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Spatial and Temporal Patterns in Fish Assemblages Following an Artificially Extended Floodplain Inundation Event, Northern Murray-Darling Basin, Australia

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Abstract Water extraction from dryland rivers is often associated with declines in the health of river and floodplain ecosystems due to reduced flooding frequency and extent of floodplain inundation. Following moderate flooding in early 2008 in the Narran River, Murray-Darling Basin, Australia, 10,423 ML of water was purchased from agricultural water users and delivered to the river to prolong inundation of its terminal lake system to improve the recruitment success of colonial waterbirds that had started breeding in response to the initial flooding. This study examined the spatial and temporal patterns of fish assemblages in river and floodplain habitats over eight months following flooding to assess the possible ecological benefits of flood extension. Although the abundances of most fish species were greater in river channel habitats, the fish assemblage used floodplain habitats when inundated. Young-of-the-year (4–12 months age) golden perch (*Macquaria ambigua*) and bony bream (*Nematalosa erebi*) were consistently sampled in floodplain sites when inundated, suggesting that the floodplain provides rearing habitat for these species. Significant differences in the abundances of fish populations between reaches upstream and downstream of a weir in the main river channel indicates that the effectiveness of the environmental water release was limited by restricted connectivity within the broader catchment. Although the seasonal timing of flood extension may have coincided with sub-optimal primary production, the use of the environmental water purchase is likely to have promoted recruitment of fish populations by providing greater access to floodplain nursery habitats, thereby improving the ability to persist during years of little or no flow.

Keywords Habitat use · Migratory barriers · Environmental flows · Floodplain rivers · Murray-Darling Basin · Recruitment

Introduction

Flow variability in dryland floodplain river systems has a fundamental influence on the environment that fish assemblages inhabit. To persist in these environments, fish must tolerate extreme hydrological variability at a range of spatial and temporal scales, and the associated varying availability of critical habitats (Balcombe and others 2006). As such, their life histories must be able to accommodate variable and unpredictable flow events, in both their habitat use and recruitment ecology. However, there is considerable debate regarding the role of hydrology in recruitment of fish populations and assemblages in Australian dryland floodplain rivers (see Humphries and others 1999; Mallen-Cooper and Stuart 2003; Roberts and others 2008; Ebner and others 2009). Understanding the hydrological and habitat requirements of fish populations for spawning and recruitment is necessary to predict responses to flow events among fish species (Growns 2008), particularly given the structural and hydrological complexity of dryland floodplain river systems (Puckridge and others 1998) and diverse life histories of fishes that inhabit these regions.

In Australia, water extraction, diversion and regulation in lowland river systems has significantly contributed to the

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declines in the ecological condition of river and floodplain habitats (Kingsford 2000a). Differences in fish assemblage composition, abundance and establishment of non-native species between floodplain rivers of varying degrees of flow regime alteration have been previously examined in the Murray-Darling Basin (MDB), Australia (e.g., Gehrke and others 1995; Humphries and others 2002; Growns 2008; Humphries and others 2008). For example, in the southern MDB, fish assemblages in the highly regulated Campaspe River are dominated by non-native species whereas the neighbouring moderately regulated Broken River has greater proportions of native species (Humphries and others 2008). Throughout the broader MDB, native fish diversity has been negatively associated with increased hydrological disturbance (Gehrke and others 1995). Furthermore, in the Cooper Creek system (central Australia), Puckridge and others (2000) found the abundance of native species such as Australian smelt (*Retropinna semoni*) and bony bream (*Nematalosa erebi*) increased in years of flooding, indicating that flooding promotes a positive response in fish assemblage productivity. Given that flow regulation influences instream habitat diversity and floodplain connectivity (Bowen and others 2003), altered water management practices, including flow extraction and regulation, may contribute to declines in fish assemblage health in dryland floodplain river systems.

In dryland floodplain rivers, fish need to be able to move between reaches to colonise habitats during flooding to ensure regional persistence is maintained. Flow regulation infrastructure, such as weirs, also compound the direct effect of flow regime change in floodplain rivers by reducing connectivity between reaches for fish. In the lower Murrumbidgee River, Australia, fish species such as native Australian smelt and non-native common carp (*Cyprinus carpio*) have been sampled in greater abundance during summer and autumn downstream of a low-level weir when compared to the upstream reach (Baumgartner 2004), indicating that the weir restricted seasonal movement. However, few studies have assessed the impacts of migratory barriers on fish assemblages under varying hydrological conditions.

Environmental water releases (EWRs) are often initiated for dryland floodplain rivers where water extraction has contributed to degraded ecological health in both river channel and floodplain habitats, by providing water to maintain refugia habitats for biota and ecosystem processes such as fish recruitment (e.g., Rayner and others 2009). Using examples of EWRs as large-scale ecological experiments (Poff and others 2003), managers and scientists can make recommendations for the specific uses of environmental water (e.g., King and others 2009) and direct management agencies to target particular regions or reaches with EWRs to maintain or improve ecological health. In April 2008, the Murray-Darling Basin Commission (MDBC) purchased 10,423 ML of water from agricultural water users in the Condamine-Balonne catchment (northern MDB) to prolong a natural flood event (MDBC 2008a). This is first time the MDBC (now Murray-Darling Basin Authority) has purchased 'temporary' water for environmental purposes in the northern Murray-Darling Basin. 'Temporary' water is defined as water extracted from rivers under approved event flow management rules and diverted to large on-farm storages for later agricultural use (MDBC 2008a). The primary purpose of this environmental flow was to extend the duration of floodplain wetland inundation within the Ramsar listed Narran Lakes Nature Reserve to increase recruitment of colonial waterbirds which had bred during the initial flooding (see Kingsford and others 2008; Cummins and Duggan 2009). This environmental water release provided the opportunity to examine the spatial and temporal patterns in fish assemblage composition and recruitment in river and floodplain habitats in the lower Narran River, and determine if a significant instream barrier (weir) limited the benefits of prolonged flooding for fish. Two predictions were made. Firstly, that while fish assemblages would use the floodplain habitat during inundation, the presence of the upstream weir would impede the ability of fish assemblages to disperse throughout the lower Narran River during flood recession. Secondly, the inundated floodplain lakes and backwaters would be dominated by new recruits and young-of-the-year (YOY) cohorts, indicating that these habitats act as a nursery environment.

Methods

Study Region

The Narran Lakes system is located in the lower Condamine-Balonne catchment, New South Wales, Australia, near the Queensland-New South Wales border (Fig. 1). The Narran River flows south from the Balonne River in southern Queensland to the Ramsar listed Narran Lakes Nature Reserve, a series of terminal floodplain delta wetlands. At the southern end of the Narran River upstream of the floodplain lakes, a 2 m high weir is located at Narran Park, where no facilities currently exist to facilitate movement by fish between reaches when the weir is not flooded. Following large flood events, floodplain areas are inundated for varying durations (weeks to months) depending on local topography and distance from the main channel of the Narran River.

Four study sites were located upstream of the Narran Park weir (29° 42′ S, 147° 22′ E) in the Narran River (sites 1–4), three sites downstream of the weir (sites 5–7) and

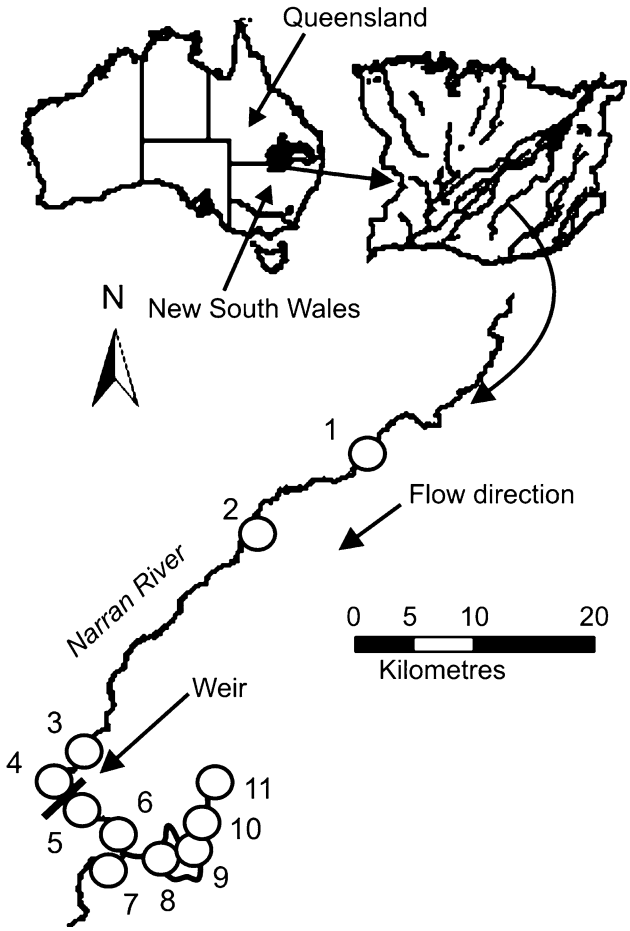


Fig. 1 Locations of study sites in the lower Narran River (Condamine-Balonne catchment, Australia)

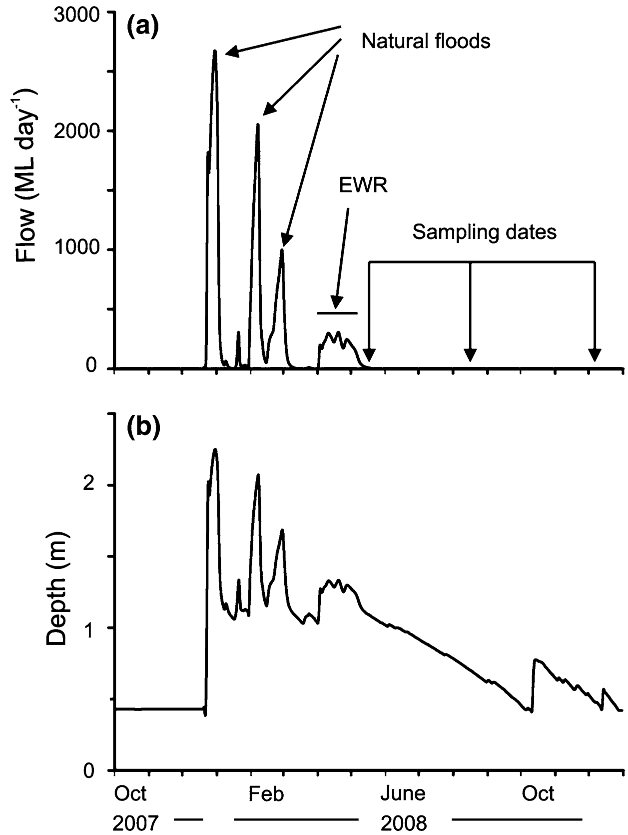


Fig. 2 **a** Total daily discharge and **b** depth in the Narran River at Narran Park between October 2007 and December 2008 indicating flood events, the environmental water release (EWR) and sampling events

four sites (sites 8-11) were in the floodplain lakes within the Narran Lakes Nature Reserve (Fig. 1). This study design was selected to test for differences in fish assemblages in reaches upstream and downstream of the Narran Park weir, and determine if the inundated floodplain lakes supported fish fauna similar to river reaches or a unique subset of species. While other potential fish barriers exist along the Narran River system, the impacts of the Narran Park weir are of particular interest by water managers given its location adjacent to the Narran Lakes Nature Reserve (Peter Terrill, personal communication).

Hydrology

The Condamine-Balonne catchment experiences dry, mild winters and warmer summers, with the majority of rainfall occurring during December-March (austral summer). Historically, flooding has typically occurred annually. However, during 1998–2008, dry spells lasting up to four years occurred more frequently (MDBC 2008b; NSW Department of Water and Energy unpublished flow data). In the 1970s, several government and privately owned water storages were constructed within the Condamine-Balonne catchment. Collectively, these storages have a total capacity of 1,145,000 ML and reduce median and mean flows in the lower Narran River system by 74 and 57%, respectively (Kingsford 2000b). Between late December 2007 and early March 2008, a series of moderate flow events (>1000 ML day^{-1}) inundated the floodplain at sites 8–11 (Fig. 2). The EWR of 10,423 ML occurred from 2 April to 22 May 2008 and was delivered from upstream off-river storages within the Condamine-Balonne catchment, and prolonged the occurrence of elevated water levels in the river channel and inundated floodplain during and following the EWR (Fig. 2). Of this EWR, 82% was delivered during April 2008 at rates varying between 169 and 306 ML day^{-1}.

Sampling Methods

Each site was sampled during May, August and December 2008, with a combination of passive and active fish sampling methods used previously for sampling fish assemblages in dryland floodplain rivers (Arthington and others

2005; Balcombe and others 2006). Three large double-wing fyke nets were set overnight (minimum of 15 h) and cleared the following morning. Three hauls of large (15 m long × 1.5 m depth, 12.5 mm stretched mesh, minimum area 50 m^2) and small (2 m long × 1.5 m depth, 2 mm stretched mesh, minimum area 20 m^2) seine nets were also made during daylight hours. Wing width of the fyke nets, sampling time and the distance and width of each seine net haul was also recorded to allow standardisation of sampling effort for statistical purposes.

All sampled fish were identified to species, counted, their standard length (mm) measured and, with the exception of non-native species and a small number of spangled perch (*Leiopotherapon unicolor*), returned alive to the water at the point of capture. All non-native species were euthanased by benzocaine overdose and small numbers of spangled perch and cyprinid species (common carp-goldfish hybrids) were preserved for identification and length-age analysis.

Statistical Analyses

Catch data from all sampling methods were standardised by sampling effort (catch per unit effort, CPUE): fyke net samples (three $site^{-1}$) were standardised to 15 h set times, large seine nets (three $site^{-1}$) to 50 m^2 sampled area and small seines (three $site^{-1}$) to 20 m^2 sampled area. All nine replicates from each site and sample time were pooled to allow meaningful comparisons be made. All subsequent statistical analyses were performed using these pooled standardised data.

Differences in the total abundance of the entire fish assemblage and the abundance of the five most abundant native species (spangled perch, bony bream, golden perch (*Macquaria ambigua*) and Hyrtl's tandan (*Neosilurus hyrtlii*)) and common carp between upstream, downstream and floodplain "zones" and sampling times (May, August, December 2008) were tested using a 2-way fixed-factor analysis. Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson 2001) tests were done using each single dependent variable based on Euclidean distance run with 9999 permutations. This analysis is capable of handling unbalanced statistical designs, such as this study (due to unequal numbers of sites sampled in each zone and over time as floodplain sites dried), calculates an identical F statistic that would be produced using traditional ANOVA and is not affected by non-normal distribution of data (Anderson 2001). Where significant differences were detected, PERMANOVA pairwise tests were used to determine specific zones, times or zone × time interaction causing overall differences.

Differences in the species composition of fish assemblages between zones and times were tested using the same statistical model tested for univariate analyses, but using Bray-Curtis similarity measure following fourth-root transformation prior to PERMANOVA. Differences in the size structure of the five abundant species were also examined using PERMANOVA. The abundance of each species was divided into "recruits" (<4 months old), "young-of-the-year (YOY)" (>4 months, <1 year) and "adults" (>1 year). As there is little information on the recruitment patterns and growth rates of these species (Balcombe and Arthington 2009), individual fish of each separate species were assigned to these size classes based on standard length (Table 1). The size structure of the catches of each species was tested using the same multivariate PERMANOVA analysis described above. These size structure tests determined if particular size classes of fish were dominant in particular zones and during specific sample times (see Smith 2003). Multivariate composition analysis was presented using multi-dimensional scaling (MDS) ordination, and all statistical tests were determined significant at $P \leq 0.1$ to increase statistical power and reduce type II errors that are of greater importance that type I errors in environmental studies such as this (Fairweather 1991; Field and others 2007). When significant differences in composition were detected, similarity percentage analysis (SIMPER) was used to determine specific species or species' size classes contributing to overall differences. All statistical analyses were carried out using PRIMER 6.1.11 (Clarke and Gorley 2006) with the PERMANOVA + 1.0.1 add-on package (Anderson and others 2008).

Table 1 Standard length classes used to classify fish life history for population structure analyses

Common name	Scientific name	Recruits (mm)	YOY (mm)	Adults (mm)
Spangled perch	*Leiopotherapon unicolor*	<50	50–78	>78
Bony bream	*Nematolosa erebi*	<75	75–150	>150
Golden perch	*Macquaria ambigua*	<75	75–400	>400
Hyrtl's tandan	*Neosilurus hyrtlii*	<100	100–135	>135
Common carp	*Cyprinus carpio*	<120	120–200	>200

Determined from Llewellyn 1973, Vilizzi 1998, Brown and others 2003, Pusey and others 2004 and Balcombe and Arthington 2009

Results

Spatial and Temporal Patterns in Fish Assemblages Following Flood Recession

Nine native, three non-native and one hybrid non-native species were sampled in the lower Narran River system during 2008 (Table 2). Three native species (spangled perch, bony bream and golden perch) comprised 81% of the total number of individuals sampled, and six common species (spangled perch, golden perch, bony bream, goldfish, common carp and gambusia) were sampled throughout all zones (upstream, downstream and floodplain) during most sampling occasions. Rare or vagrant species, such as long-finned eel, silver perch, Murray River rainbowfish, Australian smelt and carp-goldfish hybrid, were only sampled from single sites or sampling times.

Total fish abundance and the abundance of five common species varied between zones and sample times following flood recession (Fig. 3). Mean total fish abundance and the mean abundance of spangled perch and golden perch were significantly higher in the downstream river reach immediately after the EWR (Table 3; Fig. 3). Throughout the study, bony bream were more abundant in the upstream river reach than in lower reaches (Fig. 3), and were most abundant immediately following the EWR. Hyrtl's tandan and common carp had relatively consistent abundances in all sampling zones, although common carp had greater abundances in the upstream reach when compared to the downstream reach during December 2008 (Fig. 3). All five common species were sampled in floodplain sites when inundated (Table 2), although spangled perch, golden perch and bony bream were more abundant in river channel sites than inundated floodplain sites (Fig. 3).

Temporal differences in the composition of fish between upstream, downstream and floodplain reaches were inconsistent, as indicated by the significant zone × time interaction (Table 4; Fig. 4). Fish assemblage composition differed significantly between upstream and downstream zones at all sampling times, and between upstream and floodplain zones in August 2008 (Table 4). Differences in the abundance of spangled perch, bony bream and golden perch between upstream, downstream and floodplain zones in May 2008 contributed to the overall spatial separation of the entire fish assemblage between reaches (Table 3).

Spatial and Temporal Distribution of Fish Recruits, YOY and Adults Following Flood Recession

Patterns in the spatial and temporal distribution of recruits, YOY and adults following flooding varied among common species (Table 4). The size structure of spangled perch and

Table 2 Summary of fish sampled in the Narran River system in sites upstream (US) and downstream (DS) of Narran Park weir, and in the floodplain (FP) during May, August and December 2008

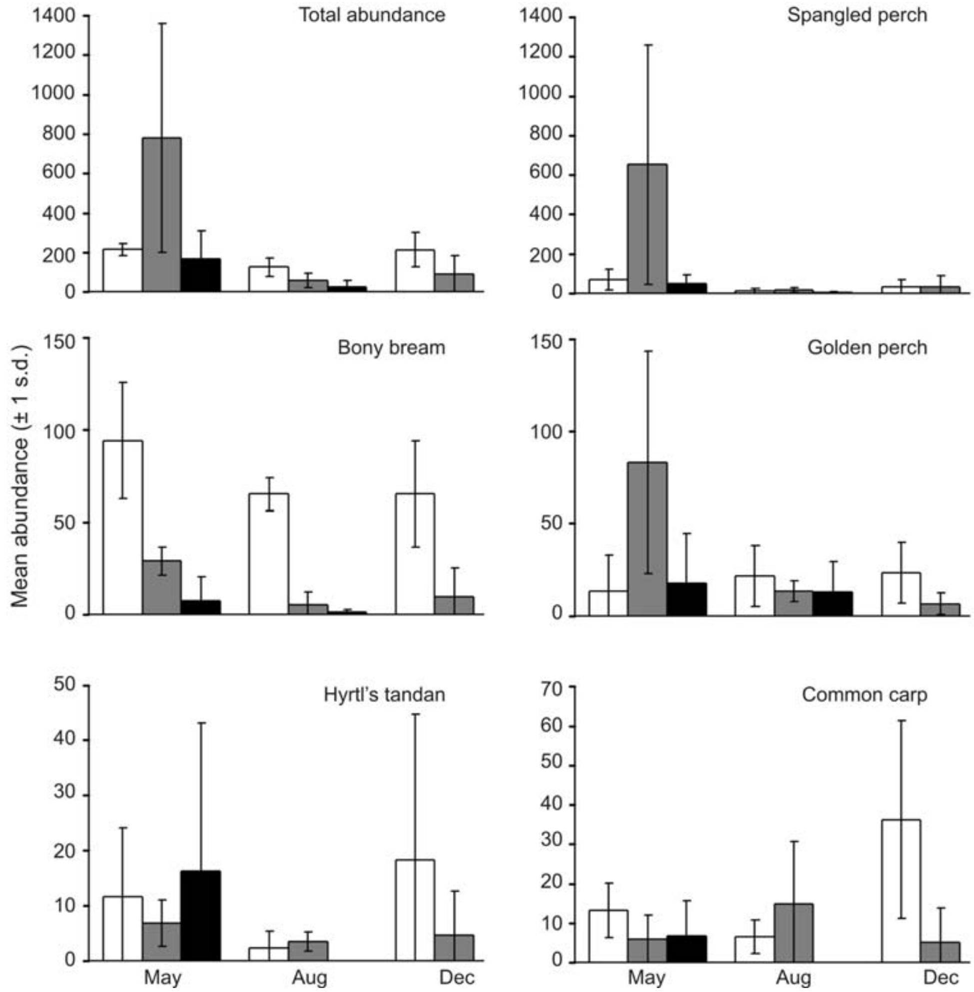
Species name	Common name	May 2008			August 2008			December 2008[b]		% of total
		US	DS	FP	US	DS	FP	US	DS	
Anguilla reinhardtii	Long-finned eel		0.3							<0.1
Bidyanus bidyanus	Silver perch		0.3			0.3				<0.1
Hypseleotris spp.	Carp gudgeon complex				1.8			0.8		0.1
Leiopotherapon unicolor	Spangled perch	80.8	732.0	66.3	16.8	22.0	5.0	42.0	37.0	50.8
Macquaria ambigua	Golden perch	15.8	100.7	24.3	29.3	19.0	17.0	29.8	6.7	12.3
Melanotaenia fluviatilis	Murray River rainbowfish				1.0	2.0				0.2
Nematolosa erebi	Bony bream	116.5	35.0	10.3	92.3	6.3	1.5	79.5	9.7	17.8
Neosilurus hyrtlii	Hyrtl's tandan	14.8	8.3	22.5	3.0	4.7		22.5	5.3	4.1
Retropinna semoni	Australian smelt				0.3					<0.1
Carassius auratus	Goldfish[a]	6.8	1.0	50.8	3.3	2.7	4.5	2.5	6.3	3.9
Cyprinus carpio	Common carp[a]	16.5	7.7	9.8	9.0	19.0		44.8	5.3	5.7
	Carp-goldfish hybrid[a]			0.5	13.5					0.7
Gambusia holbrooki	Gambusia[a]	8.8	2.7	3.3	1.8	2.3	5.0	34.0	29.0	4.4
Total abundance		259.8	888.0	187.5	171.8	78.3	33.0	255.8	99.3	100
% Native abundance		87.7	98.7	65.7	84.0	69.4	71.2	68.2	59.1	85.3
Total no. species		7	9	8	11	9	5	8	7	
Proportion native richness		0.57	0.67	0.50	0.64	0.67	0.60	0.63	0.57	

Mean standardised abundances of fish species from sites in each sampling zone are shown

[a] Denotes non-native species

[b] No floodplain sites were sampled in December 2008 due to the floodplain being dry

Fig. 3 Mean (±1 s.d.) abundance of the entire fish assemblage and individual species sampled in the Narran River system upstream (*clear bars*) and downstream (*grey bars*) of Narran Park weir, and in the floodplain zone (*solid bars*). Note different *y*-axis scales



Hyrtl's tandan remained similar in the upstream, downstream and floodplain zones during the three sampling occasions (Table 4). However, the size structure of bony bream differed between upstream and downstream, and upstream and floodplain zones (Table 4). This was due to considerably greater abundances of new recruits in the upstream zone when compared to both downstream and floodplain sites, and greater abundances of YOY individuals on the floodplain (Table 5).

Populations of both golden perch and common carp showed significant spatial differences between zones; either at single sampling times (golden perch), or consistently during all three sampling events (common carp) (Table 4). In May 2008, differences in the population size structure of bony bream, golden perch and common carp between downstream and floodplain zones were not significant (Table 4), indicating that connectivity between these zones allowed for dispersal. However, significant differences in the size structure of golden perch between upstream and downstream, and upstream and floodplain zones during May 2008 (Table 4) indicated that connectivity between these zones was limited. Greater proportions of golden perch recruits and YOY in both downstream and floodplain zones compared to the upstream zones were responsible for these differences (Table 5). Differences in the population size structure of common carp between zones were similar to that of golden perch, although they were consistent throughout the study as indicated by the non-significant zone × time interaction (Table 4). Greater abundances of new recruits of common carp upstream of Narran Park weir (compared to both downstream and floodplain zones), and higher abundances of common carp >1 year age in both downstream and floodplain zones (compared to the upstream zone) were responsible for the overall spatial differences in size structure (Table 5).

Discussion

Use of the Inundated Floodplain by Fish Following Flood Recession

Under low flow conditions prior to flooding in late 2007, large-scale river health monitoring (Murray-Darling Basin

Table 3 Results of univariate ANOVAs on the abundance of all fish species (total abundance) and individual species

Dependent variable	Source	df	MS	F	*P*
Total abundance	Zone	2	120510	3.0	**0.057**
	Time	2	269930	6.8	**0.001**
	Z × T	3	187080	4.7	**0.006**
	Error	19	39924		
Spangled perch	Zone	2	140260	3.5	**0.044**
	Time	2	195410	4.9	**0.004**
	Z × T	3	151790	3.8	**0.010**
	Error	19	40075		
Bony bream	Zone	2	13797	37.9	**<0.001**
	Time	2	1193	3.3	**0.063**
	Z × T	3	161	0.4	0.726
	error	19	364		
Golden perch	Zone	2	1080	1.6	0.229
	Time	2	1883	2.8	**0.074**
	Z × T	3	2721	4.1	**0.020**
	Error	19	664		
Hyrtl's tandan	Zone	2	91	0.4	0.740
	Time	2	282	1.1	0.361
	Z × T	3	93	0.4	0.820
	Error	19	259		
Common carp	Zone	2	369	2.3	0.124
	Time	2	259	1.6	0.222
	Z × T	3	465	2.9	**0.060**
	Error	19	161		

Significant values ($P \leq 0.1$) are indicated in **bold**

Sustainable Rivers Audit; SRA) in the lower Condamine-Balonne River catchment (including the lower Narran River) determined that fish assemblages inhabiting main channel habitats were dominated (~90% abundance) by bony bream, gambusia, Australian smelt and golden perch (Davies and others 2008). No Hyrtl's tandan were recorded from any of the 11 lowland sites (Davies and others 2008), including three sites in the reach of the Narran River upstream of the Narran Park weir sampled in this study, suggesting that recruitment is limited during prolonged periods of low flow. During these periods of minimal surface water flow, fish assemblages are restricted to pools and waterholes within the main channel, and restricted connectivity between these refugia habitats is likely to result in highly variable assemblage composition between pools (Arthington and others 2005; Balcombe and others 2006). Two species that were recorded in this study that were not sampled in the SRA were silver perch and Hyrtl's tandan. Additionally, three Murray cod (*Maccullochella peeli peeli*) were sampled in the lowland region of the Condamine-Balonne River catchment during the SRA (Davies and others 2008), whereas none were sampled in this study, including river channel sites in periods of equivalent low flows (December 2008).

During and following periods of flooding in dryland floodplain rivers, a number of fish species have been found to increase their abundance, particularly juvenile age classes, indicating that flooding and access to a greater variety of habitats promotes productivity of fish assemblages in these systems (e.g. Puckridge and others 2000; Zeug and Winemiller 2008). In the nearby Warrego River, recruitment of three species recorded in this study (bony bream, Hyrtl's tandan and golden perch) is positively associated with large flows providing access to inundated floodplain backwaters (Balcombe and others 2006). Furthermore, species such as silver perch and Australian smelt are particularly sensitive to restricted access to floodplain and flowing habitats (Rayner and others 2009), possibly due to limited breeding or recruitment habitat (King and others 2003, 2009). In the present study, both silver perch and Australian smelt were sampled in very low abundances (<3 individuals) in river channel sites when flows receded and only deeper pools remain inundated, suggesting that these species require frequent connectivity between river channel and floodplain habitats to persist at a reach-scale.

With the exception of locally rare or vagrant species, all fish species recorded in this study were sampled in inundated floodplain habitats when accessible from the main channel of the Narran River. Although the abundance of fish species varied greatly within each of the sampling zones, the mean abundance of Hyrtl's tandan was greater in the floodplain zone when compared with river channel reaches in May 2008. In recent times, the relatively limited occurrence of inundated floodplains within the MDB has prevented researchers examining the use of these habitats by fish. The occurrence of a diverse fish assemblage and different life stages of individual species migrating to the inundated floodplain during this study is therefore an important finding.

Despite the use of the inundated floodplain habitat by fish in this study, abundances of all species were higher in river channel sites (both upstream and downstream of Narran Park weir) when compared to floodplain sites. Similar patterns have been found in other lowland rivers during floodplain inundation, with higher abundances of fish sampled in main channel habitats versus floodplain habitats (e.g. Cucherousset and others 2007). However, densities of fish in river channels may be higher due to improved recruitment of flood-spawning species that benefit from floodplain nursery habitats in the short-term, and then move to river habitats to reside for longer periods during and after using the floodplain as a spawning habitat and/ or nursery area. In this study, the timing of the EWR may have limited the benefits it could have provided to fish assemblages in the Narran River. Low water temperatures

Table 4 Results of Permutational Multivariate Analysis of Variance (PERMANOVA) tests for differences in fish assemblage composition and within-population size structure between upstream, downstream and floodplain zones across the May, August and December 2008 sampling occasions

Dependent variable	Source	df	MS	F	*P*		Pairwise tests	*P*		*P*		*P*
Total assemblage composition	Zone	2	2693	3.3	**0.003**	Z × T	May		Aug	*P*	Dec	
	Time	2	2593	3.1	**0.003**		US, DS	**0.033**	US, DS	**0.086**	US, DS	**0.055**
	Z × T	3	1546	1.9	**0.045**		US, FP	0.513	US, FP	**0.066**		
	Error	19	825				DS, FP	0.286	DS, FP	0.106		
Spangled perch size structure	Zone	2	1000	1.7	0.182							
	Time	2	749	1.3	0.317							
	Z × T	3	547	0.9	0.492							
	Error	17	591									
Bony bream size structure	Zone	2	796	3.2	**0.100**	Zone	Zone					
	Time	2	84	0.3	0.867		US, DS[1]	**0.050**				
	Z × T	2	504	2.0	0.112		US, FP[2]	**0.008**				
	Error	12	247				DS, FP	0.592				
Golden perch size structure	Zone	2	1866	5.9	**0.007**	Z × T	May		Aug		Dec	
	Time	2	308	1.0	0.422		US, DS[3]	**0.027**	US, DS	0.139	US, DS	0.398
	Z × T	3	730	2.3	**0.092**		US, FP[4]	**0.072**	US, FP	0.467		
	Error	16	317				DS, FP	0.500	DS, FP	0.497		
Hyrtl's tandan size structure	Zone	2	307	0.3	0.748							
	Time	2	1780	1.9	0.184							
	Z × T	2	1078	1.2	0.360							
	Error	14	927									
Common carp size structure	Zone	2	6246	10.7	**<0.001**	Zone	Zone		Time	Dates		
	Time	2	1495	2.6	**0.094**		US, DS[5]	**<0.001**		May versus Aug	0.190	
	Z × T	2	156	0.3	0.826		US, FP[6]	**0.006**		May versus Dec[7]	**0.048**	
	Error	15	585				DS, FP	0.164		Aug versus Dec	0.342	

Post hoc pair-wise comparisons are presented where significant values ($P \leq 0.1$) were detected (indicated in **bold**); proportions of species in samples which contributed to significant pairwise test differences are presented in Table 5

in river channel and floodplain sites immediately following the EWR in May 2008 (mean river temperature = 15.8°C ± 1.79 s.d., mean floodplain temperature = 17.4°C ± 1.5 s.d.) are likely to have limited the productivity in floodplain habitats at this time, therefore providing sub-optimal conditions for larvae and YOY fish (e.g. Pease and others 2006).

YOY size classes (4–12 months age) of golden perch and bony bream were abundant in floodplain sites compared to river reaches. Inundated floodplains or within-channel backwaters are often thought to provide nursery habitats for larval and juvenile native fish in the MDB (King and others 2003; Humphries and others 2006), largely due to the availability of suitable food resources and energetically favourable habitat conditions (Gehrke 1992). Although breeding and recruitment of Murray cod and trout cod (*Maccullochella macquariensis*) occurs in river channel habitats without floodplain inundation (Koehn and Harrington 2006), recruitment of these two species increases following periods of floodplain inundation (King and others 2009). Results from other dryland river systems show that warmer, slow-flowing habitats (e.g. backwaters and isolated pools) act as key nursery areas for larval and juvenile fish (Pease and others 2006). These results suggest that floodplain inundation is likely to improve recruitment of both larval and juvenile fish, and further extending floodplain inundation with the use of EWRs is likely to enhance conditions for fish recruitment in floodplain habitats (sensu King and others 2003), assuming that food production was also sustained by prolonged flooding.

Spatial Separation of Fish Populations and Assemblages Within the Lower Narran River

Fish abundances and assemblage composition varied during this study, although no clear patterns were detected at the population and assemblage levels between river and floodplain zones. Differences in the abundance of fish populations, assemblage composition and population size structure between sampling zones indicated that the Narran

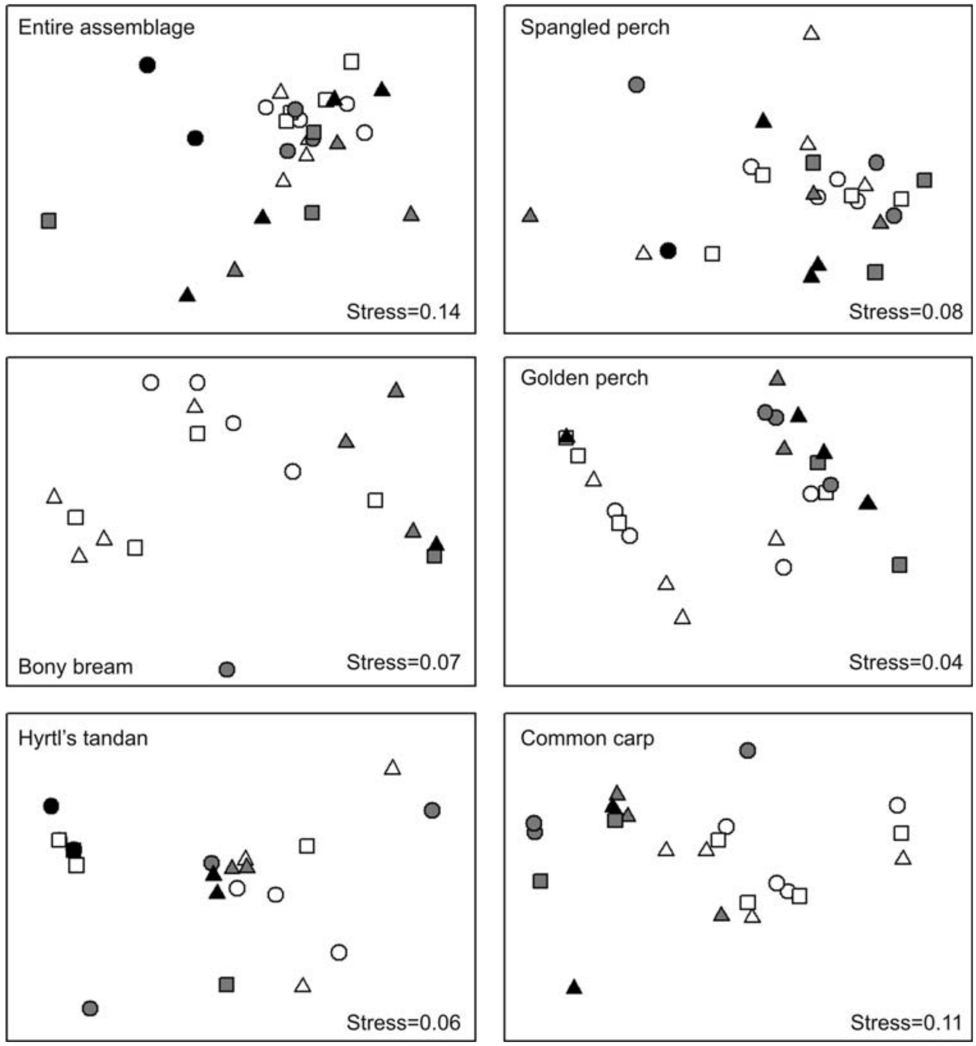


Fig. 4 Multidimensional scaling (MDS) plots representing the spatial and temporal patterns in the fish assemblage composition (entire assemblage) and population size structure of individual species (spangled perch, bony bream, golden perch, Hyrtl's tandan and common carp). *Symbols* indicate May (*triangles*), August (*circles*) and December 2008 (*square*), whereas colours indicate upstream (*clear*) and downstream (*grey*) of Narran Park weir and floodplain zone (*black*)

Park weir impeded fish movement within the lower Narran River. Physical barriers, such as weirs, are known to disconnect river reaches and, therefore, alter the longitudinal spatial arrangement of migratory fish populations (e.g. Gehrke and others 2002; Baumgartner 2004). It is likely that the Narran Park weir reduced the potential benefits of the EWR by restricting fish movement following prolonged flooding. Loss of connectivity among fish populations reduces their ability to recover from disturbance (e.g. drought) or anthropogenic changes (Propst and others 2008), such as reduced river flow due to water extraction. This demonstrates that if EWRs are to be used as a management tool for fish assemblages in dryland rivers that have both regulated flow regimes and migratory barriers, consideration of regions and river reaches should be targeted to maximise the benefits of such actions.

The non-native species, common carp, used the inundated floodplain of the lower Narran River when available; however, relatively low numbers of new recruits (<4 months age) were found on the floodplain compared to river channel sites. This pattern differs from the those found in floodplain habitats in the southern MDB, possibly as rivers in the northern MDB experience the majority of flow following summer (December–March) rainfall whereas river flows in the southern regions occur in winter and spring (June–October). In the Ovens River, Victoria, King and others (2003) sampled greater abundances of common carp larvae and juveniles in floodplain and billabong habitats compared to river channel habitats during spring flooding. Differences between these results indicate that the seasonal timing of flooding is critical for the use of inundated floodplain habitats by species, such as carp, and this issue warrants further research. The use of floodplain habitats by common carp may provide opportunities for population control (Stuart and Jones 2006). Removal or exclusion of carp and other non-native species that move in or out of floodplain zones could be readily integrated in to the management of EWRs in floodplain rivers such as the lower Narran River. However,

Table 5 Contribution of different life stages of fish species to dissimilarities in population structure between upstream, downstream and floodplain zones

Life stage	Mean abundance		Cumulative %	%D
	Upstream	Downstream		
[1]Bony bream-upstream v downstream (all times)				65.8
Recruit	73.8	7.7	79.6	
YOY	19.0	17.7	98.4	
>1 yr	0.7	0.8	100.0	
	Upstream	Floodplain		
[2]Bony bream-upstream v floodplain (all times)				62.1
Recruit	73.8	3.9	80.2	
YOY	19.0	34.1	99.2	
>1 yr	0.7	0.0	100.0	
	Upstream	Downstream		
[3]Golden perch-upstream v downstream (May 2008)				75.8
Recruit	17	69.33	57.1	
YOY	0	34.33	100.0	
	Upstream	Floodplain		
[4]Golden perch-upstream v floodplain (May 2008)				68.1
YOY	0	29.5	63.5	
Recruit	17	18.5	100.0	
	Upstream	Downstream		
[5]Common carp-upstream v downstream (all times)				80.3
Recruit	22.5	1.13	56.9	
>1 yr	0.5	9.88	86.6	
YOY	2.25	3.75	100.0	
	Upstream	Floodplain		
[6]Common carp-upstream v floodplain (all times)				87.3
Recruit	22.5	0.5	63.5	
>1 yr	0.5	8.5	86.2	
YOY	2.25	5	100.0	
	May	December		
[7]Common carp-May v December 2008 (all zones)				69.3
Recruit	7.11	27.17	63.2	
>1 yr	3.67	3.67	84.1	
YOY	2	4.67	100.0	

Average percentage dissimilarity (%D) between reaches or times ranges between 0 (identical) to 100 (dissimilar). Cumulative percentage indicates cumulative contribution of size classes to the dissimilarity between populations. Numbers in superscript relate to pairwise tests requiring SIMPER analysis (Table 4)

such management strategies require further information regarding habitat use by non-native species in dryland rivers during and after flood events.

Conclusions

Currently, there is limited information demonstrating the relationships between hydrology and population dynamics of fish in dryland rivers, such as the MDB (Growns 2008). Therefore, monitoring of future EWRs in dryland rivers needs to be adequately supported to improve knowledge. The ability to determine the specific effects of the EWR in the Narran River during this study was limited by the lack of both pre-EWR data and suitable rivers to act as reference sites to examine post-EWR responses. Unlike some parts of the southern MDB, where the limited availability of floodplain wetland systems for reference sites limits the use of Before-After-Control-Impact (BACI) designs (King and others 2010), the northern MDB has a range of river systems with relatively similar climate and floodplain landscapes to the lower Narran River that could be used as reference sites, despite variations in fish assemblages between major catchments. Further study of inter-annual patterns in fish assemblages, including years with and without floodplain inundation, would provide the fundamental information required to determine the importance of flood events for fish assemblages. This information is critical to both justify and predict the effects of EWRs on fish assemblage composition and recruitment, in terms of the seasonal timing, magnitude, duration and frequency of flood events.

This study indicates that fish assemblages are likely to have benefited from the EWR in the Narran River by artificially prolonged floodplain inundation, although it is likely that instream barriers and timing of flood extension limited the potential benefits within the lower Condamine-Balonne River catchment. Furthermore, recruitment of colonial waterbirds in the floodplain wetlands in the Narran River following flooding (Kingsford and others 2008) may have been enhanced by improving the availability of fish as a food source. Future research should focus on determining optimal seasonal timing and duration of EWRs to maximise the potential for ecosystem benefit with limited volumes of available water. Findings from field studies, such as this one, should be used to examine the influence of high flow events on biota that use floodplain habitats so that EWR strategies can be justified and accurately developed in terms of target areas and habitats, and the magnitude, duration, frequency and seasonal timing of regulated high flows.

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