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Spatial ecology of an endangered native Australian Percichthyid fish, the trout cod *Maccullochella macquariensis*

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ABSTRACT: We used radiotelemetry and mark-recapture tagging to determine the spatial movements of adults and juveniles (>180 mm total length) of a federally endangered, native Percichthyid fish, the trout cod *Maccullochella macquariensis*, in the Murray River, south-eastern Australia, to assist in its management and conservation. Trout cod exhibited strong evidence for site fidelity and homing in this study, typically utilizing only a few locations in the river channel and undertaking limited movements. The home range estimate for radiotracked fish was 61 ± 46 m (95% confidence interval). Movements of 1200 ± 46 m (95% confidence interval) were recorded for mark-recapture fish over longer time frames. No movements were recorded for 50% of fish. Larger movements (>3 km) were observed in <10% of individuals. While increased movement occurred with high flows during October and November in 1993, there was no evidence of an obligatory migration for this species. Several fish moved from the main river channel into floodplain channels and onto the nearby floodplain. No increase in movement was observed with season or with higher flows that occurred in July and August 1995. Conservation strategies for the species include the restoration of physical habitats. These results suggest that proximity to source populations may be influential in determining the likely timeframe necessary for recolonisation of restored habitats.

KEY WORDS: Movement · Migration · Radiotelemetry · Passive Induced Transponder · PIT · Murray River · Australia

INTRODUCTION

The mobility and dispersal of fishes and the connectivity of their habitats are critical for long-term survival of populations (Jungwirth et al. 2000) and have profound consequences for their management (Smithson & Johnston 1999). Barriers to fish movement and habitat degradation are both cited as causes for the decline of native freshwater fish species (Cadwallader 1978, Cowx & Welcomme 1998, Murray-Darling Basin Commission 2004). Knowledge of species' movement requirements is required for effective management decisions to be made at the appropriate 'riverscape' scales (Gowan et al. 1994, Wiens 2002). Mark-recapture methods can be useful for elucidating detailed movement patterns of fishes if the marked fish are regularly re-captured, which is often logistically difficult (Gowan et al. 1994, Rodriguez 2002). This problem has been overcome by the use of telemetry, which provides a convenient and cost-effective means of remotely monitoring the movements of wild animals (Millspaugh & Marzluff 2001), and has revealed that many fish species may be more mobile than previously recognised (Gowan & Fausch 1996, Young 1999).

The range of most native freshwater fish species in the Murray-Darling Basin, south-eastern Australia, has contracted and populations have suffered major de-

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clines (Cadwallader 1977, Cadwallader & Gooley 1984, Lintermans 2007). The need to rehabilitate populations is recognized as a necessary means of conserving native fish diversity and such projects are now underway (Murray-Darling Basin Commission 2004). Trout cod *Maccullochella macquariensis* is listed as an endangered species under Australian threatened species legislation (Department of Environment and Heritage 2003) and is protected from take by anglers. Trout cod is an elongate, deep-bodied fish, with a maximum weight of 16 kg and maximum length of 850 mm (Lake 1971, Lintermans 2007); however, they are more typically <5 kg in weight (Lintermans 2007). The natural distribution of trout cod has been significantly reduced to one single population located in the Murray River, along a reach of approximately 200 km, immediately downstream of Lake Mulwala (Douglas et al. 1994). Sexual maturity is reached at 3 to 5 yr (0.75 to 1.5 kg) (Lintermans 2007) and spawning occurs in October and November (Koehn & Harrington 2006). The eggs are large, adhesive and suspected to be laid on firm substrates such as logs (Lintermans 2007). Trout cod have been bred in hatcheries for the purpose of reintroductions and several new populations are being re-established as part of a recovery plan (Brown et al. 1998). There are 3 other species in the *Maccullochella* genus: Murray cod *M. peelii peelii*, Eastern freshwater cod *M. ikeii* and Mary river cod *M. peelii mariensis*, all of which are also listed as nationally threatened. Trout cod are similar to the larger Murray cod in appearance and ecology (Koehn & O'Connor 1990, Lintermans 2007) and occur in sympatry with this species in this reach of the Murray River downstream of Lake Mulwala.

Recent studies on trout cod in the wild have elucidated the preferred habitat of adults, which consists largely of instream wood (Growns et al. 2004, Nicol et al. 2007), and identification of larval life-stages in the main river and flowing floodplain channels (Koehn & Harrington 2006). However, detailed knowledge of movement patterns, including longitudinal and lateral movements, is incomplete for many Murray-Darling Basin fish species, including trout cod (Koehn & O'Connor 1990, Crook 2004, Lintermans 2007). In the present study, we used radiotelemetry and mark-recapture datasets from conventional and PIT (Passive Induced Transponder) tagging (see Prentice et al. 1990) to determine spatial scales of movement by trout cod.

MATERIALS AND METHODS

We studied trout cod in a 40 km reach of the regulated Murray River in south-eastern Australia, downstream of Lake Mulwala (146° 00′ E, 36° 00′ S; see Koehn & Harrington 2006, Nicol et al. 2007 for site details). The Murray River in this reach is a large, lowland river, with low energy, situated on extensive low gradient riverine plains (Mackay 1990, Rutherfurd 1990) and characterized by meandering bends (Hughes & Thoms 2002). Flows are highly regulated by upstream storages and are affected by water storage in winter and spring and the delivery of water for irrigation in summer, leading to a pattern of seasonal flow reversal (i.e. high summer, low winter flows) (Close 1990, Thoms et al. 2000). This reach of river has been considered to have intact and representative natural habitats, in contrast to other reaches of the Murray River (Koehn 2003).

Radiotelemetry. Trout cod were caught with a boat-mounted electro fisher (7.5 GPP, Smith Root); fish were weighed and total length (TL) measured. Fish >950 g were anaesthetized using a 5 mg l^{-1} Maranil solution and had a 48–49 MHz radiotransmitter (Advanced Telemetry Systems) surgically implanted into their abdominal cavity. Care was taken to avoid contact with or damage to internal organs (as per Schrader & Jones 2000). The commonly accepted 'rule' that transmitters should not weigh more than 2% of the body weight of the fish (Knights & Lasee 1996) in air or 1.25% of their weight in water (Winter 1983) was observed. Fish were then revived and released at the point of capture. The transmitters contained a 'mortality switch' (a mercury motion sensor) to indicate if the fish had died. All fish were captured, tagged and released in the river reach 29 to 38 km downstream of Lake Mulwala.

While these radiotelemetry techniques had previously been successfully used for Murray cod (Koehn 2006), there was a need to ensure that they would be appropriate for the endangered trout cod. In 1993, a pilot study was undertaken, with 4 fish (395 to 510 mm TL) captured and successfully tagged (2 on 21 July and 2 on 15 September) and tracked intermittently (mostly every 2 wk or less frequently) until 15 December. Following the survival and successful tracking of these fish, the main study commenced in 1994, with 18 fish (size range: 420 to 600 mm TL) caught and implanted with transmitters between September 1994 and February 1995. The radio signal for 3 of these fish was not detected after release and it is assumed that these fish either migrated away from the study site or that their transmitters failed. To exclude data that may have been influenced by the surgical procedure, tracking of fish did not commence until 1 mo after implantation. Fish were tracked with a receiver and antenna by boat, and could be located to within 1 m of their true position (Koehn 2006). Tracking occurred at least monthly, but typically every 2 wk until December 1995; the location and distance the fish had moved from its last known location were recorded. Aircraft tracking over a river length of 250 km centered on the study site was

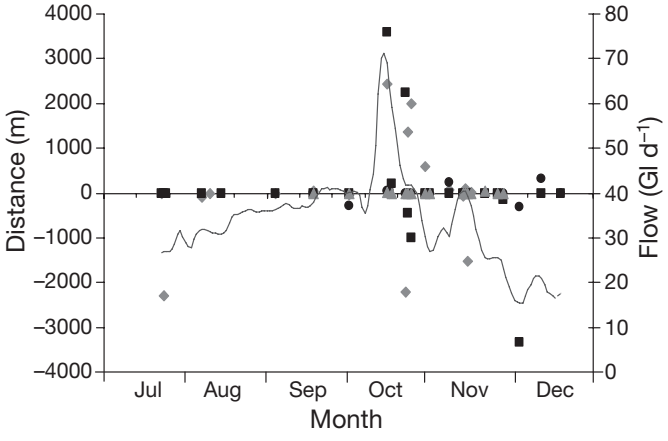

Fig. 1. *Maccullochella macquariensis*. Movement distances from the previous location for the 4 individual radiotagged trout cod (indicated by different shapes and shades) from July to December 1993. Daily flow data for this period for the Murray River (Corowa gauge) Gl: gigalitre

undertaken monthly during 1994 and 1995 to attempt to locate fish that had not been located during boat tracking.

Conventional and PIT tagging. Boat electrofishing surveys were conducted between May and July of each year from 1999 to 2006, with all trout cod >180 mm TL tagged with either an external T-bar or dart tag (Hallprint), a PIT tag (23 mm, Texas Instruments; or 11 mm, Trovan) or both. PIT tags were either inserted into the body cavity or into the dorsal musculature of the fish. Conventional tags were inserted into the dorsal musculature of the fish. External tags had an individual number and a telephone number to enable anglers to report capture of the fish. Recaptures occurred both through subsequent electrofishing surveys or reported angler captures.

RESULTS

In the pilot study, 2 of the 4 tagged fish moved distances of up to 6 km (Fig. 1). This movement mainly occurred in October and coincided with over-bank river flooding. During this period, these fish were very active and not stationed at any 'home' sites. The other 2 fish had more limited movements during this period (<320 m).

In the main radiotracking study, 6 of the radiotagged fish were only located for 3 mo after release during the study. These fish were not used in the analysis of movement. No fish were located by aircraft that had not already been located by boat tracking. Movements of >1 km were only detected in 2 individuals from the radiotelemetry dataset, with the majority of movements detected <100 m (Fig. 2a). Fidelity to particular locations within the river was evident for the 9 radiotagged fish, with fish regularly observed in the same location on multiple occasions (Figs. 2a & 3). Frequency plots are presented for 5 fish (Fig. 3) with another 4 fish not graphed as they used <3 locations. Flows during the main study had over-bank flooding during winter (June to August) (Fig. 2b).

A total of 418 recaptures (including 85 returns from angler captures) were recorded from 5653 trout cod

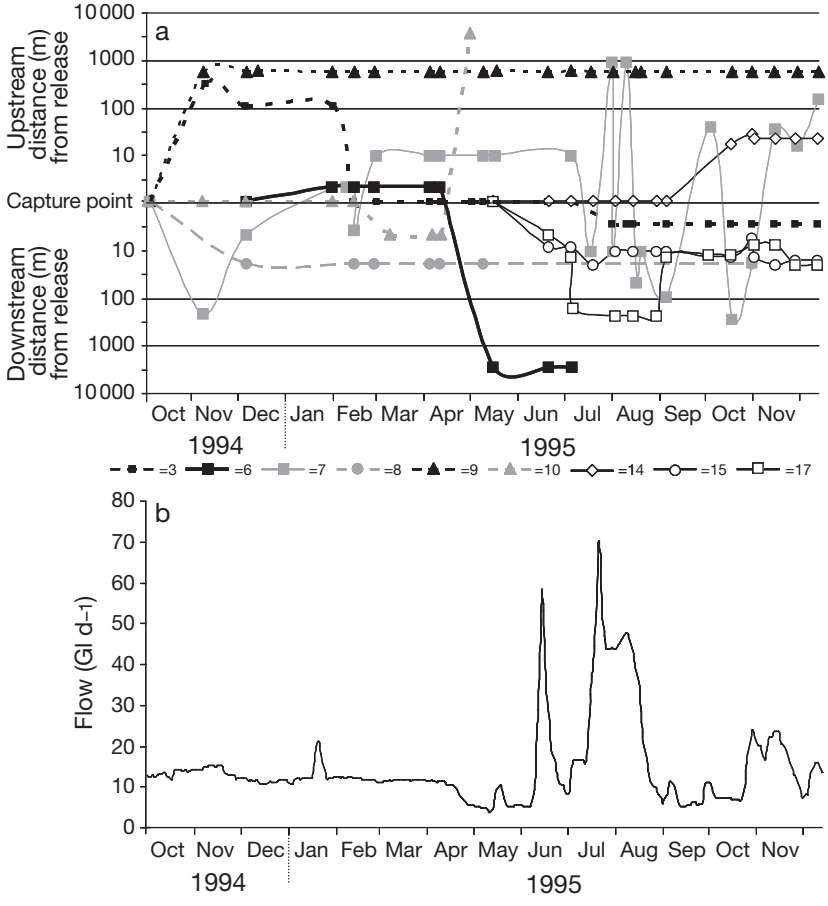

Fig. 2. *Maccullochella macquariensis*. (a) Movements from capture point of 9 individual radiotagged trout cod (identified by number) from October 1994 to December 1995. (b) Daily flow records for this period for the Murray River (Lake Mulwala gauge)

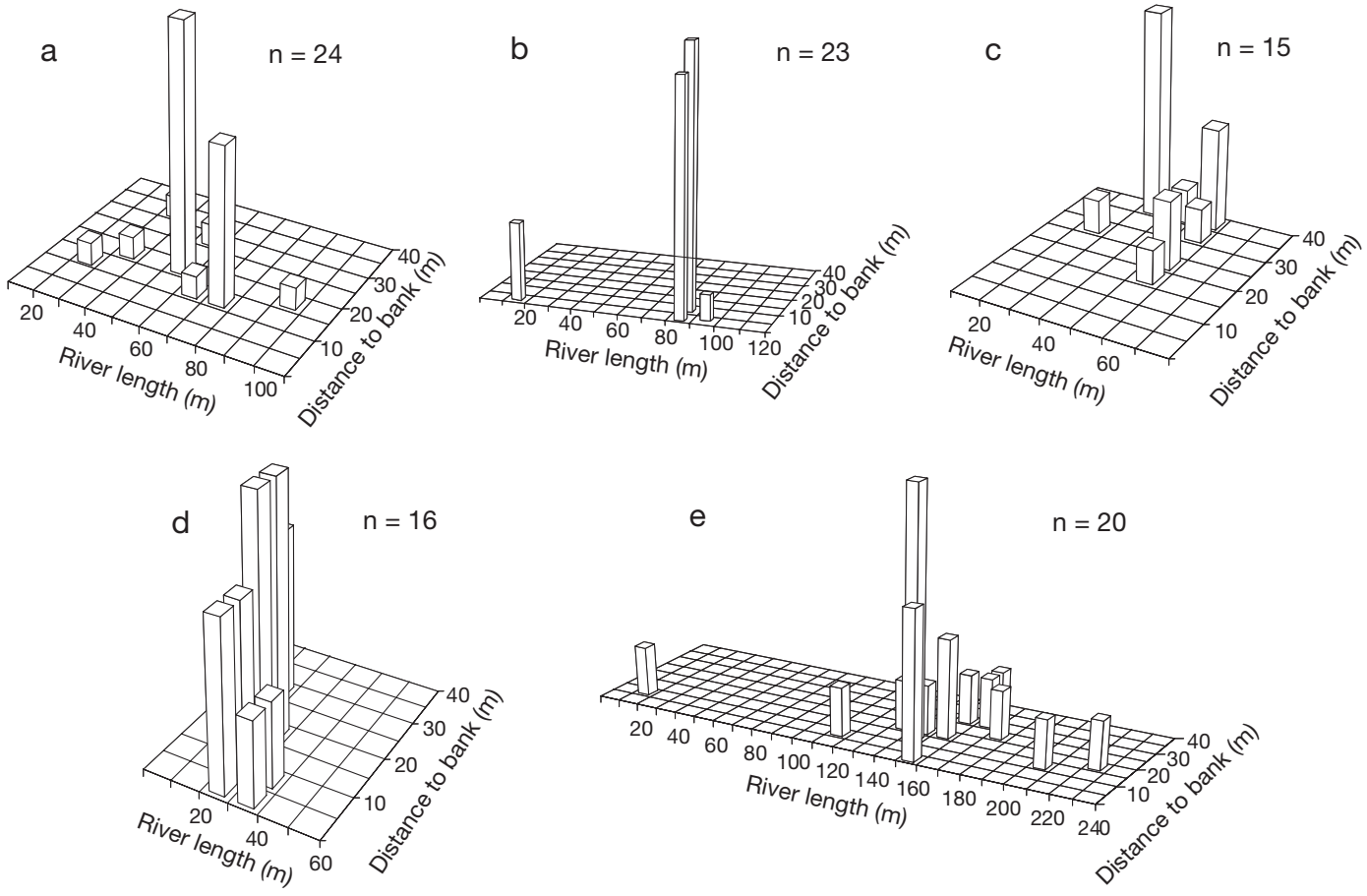

Fig. 3. *Maccullochella macquariensis*. Frequency plots for the longitudinal and lateral locations observed for 5 trout cod demonstrating site fidelity. n = no. of observations

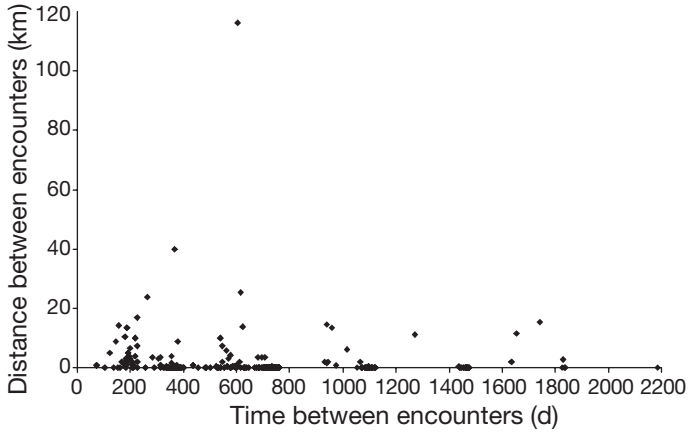

Fig. 4. *Maccullochella macquariensis*. Distance between tag and recapture sites for trout cod over time

tagged with conventional or PIT tags between 1999 and 2006. The size range of fish tagged varied between 180 and 689 mm TL. Of these recaptures, 10% reported distances between encounters in excess of 3 km. A distance of 0 km (maximum inaccuracy estimated to be ±50 m) between encounters was reported for 81% of these recaptures (Fig. 4). The greatest distance reported was 116 km, determined from an angler recapture (603 d after release) from a fish of 253 mm TL (when initially tagged). No difference was observed in average distance moved between encounters for fish of different lengths (Fig. 5).

Movement into floodplain channels was observed in 5 radiotagged individuals (2 pilot study and 3 main study fish), indicating that trout cod were not solely restricting their movements to the main river channel. Movements into anabranches were recorded over 1 km from the main river channel. Fish were recorded back in the main channel within 1 mo of entry. One fish was also located about 30 m from the main channel and another 15 m from a floodplain channel on the flooded floodplain during a high flow event. Average home range calculation for the radiotagged fish was 61 ± 46 m (95% confidence interval) and average recorded distance between encounters for conventionally tagged fish was 1200 ± 640 m (95% confidence interval).

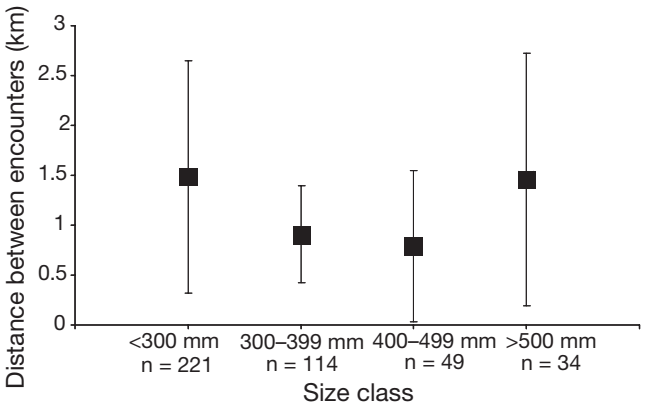

Fig. 5. *Maccullochella macquariensis*. Mean (±95% CI) distance between tag and recapture sites for each trout cod size class

DISCUSSION

Trout cod exhibited strong evidence for site fidelity and homing in the present study, typically utilizing only a few locations in the river channel. Site fidelity is the tendency of an animal to return to an area previously occupied or to remain within the same area for an extended period of time, with 'homing' being a return to that area (White & Garrott 1990). Site fidelity and return movements to 'home sites' have long been recognized amongst riverine fishes (Gerking 1953). Average home range size determined from radio-tagged trout cod in the present study was 61 ± 46 m (95% confidence interval). This is comparable to the average of 78 m reported for trout cod by Ebner & Thiem (2006) and 70 to 820 m reported for Mary River cod (Simpson & Mapleston 2002). Evidence for homing is provided for a range of species, including the Colorado squawfish *Ptychocheilus lucius* (Tyus 1985), male razorback suckers *Xyrauchen texanus* (Modde & Irving 1998), barbel *Barbus barbus* (Baras 1994), and in Australia by Murray cod (Koehn 2006), Mary River cod *Maccullochella peelii mariensis* (Simpson & Mapleston 2002), golden perch *Macquaria ambigua* and carp *Cyprinus carpio* (Crook et al. 2001, Crook 2004, O'Connor et al. 2005). Trout cod returned to home sites after movements undertaken at a range of scales from a few metres to >1 km.

Determining trends in movement patterns is often difficult when studying endangered species such as trout cod, for which the number of study fish is usually limited. There was considerable variation in the movements of individual trout cod; however, no seasonal association with movement was detected. The greater number of movements and distances traveled occurred under flood conditions in October 1993, which corresponded to the spawning period (Koehn & Harrington 2006). There was no observable association between movements and larger flow events in July–August or larger movements observed during the confirmed spawning season in 1995 (Koehn & Harrington 2006). Mean monthly distance moved was correlated to stream discharge for Mary River cod (Simpson & Mapleston 2002), and increased movements prior to spawning have been reported for Murray cod (Koehn 2006) and golden perch *Macquaria ambigua* (O'Connor et al. 2005). The lack of large-scale movements by all trout cod over the spawning period in 1995 indicates that such movements may not be obligatory for all mature individuals. Large amounts of structural woody habitat that may be considered to be suitable for potential trout cod spawning sites are found throughout the study reach (Koehn et al. 2004).

The proportion of larger movements reported for trout cod from the radiotelemetry study may be an underestimate. Information was insufficient for the analysis of movement for 9 individuals that were implanted with radio tags in the present study. These fish were either never located after release or were only relocated within 3 mo of release. It is plausible that these fish moved larger distances and were not detected. However, it is also plausible that the transmitters failed or that the fish were illegally harvested by recreational anglers. Aircraft tracking over a river length of 250 km centered on the study site occurred during 1994 and 1995, but did not locate these fish. Individuals may have also moved and returned between encounter occasions without our knowledge in this study. Developments in data storage devices/loggers that continuously monitor telemetry signals (e.g. Eiler 1995) offer a potential mechanism for overcoming this issue. Similarly, *in situ* PIT tag readers (Castro-Santos et al. 1996, Lucas & Baras 2000) may provide additional options for addressing this question. The present study was conducted solely during daylight hours, and while there have been observations to suggest that trout cod have increased movements at night, vagility remains limited (Thiem et al. 2006, J. D. Koehn unpubl. data).

Management and restoration of fish habitats should be based on an understanding of the use of those habitats at scales relevant to the fish rather than scales determined by humans (Crook et al. 2001). Movement provides the mechanism for accessing and utilizing such necessary resources (Albanese et al. 2004). The movements observed in the present study for most individuals provide important insights for the conservation and restoration of habitats for this endangered species. Habitat restoration is a key tool being implemented by resource managers to recover trout cod and other threatened fishes in the Murray River (Brown et al. 1998, Barrett 2004, Nicol et al. 2004), including the reinstatement of in-stream wood, a primary habitat of

this species (Growns et al. 2004, Nicol et al. 2007). Our results indicate a generalized movement pattern for trout cod (>180 mm TL), where most individuals occupy a limited home range, with a few fish moving larger distances. This suggests that restoration of habitat needs to occur in close proximity to source populations for it to be rapidly colonized by adult trout cod and juveniles >180 mm TL. For effective connectivity for trout cod, distances between habitat patches should be minimized (<1 km). Larger movements in 1993 may have been facilitated by high flows over the spawning period and included movements into floodplain channels and onto the nearby floodplain.

For the purposes of conservation planning, combining habitat restoration with translocation or restocking may be a sensible option if rapid colonization is desirable at locations distant from an existing population. The general pattern of movement described here is consistent with other accounts. For example, Ebner & Thiem (2006) reported a mean home range for trout cod (310 to 429 mm TL) in a stocked population of 78 m with a small number of their fish undertaking home range shifts (Crook 2004) of up to 2.4 km. A further study conducted to experimentally test the translocation of juvenile (2 yr old, 330 to 424 mm TL) trout cod into new habitats observed that all fish stayed within 5 km of their release site over the 6 mo of the study (Ebner et al. 2007). In contrast, larger dispersal distances have been recorded for hatchery-reared trout cod liberated at 4 to 6 mo of age. Anglers have reported captures of fish 100 km downstream of a stocking site on the Murrumbidgee River 2 yr later, and fish have been captured 15 km upstream of a site after 3 mo (M. Lintermans pers. comm.). Trout cod larvae are also known to drift (Koehn & Harrington 2006), and this may provide larger dispersal distances, depending on flow conditions. This information, together with the results of the present study suggests that the earlier life-stages of trout cod may be more dispersive than adults.

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