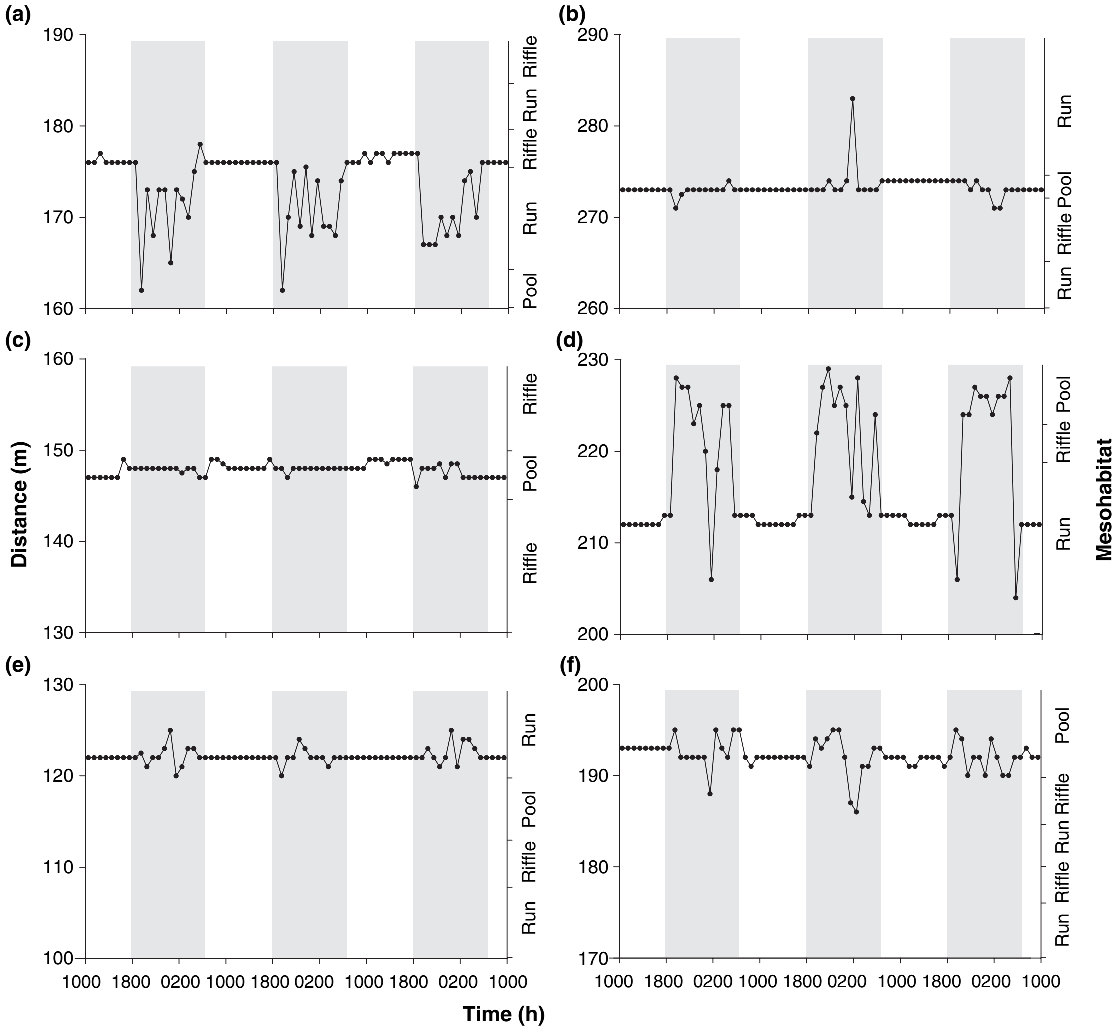

Fig. 4. Distances (m) moved and mesohabitats used by six radio-tagged river blackfish in Armstrong Creek below the west branch weir over the 3-day diel tracking period. The shaded area refers to the period between sunset and sunrise. Distance (m) refers to distance upstream of the ford crossing that was used as a reference point for the location of fish. The location of all the six river blackfish do not overlap.

Table 1. Total distance moved and total linear range (m) of six river blackfish during the 3-day diel tracking period. Total distance moved refers to the sum of all hourly movements. Total linear range refers to the distance between the most upstream and downstream positions.

	Total distance moved (m)		Total linear range (m)	
Fish	Day	Night	Day	Night
a	7	168	1	16
b	0	36	1	12
c	9	15	2	3
d	5	223	1	25
e	0	41	0	5
f	11	68	2	9
Average ± SD	5.3 ± 4.6	91.8 ± 83.9	1.2 ± 0.7	11.7 ± 8.0

Table 2. Percentage use of mesohabitats for six river blackfish during the 3-day diel tracking period.

	Day			Night		
Fish	Pool	Run	Riffle	Pool	Run	Riffle
a	0	0	100	5.1	79.5	15.4
b	100	0	0	87.2	2.5	10.3
c	100	0	0	100	0	0
d	0	100	0	66.7	28.2	5.1
e	0	100	0	0	100	0
f	100	0	0	92.3	0	7.7

blackfish during the day only, both short and long term, would have indicated that most individuals displayed little or no movement and were confined to distinct positions in the stream, most often an undercut bank. Incorporating intensive monitoring at night, however, showed that individuals occupy a much larger range and regularly move between mesohabitats during the night. This finding is similar to several previous radio-telemetry studies (e.g. Harvey & Nakamoto 1999; Snedden et al. 1999; Hilderbrand & Kershner 2000) that also found strong diel patterns in the movements of riverine fish.

Nocturnal behaviour by river blackfish has been noted by previous authors (e.g. Koehn et al. 1994; Jackson et al. 1996). However, the increased movement at night by river blackfish contrasts with the findings of the only published study on diel activity by the species (Khan et al. 2004), which found no significant difference in the distances moved by individual fish between day and night. A possible explanation for the discrepancy between the studies is that Khan et al. (2004) studied the smaller, northern form of river blackfish, which might exhibit different behavioural characteristics to the southern form. The current study was also conducted over a longer period with shorter tracking intervals and a greater number of fish. Khan et al. (2004) tracked three fish at 3 hourly intervals over a single diel period, compared with six fish tracked hourly over three diel periods. In the current study, fish frequently changed locations between the hourly tracking occasions at night: it is possible that tracking less fish at longer intervals over a single diel period resulted in a failure to detect variation in diel movement. Finally, there were differences in the timing of the studies and the techniques used to attach the radio-transmitters that could potentially affect fish behaviour. The current study was conducted between late winter and mid-spring, whereas Khan et al. (2004) conducted their radio-tracking between late spring and early summer. In the current study, radio-transmitters were implanted internally, whilst Khan et al. (2004) attached the radio-transmitters externally and attached transmitters to much smaller fish.

During our diel tracking, river blackfish used pools more frequently than their availability in the study reach, but they were also commonly located in riffles and runs. The preference of river blackfish for pools agrees with the findings of previous studies (Jackson 1978; Koehn et al. 1994; Khan et al. 2004); however, frequent utilisation of riffles and runs has not been described in previous studies. Although river blackfish were found in riffles and runs both day and night in the current study, within these mesohabitats they were often positioned in undercut banks or amongst woody debris that may have afforded shelter from the surrounding fast flowing waters. Nonetheless, the results indicate that river blackfish are not confined to pools, and suggests that small-scale features such as undercuts banks or woody debris play an important role as habitat for this species.

Interestingly, the locations of the 11 radio-tagged river blackfish rarely overlapped during the study. Larger individuals of many species are known to exclude other large individuals from territorial areas and dominance hierarchies often form with subordinate smaller individuals in these areas (e.g. Hughes 1992; David & Stoffels 2003). Whilst non-tagged river blackfish were certainly present within the ranges of the radio-tagged fish during the study, it is likely that most of these were smaller than the radio-tagged fish. We undertook extensive sampling to collect fish >220 mm TL for radio-tagging. Although all fish greater than this length were radio-tagged, many smaller fish were also collected from the study reach (average density 0.07 blackfish$\cdot$m^{-2}; unpublished data). Observations in aquaria have shown that individuals exhibit aggressive behaviour towards each other and that large individuals tend to dominate smaller fish (Cadwallader & Backhouse 1983; personal observation). It is possible that large river blackfish occupy nonoverlapping home ranges that they share with smaller, subordinate individuals as part of a dominance hierarchy. Further work on behavioural interactions between individual fish is required to confirm this suggestion however.

Over half of the fish tagged below the weir were positioned within the inundated floodplain habitats during the short-lived flood event in late August–early September. Although many fish species use flooded off-channel habitats (Ross & Baker 1983; Brown & Hartman 1988; Matheney & Rabeni 1995; Brown et al. 2001), similar observations on river blackfish have not been documented. Observations of movement by river blackfish onto flooded riparian areas have potentially important implications for management of the riparian zone of streams containing river blackfish. Riparian vegetation may provide refuge habitats during flood events, as has been reported for other riverine fish species (Matheney & Rabeni 1995). A few fish downstream of the weir also undertook large movements coinciding with the increased flows, and one of these fish also moved again coinciding with another smaller increase in flows. Previous studies have suggested that increased discharges provide important opportunities for individuals to explore and colonise other stream locations (David & Closs 2002; Crook 2004). Movement away from established locations may also occur in response to other disturbances (e.g. handling by humans; Crook 2004) or be associated with particular aspects of the species' life history (e.g. spawning; Matheney & Rabeni 1995). Movements away from established locations by river blackfish during periods of high discharge were outside the October–December spawning period for the species (Cadwallader & Backhouse 1983; Koehn & O'Connor 1990) and therefore would appear to be associated with nonreproductive behaviour. The movement behaviour of river blackfish during the spawning period is an important area for future research.

A few fish upstream of the weir also undertook rapid large movements downstream into the weir pool shortly after release. At the time of the transmitter implantations, flows had risen in Armstrong Creek upstream of the weir. It is possible that the elevated flows forced fish downstream into the weir pool whilst they were recovering from the transmitter implantations, or perhaps the movements were associated with initial postrelease mobility. Although there were no physical obstructions to the upstream movement of fish from the weir pool back into the creek, these fish remained in the weir pool for the duration of the study. This finding shows that river blackfish are capable of using modified environments such as weir pools, although their long-term viability in such environments is unclear.

In conclusion, this study documents new observations on the movements and habitat use of river blackfish. Integration of such information into management strategies has the potential to improve our capacity to provide the conditions required to conserve and restore river blackfish populations. The study has also confirmed that the scale and timing of observation can provide very different conclusions regarding the extent of movement by the fish under investigation (e.g. Hilderbrand & Kershner 2000; Ovidio et al. 2000; Horton et al. 2004), and that this should be considered when appraising the movement requirements of riverine fish.

Acknowledgements

This study was funded by Melbourne Water. We gratefully acknowledge the assistance of Rowan Compagnoni, Cameron Padgham, John De Boer, Aaron Pie, Nigel Saville and Peter MacDonald from Melbourne Water. Jed Macdonald, John Morrongiello, Damien O'Mahony, Peter Fairbrother, Zeb Tonkin, Justin O'Mahony and Karl Pomorin from the Arthur Rylah Institute assisted with the fieldwork. Jed Macdonald and John Morrongiello deserve a special mention for their unwavering enthusiasm during the long days and nights of the diel tracking trip. Damien O'Mahony provided invaluable expertise and assistance during development of the transmitter implantation method. We also thank John Koehn, Ivor Stuart and Paul Close for constructive comments on earlier versions of the manuscript. This study was conducted under ethics permit 05/001 (Arthur Rylah Institute, Animal Ethics Committee).

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