Diel Activity of the Endangered Trout Cod (*Maccullochella macquariensis*) in the Murrumbidgee River

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Diel movements and habitat use of most of Australia's large freshwater fish fauna remain unknown, despite conservation efforts for many of the threatened species, including re-stocking and habitat protection and restoration. We used radio-telemetry to monitor diel movements of the endangered trout cod (*Maccullochella macquariensis*: Percichthyidae) in a re-stocked population in the Murrumbidgee River, New South Wales, Australia. Both manual tracking and continuous remote telemetry identified that trout cod activity peaked in periods of low light; with linear ranges for individuals varying from 6–272 m. Trout cod had strong fidelity to outer river bends throughout diel periods and this has implications for targeted habitat rehabilitation efforts.

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KEYWORDS: diel activity; home range; Percichthyidae; radio-telemetry

INTRODUCTION

Trout cod (*Maccullochella macquariensis* (Cuvier): Percichthyidae) is a large freshwater fish endemic to rivers in the southeast of the Murray–Darling Basin, Australia (Ingram and Douglas 1995). The species has undergone a large scale reduction in distribution from much of its former range (Cadwallader and Gooley 1984; Douglas et al. 1994) and is currently classified as endangered (IUCN 2006). Self-sustaining populations of trout cod are now limited to a single remnant population and two translocated populations (Douglas et al. 1994; D. Gilligan, pers. comm.). Conservation efforts to re-establish the species have been strongly focussed on: 1) stocking hatchery-produced fingerlings (Lintermans and Phillips 2005) and, 2) understanding habitat requirements (Growns et al. 2004; Nicol et al. 2007).

Trout cod in both remnant and stocked lowland populations exhibit strong preferences for in-stream wood habitat (Growns et al. 2004; Nicol et al. 2007) as this generally forms the dominant structural habitat type in lowland rivers (Koehn et al. 2004). Trout cod also prefer deep sections of river (Nicol et al. 2007); often away from the river bank (Growns et al. 2004). However, both Growns et al. (2004) and Nicol et al. (2007) only report on trout cod habitat use during diurnal periods. With river restoration practices underway in some rivers, including the addition of structural wood habitat (e.g. Nicol et al. 2004), the lack of information on trout cod use of space and habitat over diel periods represents a significant knowledge gap.

In Australia, radio-tracking has successfully been used to study localised movement of large freshwater fishes, primarily percichthyids (Butler 2001; Crook et al. 2001; Simpson and Mapleston 2002; Crook 2004a, b; Ebner et al. 2005). Large percichthyids exhibit site fidelity, have relatively small home ranges (the area over which the animal normally travels in search of food (Burt 1943)) as adults over most or all of the year (Koehn 1997; Simpson and Mapleston 2002; Crook 2004a, b) and are active during periods of low light (Butler 2001; Simpson and Mapleston 2002; Ebner et al. 2005). The aim of this study was to determine diel habitat use and activity of stocked trout cod in a lowland river.

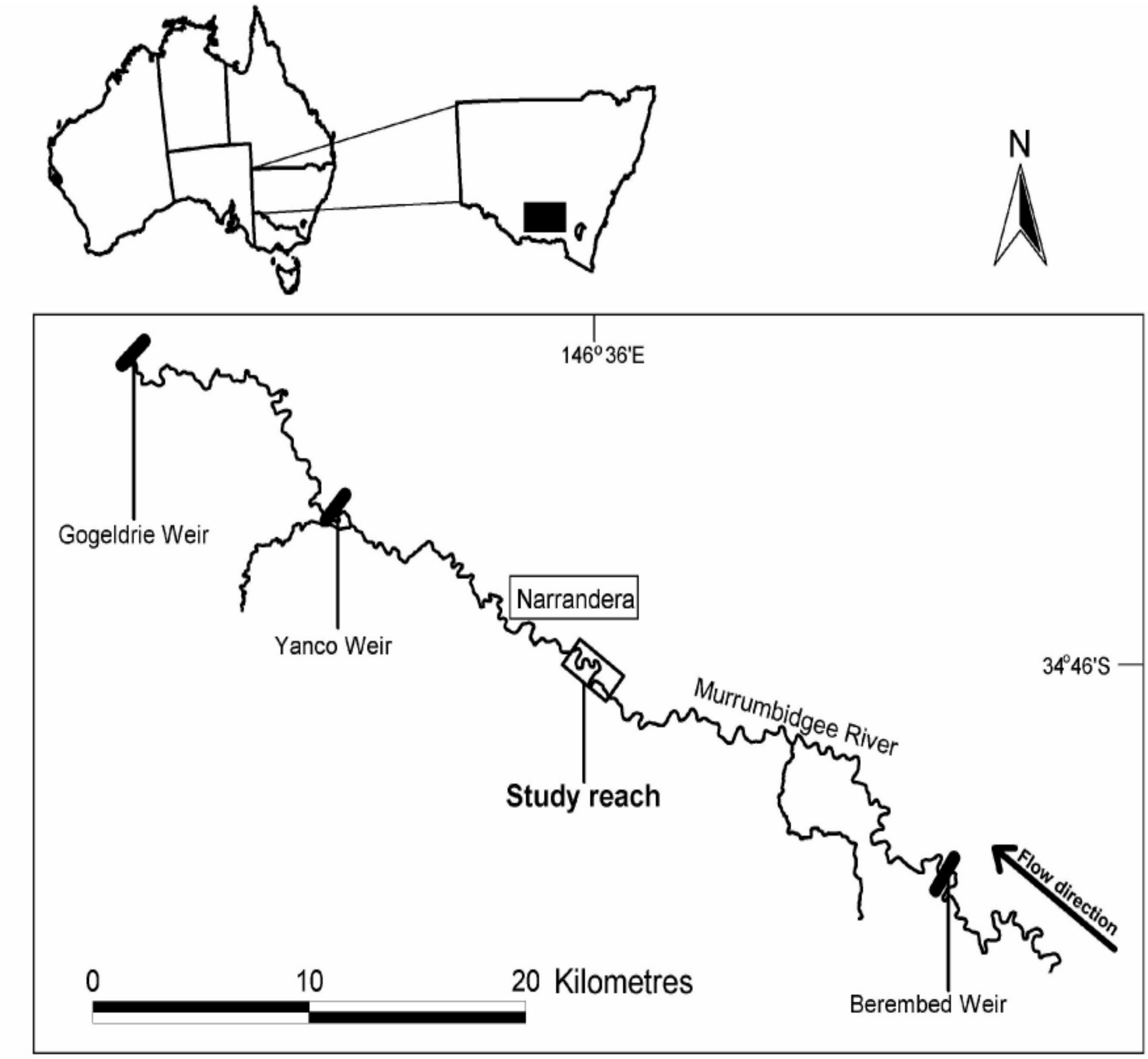

Figure 1. Location of the study reach in southern New South Wales, Australia.

MATERIALS AND METHODS

Study site

The study was conducted in a lowland reach of the Murrumbidgee River, 5 km upstream of the township of Narrandera (173 m ASL) in southern New South Wales (NSW), Australia (Fig. 1). Narrandera is one of twelve trout cod stocking sites in the Murrumbidgee catchment, with 85,000 fingerlings stocked at this location between 1996 and 2000 (Gilligan 2005). Subsequent surveys have identified survival and growth of trout cod (Growns et al. 2004; Gilligan 2005). The river channel has widths of 60–70 m and maximum water depths of 3–5 m occur on outside bends of the river. River red-gum *Eucalyptus camaldulensis* is common along both banks and fallen trees or branches comprise the dominant in-stream structural habitat for trout cod (Growns et al. 2004).

Fish collection and surgery

Movement data were collected from 10 radio tagged trout cod (370–575 mm Total Length (TL), 599–2587 g, Table 1), probably comprising a mixture of mature and immature fish (Harris and Rowland 1996). These 10 individuals comprised nine trout cod captured in the study reach by boat electro-fishing and one trout cod on-grown in a hatchery and subsequently released. These individuals were originally from samples containing 31 trout cod collected in the study reach by boat electro-fishing (formerly stocked as fingerlings and subsequently re-captured) and from 27 trout cod sourced from a state government hatchery (on-grown two year-old fish). Radio tags (internal body implants with a 30 cm trailing whip antenna, models F1830, 35, 40 and 50, Advanced Telemetry Systems (ATS), Isanti, USA) were surgically implanted into the peritoneal cavity under anaesthesia (0.5 ml Alfaxan (Jurox, Rutherford, Australia) per litre of water). The weight of radio tags in air were between 11 g and 25 g to suit a range of fish sizes and were kept to ≤ 2% of fish mass. Pulse-coded, two–stage radio transmitters were used on a frequency of 150–152 MHz and programmed on a pulse rate of 5 s on and 7 s off to increase battery life (warranted for between 230 and 504 d). For external identification, individuals were also tagged with a dart tag between the second and third dorsal spines. Tagging procedures were identical to those described by Ebner et al. (2007), with the exception that surgical incisions were 2–3 cm in this study. Individuals were initially recovered in a darkened enclosure holding 200 l of aerated water at 5 parts per thousand NaCl. Upon regaining swimming ability individuals were transferred to large circular concrete enclosures that held between 500 and 1000 l at 5 parts per thousand NaCl. Individuals were held for 2–15 d in the hatchery following surgery and all individuals were released at the same location in late September 2003. We assume that full recovery from tagging procedures and resumption of normal behaviour had occurred since this study was conducted from 14–19 November 2004.

Radio-telemetry

A modified technique of David and Closs (2001) was used to remotely monitor the activity of a single trout cod (trout cod no. 5, Table 1) continuously from 2000 h 14 November until 0900 h 19 November 2004 (Australian Eastern Standard Time). A three–element Yagi antenna (Titley Electronics, Australia) was fixed to a tree within the home range of trout cod no. 5, perpendicular to the stream (the home range location of trout cod no. 5 had been determined in a previous study (Ebner et al., 2006)). The antenna was connected to a remote data logger (DCCII Model D5041, ATS) via a receiver (Model R4100, ATS) and recorded radio signal strength every 5 s. The standard deviation of signal strength was plotted in 10 min grouped intervals to examine signal variability as a measure of activity, with high signal variability indicating active periods (David and Closs 2001). Detection range of the data logger was approximately 80 m in any direction, incorporating any movements to the opposite river bank.

Ten individuals were manually tracked every four hours for two consecutive 24 h periods (1400 h 15 November until 1400 h 17 November 2004) from a power-boat. Trout cod no. 5 was subsequently tracked hourly for an additional 24 h period (0600 h 18 November until 0700 h 19 November 2004) from an electric powered boat. Radio-tracking fixes were determined using a handheld three–element Yagi antenna (Titley Electronics) and a receiver (Australis 26k, Titley Electronics). Locations were recorded using a handheld GPS unit, with three GPS points taken at each location.

Data analysis

GPS records were averaged to provide a single location datum for each individual per radio-tracking fix. Spatial data were plotted in ArcView 3.2™ (ESRI, USA) over a base-map, generated by walking both banks of the river with handheld GPS units. A polyline was generated based on the sequential locations of each individual using the Animal Movement Extension in ArcView (Hooge and Eichenlaub 1997) and the polyline was used to construct a time series of the distance moved by fish between consecutive radio-tracking periods (activity). Linear range (the distance between the most upstream and downstream points) and area used (Minimum Convex Polygons (MCP)) were also calculated with ArcView. To determine the proportion of river used (for comparison with MCP estimates), an ‘available area’ metric was calculated. This involved constructing a line perpendicular to the river channel at the most upstream and downstream fix of each individual and estimating the wetted area within these limits. Statistical analysis was conducted using Statistix for Windows (version 2.0) with data transformed, when necessary, to achieve normal distribution (Tabachnick and Fidell 1989).

RESULTS

The linear range of trout cod over two consecutive diel periods ranged from 6–272 m, with a mean (± SE) of 83.1 ± 30.0 m (Table 1). There was a significant positive correlation between fish length (mm) and linear range (m) over the two diel periods (Pearson correlation co-efficient: 0.7219, $P<0.05$). The area of river used (MCP) over the two consecutive diel periods ranged between 18.5–4603.5 m^2 and averaged 1284.1 ± 621.1 m^2 (Table 1). There was also a significant positive correlation between fish length (mm) and area used (m^2) over the two diel periods (Pearson correlation co-efficient: 0.7337, $P<0.05$). For trout cod no. 5, increasing the temporal resolution of tracking from four–hourly to hourly increased both the linear range estimate (75 to 84 m) and the area used estimate (307 to 1010 m^2), over a single diel period. Trout cod no. 5 used the same section of river for all diel periods, however, hourly tracking resulted in an increased lateral range, reflected by a larger area estimate.

Table 1. Estimates of length and area of river used by 10 radio tagged trout cod in the Murrumbidgee River at Narrandera, NSW. Values are based on four–hourly radio-tracking, combined over two consecutive diel periods. *Trout cod no. 6 had a weak radio signal and was excluded from subsequent range and area calculations. †Denotes on-grown hatchery individual.

Trout cod no.	Total length (mm)	Weight (g)	Sex	Linear range (m)	Area used (m^2)	Available river area (m^2)	Proportion of available river used (%)
1	371	672	?	25	292	2293	13
2	370	599	F	26	280	1926	15
3	412	834	F	15	191	1128	17
4	405	827	?	6	19	585	3
5	430	1066	?	90	658	6160	11
6*	466	1249	?	N/A	N/A	N/A	N/A
7	461	1292	M	109	925	8374	11
8	481	1384	?	272	4604	20516	22
9†	407	1247	?	31	128	2332	5
10	575	2587	M	174	4463	12672	35
Mean (SE)	**437.8 (19.4)**	**1175.7 (179.4)**		**83.1 (30.0)**	**1284.1 (621.1)**	**6220.8 (2227.7)**	**14.7 (3.2)**

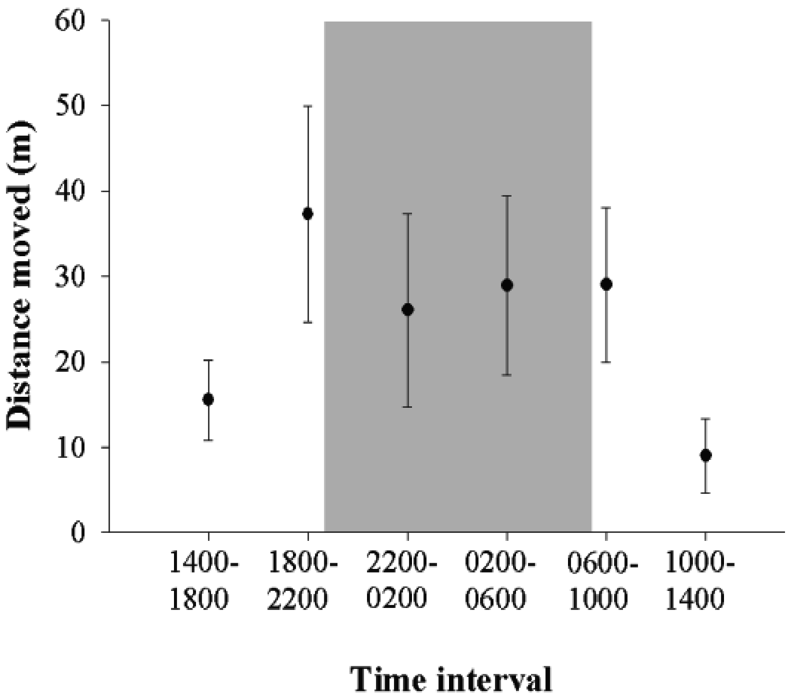

Figure 2. The diel activity of nine trout cod in the Murrumbidgee River based on the minimum distance moved between four hourly radio-tracking locations (mean ± SE). White and grey sections denote day and night, respectively. Data are from two consecutive diel periods.

The mean (± SE) area of river used by nine individuals over two consecutive diel periods, 1284.1 ± 621.1 m^2, represented only a small proportion (14.7 ± 3.2%) of the river that was available within the upstream and downstream limits of total range (Table 1), suggest-ing that individual trout cod select specific habitats in relatively small areas. All ten individuals (including trout cod no. 6 that had a weak radio signal enabling occasional detection) were always located in the thalweg during the day. For nine of ten individuals this corresponded to a location in close proximity (<20 m) to the outer river bend. An exception was the position of one individual on the inside of a bend at the upstream end of a braided channel section. Nine of 10 individuals did not cross from one side of the river to the other during the study. One individual

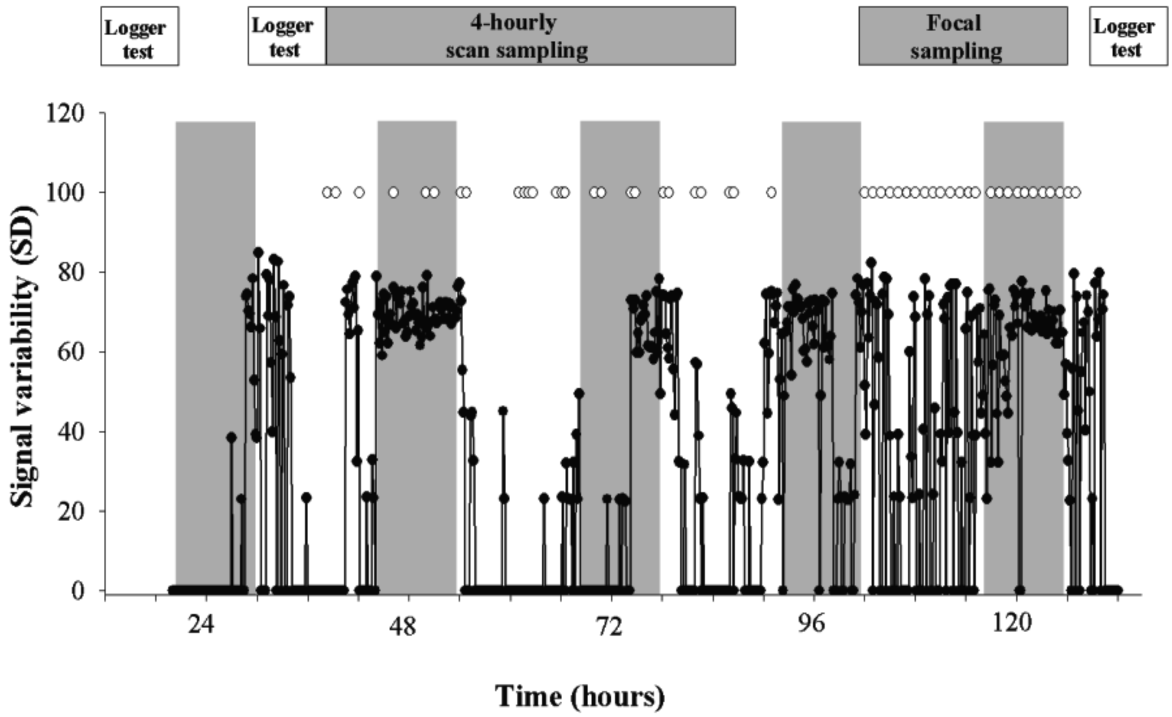

Figure 3. Activity of trout cod no. 5, based on continuous logging of signal strength from its radio transmitter, 14–19 November 2004. Data are grouped at 10 min intervals and plotted as the variation in radio transmitter signal strength. Open circles at the top of the graph denote boat activity (predominantly investigator related) within the reach. Day and night periods are represented in white and grey respectively.

(trout cod no. 10, Table 1) was recorded crossing the channel. This occurred in a straight section of river that was without shallow water associated with either bank. Additionally, four individuals had overlapping ranges during this study. Two of these individuals were found to co-inhabit the same hollow log during the day for the duration of the study.

Movements of trout cod were generally greater at night, dusk and dawn relative to daytime (Fig. 2). The period of greatest movement (mean ± SE) 37.27 ± 12.6 m was between 1800 h and 2200 h, with the period of least movement 8.98 ± 4.34 m between 1000 h and 1400 h (Fig. 2). Differences in distance moved between time periods were non-significant (Kruskal-Wallis One–way ANOVA, d.f.=107, H=9.1671, P>0.05).

Data from the remote logger revealed sporadic variations in signal strength for the first three daylight periods (Fig. 3). In comparison, variations in signal strength were consistently higher and sustained for longer periods of time during the night or during dusk or dawn periods, indicating periods of heightened activity. Additionally, radio transmitter signal strength varied repeatedly throughout the fourth daylight period of remote telemetry logging (Fig. 3). This period coincided with a decrease in water discharge (4376–3336 ML/day) and river height (0.21 m decrease) (NSW DNR 2004). The fourth daylight period also coincided with more intensive radio-tracking of trout cod no. 5, changing from four to one hourly (Fig. 3).

DISCUSSION

Trout cod occupied small (<300 m) lengths of river over consecutive diel periods in this study and the size of movements (linear range and area used) were positively correlated with fish length. These individuals had previously demonstrated fidelity to the same diurnal locations throughout much of the previous year (Ebner et al. 2006). Similarly this species has been shown to be relatively sedentary in the Murray River (Koehn 1997; Koehn and Nicol 1998). The small movements of trout cod are similar to that reported for other Australian percichthyids (Butler 2001; Simpson and Mapleston 2002; Crook 2004a, b).

Individual trout cod demonstrated a preference for movements along outer river bends within diel periods in this study. These outer bends are associated with deeper areas and contain more structural woody habitat in lowland rivers (Hughes and Thoms 2002; Koehn et al. 2004). Efforts to conserve trout cod and other threatened percichthyids should be aided by an improved understanding of their lateral movements in large lowland rivers. This information provides the basis for strategic placement of structural woody habitat in stream restoration programs (e.g. Nicol et al. 2004).

Differences between estimates of available river area and the area used by each individual reflected the fidelity of trout cod to outer bends. Where linear movements of a species predominate, standard methods to calculate home range often produce considerable over-estimates (Blundell et al. 2001). Therefore equating home range size to the area of river within the upstream and downstream limit of a radio-tracked individual (e.g. Gust and Handasyde 1995) is an overestimate when applied to trout cod in a large lowland river. The lateral distribution of trout cod within a large lowland river is likely to be a direct response to in-stream habitat differentiation (Hughes and Thoms 2002; Koehn et al. 2004).

The logger method detected distinct nocturnal activity of an individual whereas coarse-scale manual radio-tracking did not. There was an indication of greater movement during crepuscular and nocturnal periods, based on manual radio-tracking of ten individuals. Simpson and Mapleston (2002) found that the activity of Mary River cod *Maccullochella peelii mariensis* Rowland was matinine, based on real-time manual radio-tracking within one–hour periods. Our findings indicate that application of the continuous remote telemetry method of David and Closs (2001) based on increased sample sizes (e.g. David and Closs 2003) is likely to be an effective means of elucidating the diel activity patterns of trout cod.

The cause of the shift from nocturnal to both nocturnal and diurnal activity of an individual in this study is unknown. The shift corresponded to both the use of one–hourly boat-based manual radio-tracking and a change in discharge and river height. This demonstrates the capacity to use variation in signal strength from remote loggers to monitor disturbance (e.g. by the researcher, releases from dams) in experiments. To date the application of variation in signal strength has only been used to record diel activity (see Baras et al. 1998; David and Closs 2001; Hiscock et al. 2002; David and Closs 2003). Possible observer effects could be investigated by remotely monitoring the activity of an entire sample, whilst conducting manual radio-tracking of a subset of individuals.

To produce reasonable estimates of the extent of diel range, four–hourly radio-tracking (of about five to ten individuals) appears to represent the most pragmatic solution for a team of two researchers. Before results of this study are used in a management context, observations of home range size and shape should be replicated among seasons to strengthen the data set. This study indicates that trout cod inhabit small reaches of river on a scale of tens to hundreds of metres, within the deeper outer bank of the Murrumbidgee River, over short periods of observation. Consequently, the recovery of this species can probably be conducted within small reaches of river and specific in-stream habitats can be prioritised for rehabilitation.

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