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Short communication

Golden perch *Macquaria ambigua* are flexible spawners in the Darling River, Australia

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Abstract The role of flow and floodplains for the recruitment of fishes in the Murray-Darling Basin, Australia, remains a contentious issue. In this context, the reproductive ecology of golden perch *Macquaria ambigua*, a widespread, high-profile angling species with a propensity to produce large numbers of semi-pelagic eggs remains to be resolved. Back-calculation of spawning dates from otoliths of juvenile golden perch (*Macquaria ambigua*) collected in August and November 1997 from the Menindee Lakes on the floodplain of the Darling River, in western New South Wales, Australia, advances understanding of spawning of this species in three ways: (1) golden perch spawned at lower temperatures (≤18.8°C) than has previously been reported from the Murray-Darling Basin; (2) golden perch in the Menindee Lakes can be derived from spawning in all seasons of the year in contrast to what is apparent in more southerly locations of the Murray-Darling Basin; and (3) spawning can occur in the absence of floods.

Keywords *Macquaria ambigua*; recruitment; flow; temperature; floodplain; otolith

INTRODUCTION

Considerable effort has been expended documenting the changes in fish assemblages including the large-scale decline of the native fish fauna in the highly regulated lowland river systems of the Murray-Darling Basin, Australia (e.g., Llewellyn 1983; Harris & Gehrke 1997; Humphries & Lake 2000). However, causal links between environmental variables and recruitment of native fish populations remain poorly understood. Fish native to the Murray-Darling Basin have evolved in an unpredictable, fluctuating environment in which large variations in population size are to be expected. Flow regulation through its impact on the movement of fish both in-channel and onto the floodplain has been implicated in the decline of native fish populations of the Murray-Darling Basin (Cadwallader 1978; Reynolds 1983; Gehrke 1991; O'Connor et al. 2005). Ultimately, to improve fish spawning and recruitment success through improved river and floodplain management, the empirical relationships between life history phase requirements and habitat availability need to be understood (Petts et al. 1989; Gehrke 1991; Arthington & Pusey 1993; Krebs 2002).

Golden perch (*Macquaria ambigua* Richardson 1845; Percichthyidae) is one of the most widespread and abundant of the large native fishes in the lowlands of the Murray-Darling Basin (e.g., Harris & Gehrke 1997; Lintermans 2007) and represents an important recreational fisheries species (McNee 1993). Temperature and changes in flow or water level are generally considered important cues stimulating spawning of golden perch (Koehn & O'Connor 1990; Gehrke 1991; Humphries et al. 1999; O'Connor et al. 2005). Specifically, spawning

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in golden perch has been reported to occur between October and April (Lake 1959, 1967a; Cadwallader 1977; Koehn & O'Connor 1990), when water temperatures exceed about 23°C (Lake 1967a,b,c,d; Llewellyn & MacDonald 1980; Richardson 1984), or when warm temperatures coincide with a rise in water level (Lake 1967d; Mackay 1973; Richardson 1984; Gehrke 1991,1994; Harris & Gehrke 1994). But as early as the 1950s, it was recognised that golden perch could spawn in response to both a rise and a fall in river height (Cadwallader 1977).

Fish recruitment models, such as the "flood-recruitment model" (Gehrke 1991; Harris & Gehrke 1994) and the "low flow recruitment hypothesis" (Humphries et al. 1999), have attempted to link spawning and subsequent recruitment success under different flow/water level conditions to food resource availability, as suggested by the "prey match-mismatch hypothesis" (Cushing 1975, 1990). Although it now appears that a number of native species recruit under low flow conditions (Humphries et al. 1999, 2002; King et al. 2003) and that golden perch are not obligate-flood-spawners (Mallen-Cooper & Stuart 2003), information describing links between water level, temperature and spawning in golden perch within the Murray-Darling Basin remains limited. Moreover, little information is available from study of populations in large floodplain systems such as the Menindee Lakes in the west of the Murray-Darling Basin. The Menindee Lakes are ephemeral deflation basin lakes that are used to provide environmental flows to the lower Murray River and water for the town of Broken Hill (Gawne & Scholz 2006; Pigram 2006).

Gehrke et al. (1997) report of a single collection of golden perch larvae in Lake Pamamaroo (one of the Menindee Lakes) and Balcombe et al. (2006) used collections of juveniles to infer hydrology-spawning relationships of golden perch in the Warrego River catchment (in the northern Murray-Darling Basin). Recently, Brown & Wooden (2007) validated the use of daily growth increments in golden perch otoliths, opening the way for using field collections of larvae and juveniles to confirm time of spawning in this species.

The current study was part of a larger investigation into ecological responses to wetting and drying of the Menindee Lakes, which included seasonal monitoring of shifts in the resident fish community. Monitoring of the fish community revealed that golden perch inhabit the littoral zone of a number of these lakes as small juveniles (<50 mm total length) (B.C. Ebner unpubl. data). Specimens were retained for diet analysis (not reported here) and ageing since the necessity of flows and flooding for golden perch spawning and recruitment remain unknown. The aim of the current study was to describe the water level and thermal conditions under which golden perch spawned.

MATERIALS AND METHODS

The timing of golden perch spawning was determined by back-calculating the age of individuals from daily growth increments in otolith microstructure. Seventy-two juvenile golden perch collected from lakes Malta, Balaka, Bijiji, Tandure, Menindee, and Cawndilla (Fig. 1) during August (late winter) and November (late spring) 1997 were retained for analysis (Table 1). Field collections were achieved principally by seine netting (2 mm stretched mesh) in shallow water as overnight sampling with three fine mesh fyke nets (3 mm stretched mesh) at three sites around the littoral zone of each lake typically yielded few specimens (although specimens were also retained from fine mesh fyke nets). Specimens were preserved in 70% ethanol (this concentration was used to reduce shrinking of both specimens and stomach contents thereby facilitating diet analysis). Both standard length (SL) and total length (TL) measurements (to the nearest mm), were recorded before preservation and extraction of sagittae (although the SL of three individuals was not measured). Extracted otoliths were stored in water for 1 week to displace any alcohol that may cause cracking on drying, thereby reducing readability. Air-dried otoliths were then weighed (0.0001 g) and mounted on glass slides for polishing (with 800 grit glass paper attached to a rotating disc followed by 1200 grit glass paper) before counting growth increments at 400× to 1000× magnification. Age was estimated by a single experienced reader counting increments along a radial transect originating at the primordium. Each prepared otolith was counted twice to provide an indication of the error between age estimates. Error between age estimates was calculated as an index of average percentage error (APE) developed by Beamish & Fournier (1987). APE was relatively high (3.5%), but compared favourably with readings of golden perch annuli reported by Anderson et al. (1992) (APE = 3.9%). Among-individual variation in the deposit of first increment is in the order of 10 days in golden perch (Brown & Wooden 2007) and was inconsequential in the current study since the focus was on identifying spawning period in relation to time of year and flood events.

Of the 72 otoliths examined, those corresponding to the 35 largest specimens (76–173 mm SL) possessed

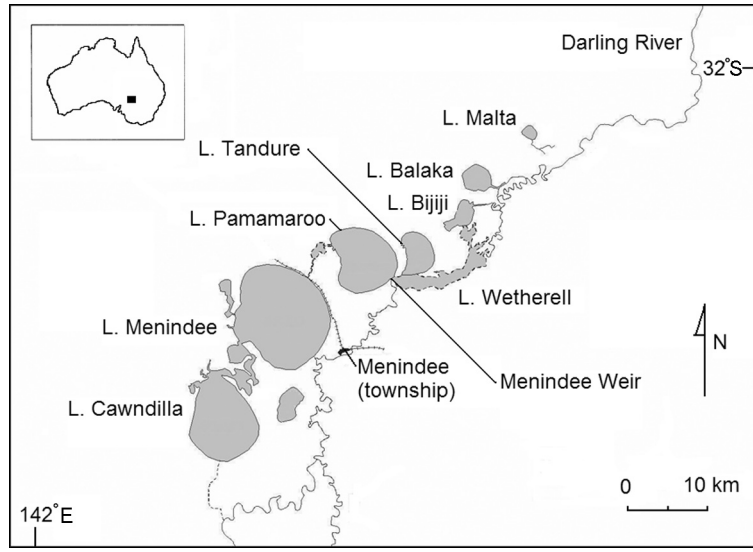

Fig. 1 Menindee Lakes (Murray-Darling Basin, Australia) where the study was conducted.

a large opaque increment near the outer edge. Daily increments were too fine and diffuse to count at the opaque increment under 1000× magnification precluding accurate daily age determination. Therefore, specimens bearing an opaque increment near the outer edge of the sagittae (which included all specimens collected from Lake Cawndilla) were excluded from further analysis. Daily age estimates were reliably determined from 33 of the remaining 37 specimens (18–65 mm SL). Estimates could not be determined from four (SL = 31, 37, 38, 40 mm) of the preparations as increments were too irregular and diffuse to count accurately.

Weekly water temperature (recorded at midday immediately downstream of the Menindee Weir and therefore approximating surface temperature in the Darling River) and water level data obtained from lakes Wetherell and Menindee were sourced from the New South Wales Department of Infrastructure Planning and Natural Resources (NSW DIPNR unpubl. data). Fluctuations in the water levels of lakes Malta, Balaka, Bijiji and Tandure were assumed to be similar to those recorded for Lake Wetherell (since these other lakes remained connected to Lake Wetherell during the study period, NSW DIPNR unpubl. data). Similarly, lakes Menindee and Cawndilla remained connected to each other throughout the study period (NSW DIPNR unpubl. data). Simples linear regression equations were calculated using SYSTAT®10.2 (SPSS Inc. Chicago, United States).

Table 1 Location (Murray-Darling Basin, Australia), date of capture, and number of juvenile golden perch *Macquaria ambigua* used in this study, including the number of specimens from which reliable estimated daily age estimates were determined, and number of specimens examined (in parentheses).

Lake	Date of capture	No. of individuals
Malta	7 August 1997	11 (11)
Malta	20–21 November 1997	3 (10)
Balaka	20 November 1997	3 (9)
Bijiji	25 November 1997	5 (10)
Tandure	26 November 1997	7 (11)
Menindee	24 November 1997	4 (12)
Cawndilla	27 November 1997	0 (9)

RESULTS

Estimated daily age (EDA) and otolith weight (OW) was significantly positively related (simple linear regression: EDA = 7085OW + 76.743, $r^2 = 0.5682$, $n = 33$, $P < 0.0001$). The individuals examined ranged between 18–65 mm SL and EDA of 64–133 days. Both EDA and SL data pairs were available from only 30 individuals. Although EDA and SL were significantly positively related (EDA = 1.29SL + 47.069, $r^2 = 0.723$, $n = 30$, $P < 0.0001$), the relationship appeared to weaken as fish grew. Therefore, otolith weight provided an indication of EDA, but fish length provided a better one (based on r^2 values) while also affording a non-destructive technique.

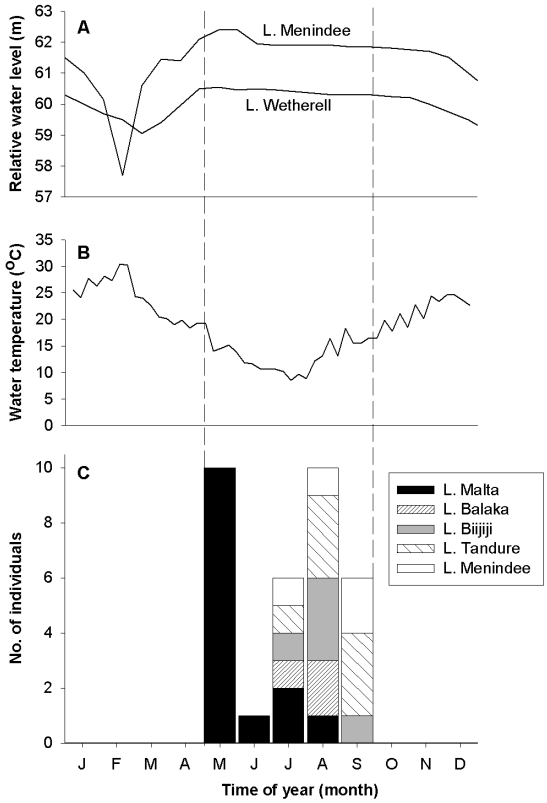

Fig. 2 Conditions under which golden perch *Macquaria ambigua* spawned in the Darling River based on: **A**, changing water level expressed as Australian Height Datum (AHD) in lakes Wetherell and Menindee (NSW DIPNR unpubl. data); **B**, water temperature just downstream of Menindee Weir (NSW DIPNR unpubl. data); and **C**, hatch month of juvenile golden perch (n = 33) collected from the Menindee Lakes in 1997. (Note: Water level of Lake Wetherell was equivalent to that of lakes Malta, Balaka, Bijiji and Tandure as each of these lakes remained connected to Lake Wetherell, and local rainfall had a negligible effect on lake levels. The water level of Lake Cawndilla was similar to that of Lake Menindee over the study period.)

Juvenile golden perch captured during August from Lake Malta were spawned between May and June (late autumn/early winter) (Darling River discharge at Wilcannia: 534–2176 ml/day, NSW DIPNR unpubl. data), several months after the start (1 March) of inflows from Lake Wetherell (the impounded Darling River) (Fig. 2) (peak daily discharge at Wilcannia: 25534 ml/day, 12 April 1997, NSW DIPNR unpubl. data). Individuals captured during November were spawned between July and September (winter to early spring) (Fig. 2). Water levels did not vary greatly during this second spawning period (Fig. 2) and flows in the Darling River were low (discharge at Wilcannia: 140–794 ml/day, NSW DIPNR unpubl. data). Spawning by golden perch occurred over a water temperature range of 10–19°C, with maximum spawning activity occurring during May and August, when weekly water temperatures reached a maximum of 18.5°C and 18.8°C, respectively (Fig. 2). Autumn spawning was not preceded by large changes in temperature, whereas the late winter spawning activity peak was associated with rising water temperatures (Fig. 2).

DISCUSSION

Slow growth rates of juvenile golden perch were recorded in this study. Arumugam & Geddes (1987) reported golden perch were 30.0–31.6 mm SL after 46 days, in aquaculture ponds, whereas in the current study a comparable length was attained at c. 85 days. In another aquaculture pond trial, Rowland (1996) reported a mean TL of 23.7–35.0 mm within 28–50 days. Comparable lengths were attained within about 65–90 days in the current study. The slow growth of golden perch in the Menindee Lakes may have been a function of comparatively low water temperatures slowing metabolism during the colder months of the year (cf. Rowland 1996).

In the current study, spawning dates determined from 33 juvenile golden perch caught in Menindee Lakes indicated that spawning occurred between May and September 1997. However, it was not possible to determine whether these individuals had moved from Darling River/Lake Wetherell or were spawned within the floodplain lakes. Presumably spawning occurred in the river since adults were rarely collected in these lakes during an 18-month survey (B.C. Ebner unpubl. data). Telemetry studies would clarify spawning sites (e.g., O'Connor et al. 2005). In the current study, a sample of offspring collected from Lake Malta was the result of spawning during May, 2 months after the start of inflows from Lake Wetherell into Lake Malta. Spawning coincided with the highest water levels in Lake Malta over the flood stage. This finding was comparable with reports of golden perch spawning on floods or in relation to elevated water levels previously in the Menindee Lakes (Brown & Neira 1998) and elsewhere in the Murray-Darling Basin (Lake 1967d; Mackay 1973; Battaglene 1991; McKinnon 1997; O'Connor et al. 2005; Balcombe et al. 2006).

A second spawning period in winter and early spring, was identified from offspring that were recovered from five of the six lakes sampled and did not coincide with marked changes in water level, indicating that spawning was not flood-related. Similarly, Humphries & Lake (2000) collected two golden perch larvae in Broken River in a non-flood/low flow year. Mallen-Cooper & Stuart (2003) provide evidence of strong recruitment by golden perch in the mid-reaches of Murray River during what they classed non-flood years. However, overbank flooding did occur in each of the 5 years (including during spring in each year) of their study (Mallen-Cooper & Stuart 2003), and daily increments were not examined to determine the relationship between timing of spawning and overbank flooding. Furthermore, the collections of Mallen-Cooper & Stuart (2003) were based on individuals of age ≥1 year, and since golden perch of this size were found to migrate, the possibility of immigration to the study reach could not be rejected. Similarly, Balcombe et al. (2006) inferred no-flow spawning from collections of juveniles in the Warrego River catchment (albeit based on much smaller juveniles than reported by Mallen-Cooper & Stuart (2003)) and the age of these fishes is unknown. Consequently, obligate flood-spawning cannot be conclusively ruled out from the evidence of Mallen-Cooper & Stuart (2003) or Balcombe et al. (2006). Our study and that of Humphries & Lake (2000) provide evidence in support of the conclusion of these two previous studies that not all golden perch are obligate-flood-spawners, in contrast to previous reports (e.g., Gehrke 1991). However, it is possible that spawning intensity or recruitment is flood-dependent.

Spawning occurred over an extended period, encompassing autumn, winter, and spring in this study. Furthermore, golden perch larvae have been collected from the Menindee Lakes in mid-summer (Brown & Neira 1998). Confirmation of the age-at-length of juveniles in the current study also provides a means of interpreting the length-frequency data of Balcombe et al. (2006), which in turn suggest spawning had occurred in each season at some stage from 2001 to 2003 in the Warrego River catchment in the northern Murray-Darling Basin. That this species can spawn in any of the four seasons at Menindee Lakes and the Warrego River catchment contrasts with reports of spawning in spring and early summer from more southern localities within the Murray-Darling Basin (Lake 1967d; Mackay 1973; Koehn & O'Connor 1990; McKinnon 1997; Mallen-Cooper & Stuart 2003; King et al. 2005). Battaglene (1991) found that golden perch spawned over a wide period from early September until late March in the Namoi catchment, at similar latitude to Menindee Lakes in the east of the Murray-Darling Basin. Collectively, these findings indicate the spawning period of golden perch widens with decreasing latitude within the Murray-Darling Basin. A relationship between duration of breeding season and latitude has been reported in other freshwater fishes (Duponchelle et al. 1999; Vila-Gispert et al. 2002) and requires confirmation for golden perch.

Golden perch spawned at lower temperatures (≤18.8°C) in this study than has previously been reported from the Murray-Darling Basin. The weekly temperature records used in this study are unlikely to have obscured daily spikes in temperature since the Darling River from Menindee to Wilcannia does not reach 23°C between May and September each year (Clayton Sharpe, Murray-Darling Freshwater Research Centre unpubl. data). Generally, 23°C has been considered the minimum temperature to facilitate spawning (Lake 1967a,b,c,d; Llewellyn & MacDonald 1980; Richardson 1984), although a female golden perch was collected "running ripe" from the Murrumbidgee River at 16°C and hormonally induced to spawn at 25°C shortly after in captivity (Steve Thurstan, New South Wales Department of Primary Industries pers. comm.). These results highlight that golden perch are capable of spawning at different water temperatures.

Golden perch are highly fecund migratory fish that tend to spawn in particular localities rather than broadly throughout their adult habitat (Harris & Gehrke 1994; O'Connor et al. 2005). Our results suggest that flood and elevated temperature are not crucial to spawning success in golden perch as has previously been considered. It appears that a single factor such as temperature or flow does not dictate the timing of spawning in golden perch (cf. Vila-Gispert et al. 2003; King et al. 2003).

The spawning of golden perch under low flow conditions in the current study is congruous with the low flow recruitment hypothesis (Humphries et al. 1999). Conversely, evidence of six of the Menindee Lakes functioning as nurseries for this species (cf. King et al. 2003) indicates that elements of the flood-recruitment model (Gehrke 1991; Harris & Gehrke 1994) apply. In future, a wider research focus that develops a quantitative understanding of cohort survivorship through larvae, juvenile and adult phases of development in relation to environmental variables, should facilitate sound fisheries and water

resource management within the Murray-Darling Basin. The effective sample size in the current study was small but has proved informative, particularly since reports of newly hatched golden perch are rare in the southern Murray-Darling Basin (despite greater research effort in the southern relative to northern parts of the basin). The current study was limited to opportunistic sampling within two seasons of a single year, and clearly more comprehensive sampling is required to describe the spawning and recruitment of golden perch. Future efforts to understand the spawning and recruitment of this important species would benefit from inclusion of sampling at localities where the early life history phases can be readily collected in sufficient numbers. To this end, the Menindee Lakes represent a place where recruitment of golden perch can be investigated potentially year-round, and the current study indicates that EDA can be obtained from otoliths in juveniles up to 4 months in age.

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