The distribution of trout cod in Yanco Creek, 2014
Summary of findings

Clayton Sharpe and Ivor Stuart

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by

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Contact Details:

Name: Dr. Clayton Sharpe
Company: CPS Enviro Pty Ltd
P: (0466) 048 048
E: sharpe.clayton@gmail.com

Name: Dr. Helen Waudby
Company: NSW Murray Local Land Services
P: (02) 02 6051 2200
E: helen.waudby@lls.nsw.gov.au

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1. INTRODUCTION

The Billabong, Yanco and Colombo creeks (BYC Creeks) are significant natural resource assets of the Murray and Riverina Local Land Services (LLS) regions. These waterways support important bird, vegetation and native fish communities, and support water delivery to important irrigation regions (Alluvium 2013).

The 'Billabong Creek Fish Baselining Survey' was undertaken in 2013 (Sharpe et al. 2013). This study was the first extensive survey of the BYC system, describing the structure of fish communities and the distribution of species at 40 sites across the system. One important finding from this survey was the detection of a previously unknown population of the endangered trout cod in Yanco Creek (Figure 1). The present project was commissioned to build on the original fish baselining survey to examine the extent of trout cod distribution in Yanco and Colombo Creeks.

Specifically, the aims of this study were to:

- Determine the spatial distribution of trout cod in Yanco Creek, expanding the survey from sites where the species was located in 2013,
- Describe the population structure (demographics) of trout cod in Yanco Creek,
- Examine habitat features associated with the presence and absence of trout cod in Yanco Creek, and
- Analyse the historical flow regime and recommend an enhanced flow regime to ensure the persistence of trout cod in Yanco Creek.

1.1 Trout cod distribution and ecology.

Trout cod (*Maccullochella macquariensis*) is listed as an endangered species under Australian legislation (*Environment Protection and Biodiversity Conservation Act 1999*). The species was once widespread throughout the southern tributaries of the Murray and Darling rivers, but is now very patchily distributed in the Murray River and some of its tributaries (e.g. Goulburn and Murrumbidgee Rivers) and in the Macquarie River (NSW DPI 2006; Koehn et al. 2008). Populations crashed from the late 1800's and throughout the 1900's in line with European settlement and associated habitat degradation. Changes to flow regimes, overfishing, and competition with exotic species have been linked to the species' decline (Koehn et al. 2008). In 2006 the only naturally occurring population was considered to occur in the Murray River from Yarrawonga to Barmah, a reach of about 200 km (Koehn and Harrington 2006). However, fish occasionally appear as far downstream as Gunbower Island (Douglas et al. 2012). That population is stable (Lyon et al. 2012) and other populations have been re-established by stocking programs (Koehn and Harrington 2006).

Figure 1. Trout cod (*Maccullochella maquariensis*), captured in Yanco Creek.

The maximum total body length (TL) and mass reported for trout cod is 850 mm and 16 kg, respectively (Lintermans 2007; Truman 2007), but much larger individuals have been reported anecdotally (~25 kg; Truman 2007). Sexual maturity is reached at 3-5 years and about 320 mm in length for males and 400 mm for females (Lyon et al. 2012). The relative fecundity of females is lower than that for Murray Cod. Studies examining the timing of spawning show that breeding can occur from September-December, but the spawning period is brief, occurring for about two weeks, with water temperature >15^{o}C required for spawning to occur. This period is much shorter than the sympatric Murray cod (up to 4 months; Koehn and Harrington 2006) and other native species. Spawning appears to be dependent on a critical minimum water temperature rather than flow cues, with spawning having been observed under a range of flow conditions, including when flows are confined to the main channel and during floods (Kohen and Harrington 2006). However, spawning in the wild has only been observed in flowing water (Koehn and Harrington 2006; King et al. 2010; Koehn 2014). Consequently, flow, or flowing water, is considered an important habitat element influencing the species' reproductive ecology.

Tagging studies examining the movement and habitat use of trout cod have typically revealed that juveniles and adults are mostly 'sedentary'; they occupy a narrow home range of only 10's of metres (up to ~200 m), with strong site fidelity for a selected snag, snag complex or stream bank (Koehn et al. 2008). Movements from the home site are usually <10 m (Koehn et al. 2008). Despite tagging studies failing to reveal extensive fish movements there is strong evidence that some adult and sub-adult trout cod do migrate. For example, data from the Yarrawonga fish lock show that significant numbers of trout cod enter the fishway with some individuals traveling relatively long-distances (~80 km) upstream (Stuart et al. 2010). Unlike Murray cod, trout cod appear not to undertake pre-spawning migrations. Instead, spawning occurs within the species' home range or very close to it. However, one major lifetime

movement event occurs during the larval stage when larvae disperse long-distances downstream as they leave the nest (Koehn and Harrington 2006; Koehn et al. 2008).

Trout cod are associated with fast flowing water and high loadings of large and complex structural habitat, including submerged rocks, undercut banks, submerged trees and branches (snags) (Koehn and Nicol 2014). Koehn and Nicol (2014) suggested that snag loadings of >70% coverage, >1.5 m height, located within 15% of the channel width closest to the bank, and where water velocities were 0.3-0.6 m/s, were key habitat elements for trout cod.

Koehn and Harrington (2006) considered that the short breeding period of the species meant that recruitment (i.e. survival of larvae to age 1) success was highly susceptible to match/mismatch between larvae and the availability of suitable food (principally zooplankton), with starvation potentially a key factor in post-hatching larval survival rates. Likewise, spawning success could be affected by factors influencing the ecology of spawning, with disruption to nest selection, courtship and nest guarding potentially affected by extreme flow variability during the spawning period. Rapid drops in water level during the breeding period can affect courtship, cause nest abandonment and ultimately affect the survival of eggs.

Trout cod survival in irrigation rivers

In irrigation systems (i.e. anabranches, creeks and rivers conveying irrigation water), extreme water level variability occurs in response to irrigation demand and extraction rates. Irrigation demand can increase rapidly in response to heatwaves, forcing dramatic fluctuations in water level at daily and often hourly scales (Sharpe and Stuart 2015). This variability may be especially detrimental for trout cod, Murray cod and other nesting species in the relatively shallow Yanco Creek, which is usually <2 m deep in the upper reaches where trout cod occur (Alluvium 2013; Sharpe et al. 2013). Short-term variations in discharge and water level (depth) can occur over hours or days, causing trout cod to abandon their spawning nests (Rowland 1998). As the species spawns only once a year, these extreme fluctuations can negatively affect the entire spawning season (Mallen-Cooper and Zampatti 2015a).

New South Wales (NSW) Office of Water data show that in upper Yanco Creek (at Yanco take-off) water levels can oscillate by more than 1.2 m or at least half of the overall stream depth over a few days (Figure 2). Furthermore, recruitment success for trout cod within Yanco Creek may be affected by inappropriate flow delivery during the winter period, when low irrigation demand ceases and extremely low water levels occur (Figure 2). Negative impacts on young fish during periods of very low water level during winter include: reduced food availability and increased exposure to predation and recreational fishing.

The background biological data provided above provide context for one of the major aims of the present study: to examine the irrigation hydrograph or typical pattern of water level variability in Yanco Creek in view of potential impacts on the spawning and recruitment ecology of trout cod in Yanco Creek. In this report we also identify on-ground recommendations for management that will enhance the status of trout cod and other native fish species populations in the Yanco system.

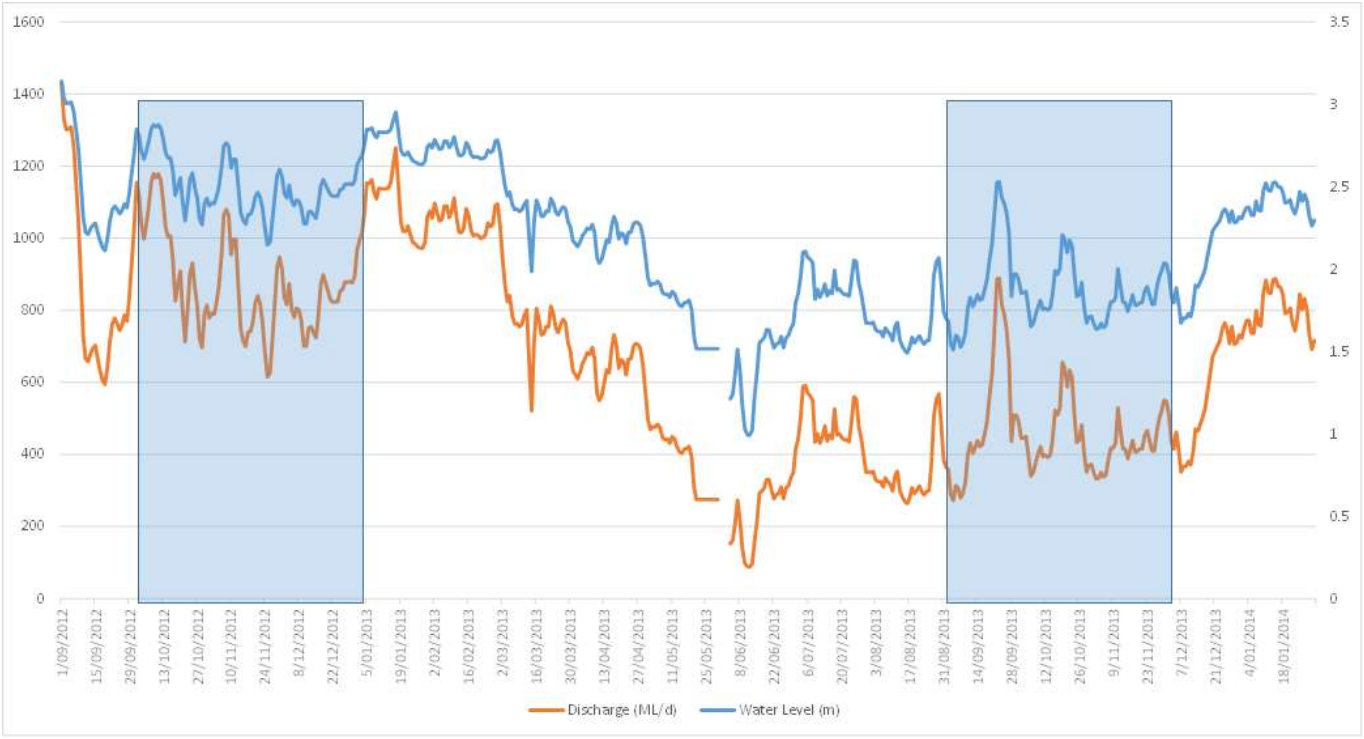

Figure 2. Average daily water level (metres) and discharge (ML/d) in upper Yanco Creek for the period September 2012 to January 2014. Note the wide oscillation in water levels during the trout cod breeding period (highlighted in shaded area). Data source: NSW Office of Water (2014).

2. Methods

2.1 Study Area

Trout cod were recorded at four sites in Yanco Creek during the 2013 BYC fish baselining survey, all upstream of Morundah (Sharpe et al. 2013). Trout cod also occur in the nearby Murrumbidgee River, both upstream and downstream of the Yanco Creek offtake (Baumgartner 2007), but the species had not been formally recorded in the BYC system prior to the 2013 baselining survey (Sharpe et al. 2013). The sites in Yanco Creek where trout cod were recorded in 2013 formed the geographic centre point from which sampling was expanded in the present study, with the aim of determining the upper-most and lower-most distribution of trout cod in Yanco Creek.

Sites were selected from aerial imagery, with areas of intact native riparian vegetation selected for survey where possible to enhance the likelihood of encounter rates with Trout cod. Where they occur elsewhere, trout cod exhibit an affinity for areas with an intact riparian over storey and high densities of submerged large woody debris (Koehn and Harrington 2009; Koehn and Nicol 2014). At the project planning phase, nine survey sites in Yanco Creek were selected for the baseline survey, from the offtake of the Yanco Creek from the Murrumbidgee River at Yanco Weir to downstream of Morundah at Bundure. Nine sampling sites were confirmed with Murray LLS project staff, but 13 sites were eventually surveyed because of the inclusion Colombo Creek sites. These sites were selected for survey based upon inspections during the fieldwork period and the occurrence of trout cod at neighbouring upstream sites.

2.2 Fish surveys

Aims:

- Determine the spatial distribution of trout cod in Yanco Creek, expanding the survey from sites where the species was located in 2013 (Sharpe et al. 2013)
- Describe the population structure (demographics) of trout cod in Yanco Creek

Fish surveys were conducted from 15-19 Dec 2014 using boat-mounted electrofishing equipment at each survey site following Sustainable Rivers Audit (SRA) protocols (12 x 90 sec electrofishing shots per site). While trout cod were the focus of this work, all fish were identified following McDowall (1996) and Lintermans (2007). Carp gudgeons were identified to genus level only (i.e. *Hypseleotris* spp.). Large-bodied fish species were measured for total length (nearest 1.0 mm) while small-bodied species were counted and released so as to minimise handling stress and mortality rates.

2.3 Quantitative Habitat Mapping

Aim:

- Examine habitat features associated with the presence or absence of trout cod in Yanco and Colombo creeks

At each fish survey site, 10 aquatic habitat attributes were assessed and scored. These attributes included the eight used in the 2013 BYC baselining survey (Table 1) together with flow velocity and water depth (Table 2). These attributes are directly relevant to the occurrence, distribution and status of large-bodied native fish populations (Koehn and Nicol 2014) and similar to those used in other contemporary fish-habitat assessment projects (Koehn et al. 2008; Sharpe et al. 2009; Koehn and Nicol 2014) (Table 1).

Habitat value for trout cod at each Yanco creek survey site was qualitatively measured with a hierarchical scoring system set for each parameter (Tables 1 and 2). The habitat value of a site was the sum of scores for nine parameters (excluding channel width), which was related to the sum of the maximum possible habitat score of 50 (Tables 1 and 2). Patterns in occurrence of trout cod were related to habitat attributes to identify what if any habitat features were associated with the occurrence or absence of trout cod in Yanco and Colombo creeks.

Hydrological variables for the habitat mapping component were water velocity and depth. Increments selected for these variables correspond to known attributes of fish habitats and fish behaviour observed elsewhere in the Murray Darling Basin (MDB) (e.g. by Koehn and Nicol (2008) in the Ovens and Murray Rivers; by Mallen-Cooper et al. (2011) at Chowilla South Australia; by Saddlier et al. (2008) in Mullaroo Creek and by Mallen-Cooper et al. (2014) in Gunbower Creek).

The water velocity and depth increments, and their alignment to fish-habitat types, were assigned a hierarchical score in relation to the present understanding of habitat value for trout cod (Table 2). Flow velocity was measured with a FlowMate® water velocity meter at the point of highest flow (determined visually) at the start and end points for each 'survey reach' (each survey reach refers to survey site electrofishing reach, ~400-1200 m). Water depth is also a key determinant of fish habitat. Cross-sectional depth was measured at three points across the channel at the start, middle and end points of each survey reach using boat-mounted sonar. The score for each hydrological attribute was included in the overall determination of habitat value for trout cod at each survey site.

3.4 Historical Flow assessment

Alluvium (2013) assessed the modelled natural flow regime and the regulated (current operating conditions) regime in Yanco Creek. Their description of patterns in the total annual flow, flow duration and seasonality provide a useful context with regard to the prevailing flow regime of the BYC system and for evaluating the distribution of trout cod in the present study. Discharge (ML) and water level variability data (m) were provided by NSW Office of Water for annual and daily observations at i) Yanco Creek at its offtake from the Murrumbidgee River ('Yanco offtake'), ii) Yanco Creek downstream of Tarabah Weir, iii), Yanco Creek at Morundah, and iv) Colombo Creek at Morundah. The ecological effects of the

managed historical flow regime were considered in relation to population status of trout cod in Yanco Creek.

Table 1. Habitat mapping framework used for each of 13 fish survey sites to relate the occurrence of trout cod to particular habitat features in Yanco and Colombo creeks.

Variable	Score 1	2	3	4	5	6
1. Channel flow status	Water present as disconnected, isolated pools	Water present as continuous standing pool	Very little water in channel, channel connected	Water fills 25–75% of both banks, deposition bars exposed	Water fills > 75% of both banks, or < 25% of channel exposed	Water reaches base of both banks (bankfull)
2. Flow velocity	Backwaters	Weirpool	Slow-flowing	Moderate-flowing	Fast-flowing	Very fast
3. Hydrodynamics	No/slow flow Dominated by one velocity regime, usually No flow shallow	Low flow velocity, low flow diversity	Slow-moderate flowing pool; Low flow velocity, some flow diversity	Pools with runs (aka riffle/run). Moderate-high flow velocity, high flow diversity (Fast and slow flowing areas)	–	–
4. Macrophytes	No submerged or emergent	< 5% cover submerged and or emergent	5–10% cover submerged and or emergent	10–15% cover submerged and or emergent	15–20% cover submerged and or emergent	> 20% cover submerged and or emergent
5. Structural Woody Habitat (Snags) density	Open Water (no snags visible)	< 5% channel cover comprising twigs and branches 1–5cm diameter	5–10% channel cover comprising branches and trees	10–20% cover comprising branches and trees	20–50% cover comprising branches and trees	>50% channel cover comprising branches and trees
6. Structural Woody Habitat (Snags) complexity	Open Water (no snags visible)	< 5% channel cover Twigs and branches 1–5cm diameter	5–10% channel cover composed of a single trunk or limb	5–10% channel cover composed of a trunk or limb with one or two branches	5–10% channel cover composed of one or more trunks with multiple branches	>5–10% channel cover comprising complete tree most limbs including the root–ball
7. Riparian zone	Width of RZ <6m, little or no RZ present due to human activities	Width of RZ 6-12m, human activities have impacted the RZ to a high degree	Width of RZ 12-18m, human activities have impacted the RZ only minimally	With of Riparian zone 18-40m, human activities i.e. roads, crops, lawns etc.) present but impact minimal	Width of Riparian zone >40m, human activities do not impact the RZ	Width of RZ <6m, little or no RZ present due to human activities
8. Channel width	Recorded with range finder					

Table 2. Water velocity and depth increments relevant to fish habitat use (after Mallen-Cooper et al. 2011).

Water velocity (m/s)	Fish habitat	Score
0.00- 0.03	Backwaters	1
0.04- 0.10	Weirpools	2
0.11- 0.17	Slow-flowing	3
0.18- 0.30	Moderate-flowing	4
0.31- 0.50	Fast-flowing	5
> 0.50	Very fast	6

Depth (m)	Score
0.51 – 1.00	1
1.01 – 1.50	2
1.51 – 2.00	3
> 2.00	4

3. Results

3.1 Trout cod occurrence

Twenty trout cod were collected in this study: 13 from Yanco Creek and seven from Colombo Creek. A further five native and two exotic fish species were collected, including the native Australian smelt, carp gudgeon, golden perch, Murray-Darling rainbowfish and Murray cod, and the non-native common carp and goldfish (Table 3). In Yanco Creek, trout cod were not collected downstream of Tarabah Weir (from four sites downstream), but were collected at each of four upstream survey sites. In Colombo Creek, trout cod were collected to just downstream of Morundah township. Trout cod were not collected at sites further downstream in Colombo Creek (two sites were sampled further downstream of Morundah). The results of this survey has built upon the 2013 BYC fish baselining survey by extending the known range of trout cod in Yanco Creek, and provides the first record of trout cod in Colombo Creek.

The population size structures for trout cod in Yanco Creek and Colombo Creeks were similar, with fish ranging from 104 mm – 560 mm in Yanco Creek and 160 mm – 582 mm in Colombo Creek (Figure 4). The size range of fish in Yanco Creek corresponded to age 1+ juvenile size fish (>100 mm) and larger age 5+ mature sized fish (>400 mm; Lyon et al. 2012) (Figure 3). In Yanco Creek the most abundant size class was the 150-200 mm cohort, representing fish age 1+ and 2+ years old. Most size classes were represented by one or two individuals, up to the maximum size (560 mm) for the Yanco Creek population (Figure 3).

While the abundance of trout cod was relatively lower in Colombo Creek (seven individuals), a similar size range to the Yanco Creek population was encountered. However, several size classes captured in the Yanco were not represented in the Colombo Creek (Figure 3). Among the size classes present, each was represented by only one or two individuals.

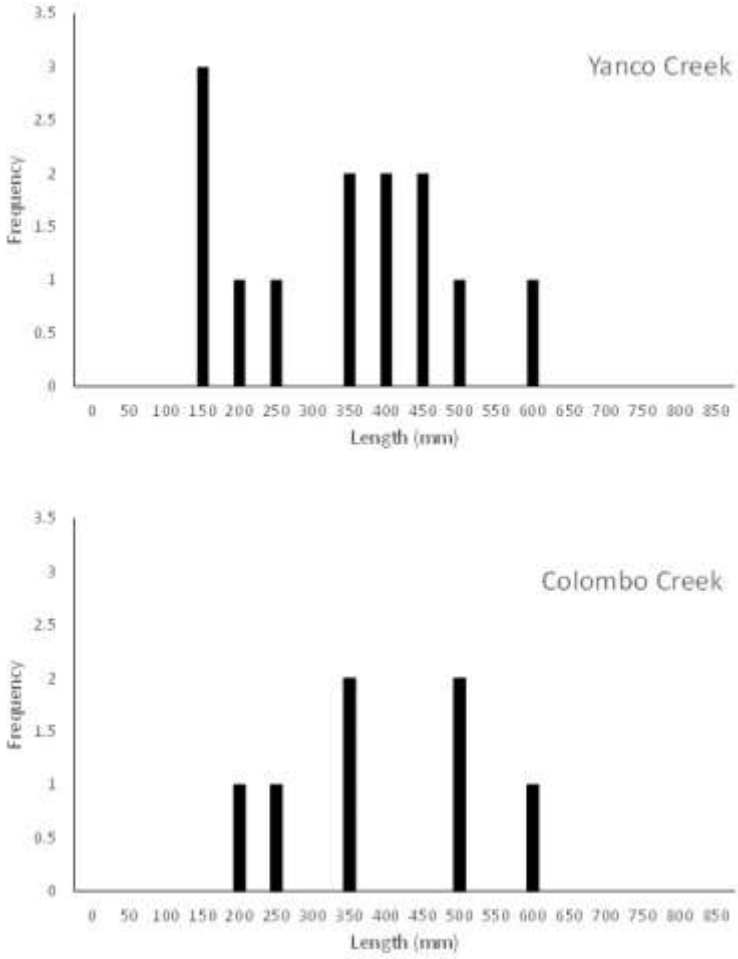

Figure 3. Total length (mm) frequency of trout cod collected in Yanco Creek (top) and Colombo Creek (bottom) during December 2014.

3.2 Overall fish assemblage

Overall, six native and two exotic species were collected (Table 3). All species collected in Yanco Creek were found in Colombo Creek with the exception of Murray-Darling rainbowfish (Table 3). The most abundant species encountered in both creeks was common carp (Table 3), which were present at each survey site. The small-bodied Australian smelt was the most abundant native species (Table 3) being found at all but one site in Yanco Creek, and at each site in Colombo Creek. With the exception of native carp gudgeons, all native species were more abundant in Yanco Creek (Table 3). However, more sites were sampled in Yanco Creek (eight sites) as compared to Colombo Creek (five sites).

Table 3. Fish species and their overall abundance collected in Yanco and Colombo Creeks in December 2014. Note that there was almost double the number of sites and hence sampling effort for Yanco Creek.

Yanco Creek	Abundance	Colombo Creek	Abundance
Native		**Native**	
Australian smelt	43	Australian smelt	17
Carp gudgeon	8	Carp gudgeon	13
Golden perch	12	Golden perch	9
Murray cod	25	Murray cod	11
Murray-Darling rainbowfish	8		
Trout cod	13	Trout cod	7
Exotic		**Exotic**	
Goldfish	6	Goldfish	4
Common carp	109	Common carp	33

3.3 Habitat Mapping

Habitat value scores varied among the 13 survey sites by up to 34%, from the sites with the highest scores (Yanco Creek site 3, score 40) to sites with lowest scores (Colombo Creek site 13, score 23; Yanco Creek site 10, score 23) (Table 4). Habitat value scores reflected the quality of the overall habitat character for trout cod, with a maximum possible habitat quality score of 50 (100%) reflecting the highest possible habitat value achievable in this study. No sites reached the highest possible score, but five consecutive sites in Yanco Creek attained habitat quality scores of >70%.

All 13 survey sites received the highest possible score for 'flow status'. At the time of survey, the wetted channel width reached the base of both banks at all sites (Table 4). The highest flow velocity score of 6 (equating to a flow velocity of >0.5m/s) did not occur at any site. However, most survey sites exhibited moderate-fast flowing water velocities, with four sites in the upper reaches of Yanco Creek, outside of the influence of Tarabah weir, exhibiting the highest flow velocities of 0.3-0.5m/s (Table 4).

Colombo Creek site 5 exhibited moderate-high flow velocity (Table 4). Further downstream than site 5 in both Yanco and Colombo Creeks, flow velocity progressively declined, as did hydrodynamic diversity (fast and slow flowing reaches), which was also highest at each of the five upstream sites (Table 4). This

decline in hydrodynamic diversity, displayed as lower scores for the attribute 'hydrodynamics' (Table 4), coincided with a gradual increase in stream width in both Yanco and Colombo creeks (Table 4). Increasing stream width occurred for both Yanco and Colombo Creeks downstream of Tarabah Weir and downstream of the Yanco/Colombo confluence (Table 4). The occurrence and density of submerged aquatic plants increased with increasing stream width, decreasing hydrodynamics and decreasing flow velocity (Table 4). Submerged aquatic plants were absent from sites in the upper Yanco and Colombo Creeks (Table 4). As for flow velocity and hydrodynamics, snag density and snag complexity, together with riparian zone condition, were considerably higher for the upper Yanco and upper Colombo Creek reaches (Sites 1-4 for Yanco Creek, sites 5-6 and 11 for Colombo Creek) in relation to the remainder of study sites.

Table 4. Habitat value scores for each site surveyed in Yanco and Colombo Creeks. The red bars represent the maximum possible habitat value score for each attribute (second row, from left to right); blue bars represent individual attribute scores for each survey site (from left to right across attributes), yellow bars represent the total score for each survey site (survey sites listed consecutively from top to bottom) and the green bars represent the % quality determination for each site in relation to the maximum possible habitat value score (survey sites listed consecutively from top-bottom, green bars).

Waterway	SITE #	Flow status	Flow category	Hydrodynamics	Macrophytes	SnagDens	SnagComp	Riparian	Max velocity	Max depth	SCORE	%	ChaWidth
*MAX POSSIBLE SCORE	*NA	6	6	4	6	6	6	6	6	4	50	100	
Yanco	1	6	5	4	1	4	6	5	5	3	39	78	23
Yanco	2	6	5	4	1	4	6	5	5	3	39	78	29
Yanco	3	6	5	4	1	5	6	5	5	3	40	80	28
Yanco	4	6	5	4	1	3	6	5	4	3	37	74	26
Colombo	5	6	5	4	1	3	6	5	4	4	38	76	26
Colombo	6	6	4	3	1	3	6	5	3	3	34	68	36
Yanco	7	6	3	2	4	2	3	2	3	2	27	54	32
Yanco	8	6	3	2	4	2	3	3	3	2	28	56	25
Yanco	9	6	3	2	3	2	3	2	2	2	25	50	26
Yanco	10	6	3	2	2	2	3	2	1	2	23	46	36
Colombo	11	6	4	3	1	3	3	4	3	3	30	60	31
Colombo	12	6	3	2	2	3	3	3	2	3	27	54	29
Colombo	13	6	2	2	2	2	2	3	1	3	23	46	41

3.4 Trout cod distribution and habitat observations

Trout cod were recorded at seven survey sites: four in Yanco Creek and three in Colombo Creek (Table 5). Sites where trout cod were encountered were unique compared to the remainder of sites showing markedly higher flow velocities, greater hydrodynamic diversity, greater snag density and complexity, and distinctly better riparian zone condition (Tables 4 and 5). Trout cod were absent from sites where submerged aquatic plants were present, maximum recorded depth was < 2.0 m and where hydrodynamic diversity and riparian condition was poor (riparian zone 6-12 m with high level of human/livestock impacts) (Table 4). Likewise, snag complexity was low (<10% channel cover, single limbs or trunks) and snag density was very low (<5% channel cover).

Table 5. Occurrence of trout cod at survey sites in Yanco and Colombo Creeks in December 2014. Tick marks (✓) indicate that trout cod were recorded at the site; X indicates trout cod were absent. The sites are numbered from upstream (1) to downstream (10).

Yanco Creek		Colombo Creek	
Site #	Trout cod	Site #	Trout cod
1	✓		
2	✓		
3	✓		
4	✓		
		5	✓
		6	✓
7	X		
8	X		
9	X		
10	X		
		11	✓
		12	X
		13	X

The occurrence and abundance of trout cod was closely associated with the following habitat attributes:

- Moderate-fast flow velocity (0.3-0.5m/s)
- Moderate-high hydrodynamic diversity (fast and slow flowing reaches)
- Zero aquatic macrophytes
- Moderate-high snag density (10-20% or 20-50% channel cover)
- Very high snag complexity
- Riparian zone condition 'high': width >40 m, human/livestock impact low

3.5 Hydrology and trout cod ecology

Inflow to Yanco Creek is regulated by Yanco Weir on the Murrumbidgee River, with the offtake to Yanco Creek situated in the Yanco Weir pool <300 m upstream of Yanco Weir (Alluvium 2013). With no flow control structure at the offtake, inflows to Yanco Creek are managed by manipulation of water levels in the Yanco Weir pool. A detailed description of the hydrology for Yanco Creek was provided by Alluvium (2013). That study used hydrological data sourced from NSW Office of Water and two integrated water quantity and quality (IQQM) simulation models developed by NSW Office of Water for the Yanco Creek system: one 100 year model pre-development and one 100 year model current conditions. Alluvium (2013) used the modelled flow series to develop three hydrological indicators for pre- and-post development conditions: total annual flow, flow duration, and flow seasonality.

The pre-development conditions described for Yanco Creek identified that Yanco Creek would have only flowed when Murrumbidgee flows exceeded about 40,000 ML/d at Yanco Weir (Alluvium 2013). Yanco

Creek was an intermittent system which could experience very high flows in one year and near zero flow the next, displaying very high inter-annual flow variability (Alluvium 2013). Under pre-development conditions, trout cod may have vagrantly occupied Yanco Creek during periods of high flow, returning to the Murrumbidgee when flows receded, as Koehn et al. (2008) observed for trout cod movement from the Murray River into floodplain anabranches during high flows. However, it is unlikely that trout cod would have permanently occupied Yanco Creek outside of high flow periods, as Yanco Creek would have ceased to flow for extended periods and trout cod appear to prefer moderate-fast flowing water (Koehn et al. 2008).

The presence of trout cod in Yanco Creek, across a broad spatial range in 2013 (Sharpe et al. 2013) and again in the present 2014 study (albeit with the known distribution extended to Colombo Creek), is indicative of a persistent and resident population. Trout cod are typically rare across the MDB (Koehn et al. 2014); the presence of the species in Yanco/Colombo Creeks indicates that some aspects of the regulated flow regime and existing habitat features are at least somewhat suitable for the species. Since European settlement, trout cod have undergone wide-scale population declines. Consequently, a population in the regulated Yanco Creek is of great conservation importance. Managing the regulated flow regime to support this population is a major management priority.

The species' requirement for permanently flowing conditions is highlighted by the permanent prevailing flow regime of Yanco/Colombo Creeks (Figure 4). For the period 2000-2015, Yanco Creek did not cease to flow, with the lowest average daily flows recorded for that period in the order of 70-100 ML/d (generally May-July each year) (Figure 4). This pattern was reflected in Colombo Creek at Morundah (Figure 5). Therefore, the present managed irrigation flow regime offers support for a small trout cod population. The population could be enhanced with a slightly modified hydrograph that is more suited for trout cod, but does not reduce service to irrigators.

Consideration of the interaction between discharge (ML/d) and water level (m) is required, especially in relation to the life-history requirements of Trout cod. In particular, low water levels that occur at low flows (Figure 4), and indeed wide variability in daily water levels generally, are likely to negatively affect aspects of the species' spawning/recruitment, and ultimately the persistence of the trout cod population.

Wide fluctuations in average daily discharge and water level occur in Yanco and Colombo Creeks during spring/summer (Figures 4 and 5). These fluctuations meet varying irrigation needs, but are not part of the natural daily variation of lowland river systems or anabranch systems where variation is buffered. These fluctuations are typical of irrigation systems (Mallen-Cooper et al. 2013). In this study, at Yanco Creek downstream of the Yanco offtake, water level consistently fluctuated in an oscillating high-low pattern over 7-10 days throughout spring and summer periods (Figure 5) by up to 1.0 m (Figure 6). This variability would be experienced at Yanco Creek sites 1-4, where adult and juvenile trout cod were recorded. This fluctuation in water level is extreme when considered in relation to the maximum water depth recorded at those survey sites, which was < two m stream depth at each site at the time of the survey (15–19 Dec 2014).

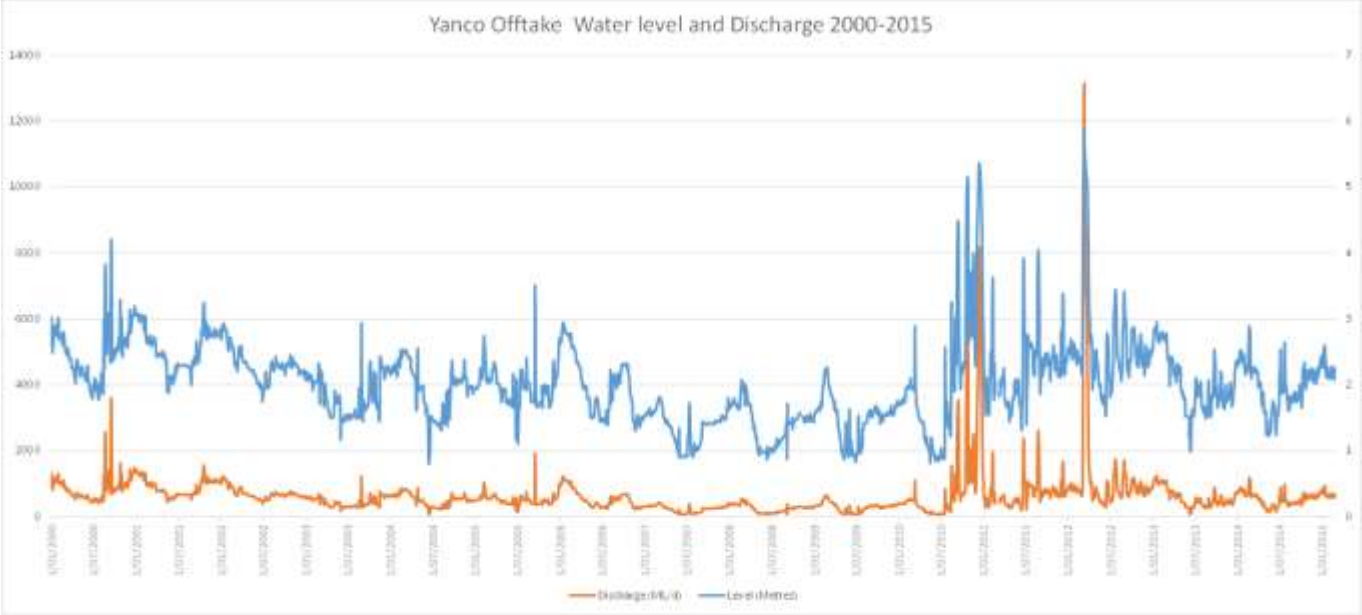

Figure 4. Daily average discharge (ML/d) and water level (m) in Yanco Creek at the offtake from the Murrumbidgee River for the period 2000-2015. Data source: NSW Office of Water.

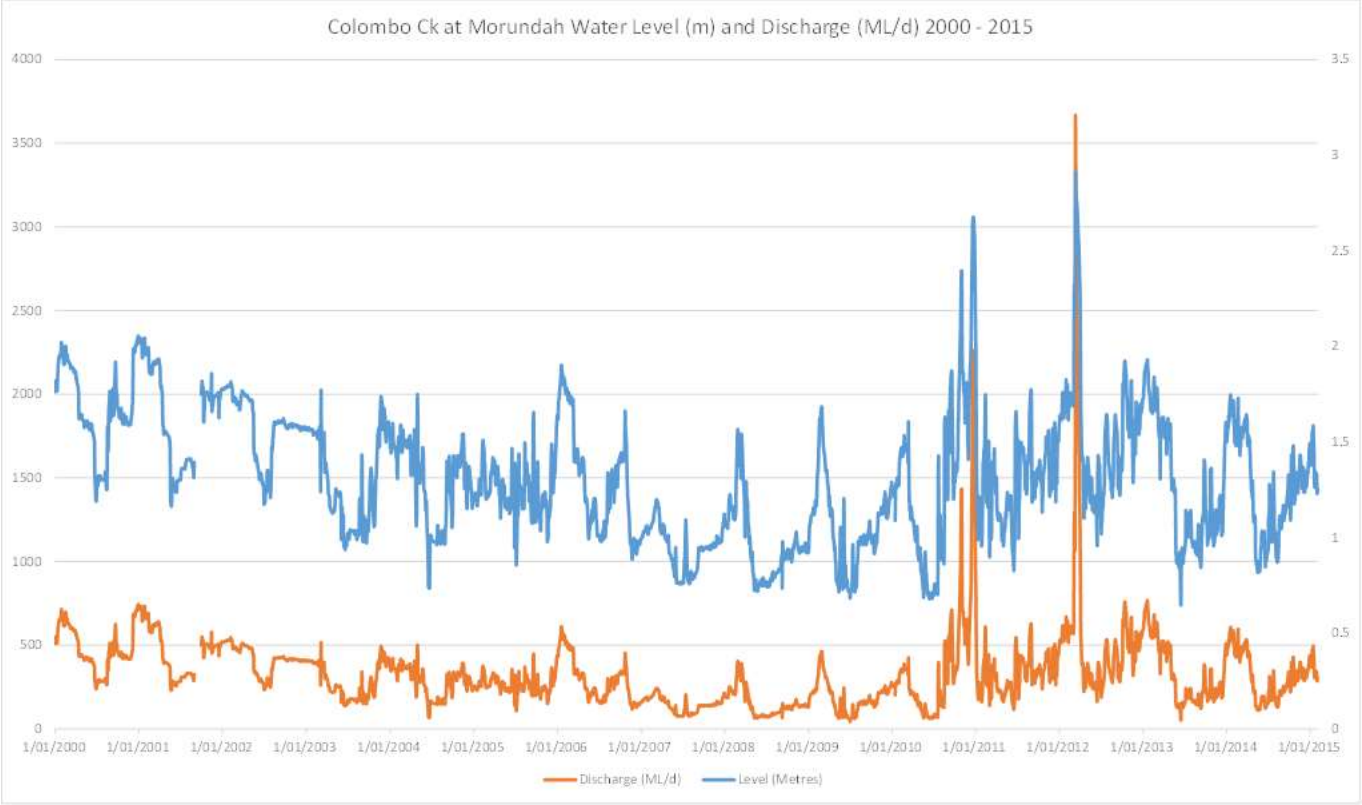

Figure 5. Daily average discharge (ML/d) and water level (m) in Colombo Creek at Morundah for the period 2000-2015. Data source: NSW Office of Water.

At the time of surveys, water levels were relatively high (mean water level 2.2 m gauged at Yanco offtake for the period 13-19 December 2014; Figure 7). This fluctuation, therefore, results in oscillating water levels of more than half of the channel depth at Yanco Creek sites 1-4 (Figure 6), and which is reflected for Colombo Creek at Morundah, adjacent to Colombo Creek site 6 and site 11 (Figure 7). The oscillation in water level and hence overall stream depth occurs throughout the year and is especially pronounced during autumn/winter periods (Figures 5, 6 and 7). An important consideration for the present study is that the extreme water level variation, every 10-14 days, by up to half of the channel depth, is persistent during the known breeding period for trout cod (October-December) in both Yanco Creek (Figure 6) and Colombo Creek (Figure 7).

Figure 6. Daily average discharge (ML/d) and water level (m) in Yanco Creek at the offtake from the Murrumbidgee River for the period 2012-2014. The trout cod breeding period is shaded with blue bars. Data source: NSW Office of Water.

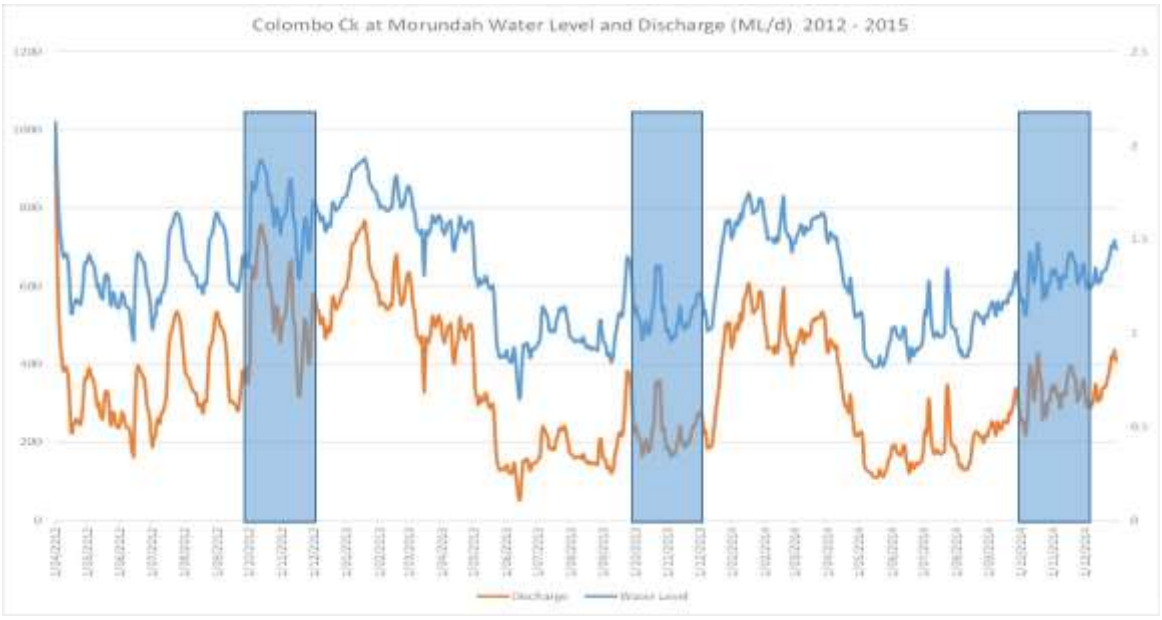

Figure 7. Daily average discharge (ML/d) and water level (m) in Colombo Creek at Morundah for the period 2012-2014. The trout cod breeding period is shaded with blue bars. Data source: NSW Office of Water.

Discussion

4.1 The distribution of trout cod in Yanco and Colombo Creeks

Trout cod were first reported in Yanco Creek in 2013, at four sites in the upper reaches of the creek, upstream of Tarabah Weir (Sharpe et al. 2013). Trout cod were not collected at sites further downstream in Yanco Creek or in the connected Colombo or Billabong Creeks in the 2013 BYC fish baselining study. During the present study, the known distribution of trout cod in the BYC system was extended in Yanco Creek and into Colombo Creek, where trout cod were recorded from downstream to near Morundah. This finding represents a considerable range extension for the species, with the known distribution now occurring for more than 50 km in the BYC system. The Yanco Creek trout cod population now represents a nationally significant population that can be enhanced with targeted management initiatives.

Continuity in occurrence of trout cod among sites throughout the BYC is considered to represent the spatial range of the species in Yanco/Colombo Creeks, rather than discrete, restricted metapopulations. The extended spatial distribution finding is important as:

- Trout cod are listed as endangered at State (NSW) and National levels
- The species is rare across the MDB, occurring as restricted, isolated populations
- The management area for the species has been extended
- Managers can potentially accommodate the habitat and life history requirements of trout cod to ensure that the population is protected and enhanced
- The irrigated flow regime in Yanco Creek could be modified to potentially enhance the trout cod population without impacting on irrigators

4.2 Trout cod habitat requirements and management

The distribution of trout cod in Yanco and Colombo Creeks was associated with a particular suite of habitat and hydrological features including:

- Moderate to fast flowing water (0.3-0.5 m/s)
- High hydrodynamic diversity, including fast- and slow-flowing reaches
- Moderate-high snag density (20-50% channel cover)
- High snag complexity (multiple limbs, trunks and complete trees including rootballs)
- Good to very good riparian condition (18-40 m wide, minimal human/agricultural impacts)
- depth > 2.0 m

Overall, trout cod were associated with hydraulic complexity, including variation in water depth, river width, habitat attributes, water velocity and flow vectors (direction).

The above habitat features are known to influence the occurrence of healthy native fish populations, including trout cod populations (Koehn et al. 2014). High hydrodynamic diversity, high snag complexity and good riparian condition were a distinct feature of sites where trout cod occurred in this study. At sites where trout cod were absent, those habitat features scored lower.

In order to protect and enhance the density and complexity of snag habitats, we recommend that a strategic management regime be developed to ensure that the condition of the riparian zone is maintained or enhanced throughout the upper reaches of Yanco Creek (upstream of Tarabah Weir to the offtake from the Murrumbidgee River) and Colombo Creek (from ~10 km downstream of Morundah upstream to the Yanco Creek confluence). This management is essential to maintaining the condition of the riparian zone and to the long-term contribution of small and large woody debris to the creek channel. These factors are critical to maintaining and enhancing snag density and complexity for trout cod. Limiting livestock access to the riparian zone and the stream bank is a high management priority for both Yanco and Colombo creeks. The study indicated that livestock were affecting the riparian zone at 6 of the 13 survey sites, where trout cod were absent (Figure 8).

Figure 8. The effect of livestock access on the condition of the riparian zone a site on Yanco Creek was evident by the lack of understory vegetation, no recruitment of overstory vegetation, eroded banks and ultimately limited contribution of critical trout cod habitat – high densities of complex woody debris – to the creek channel.

In this study, several sites at which trout cod were recorded were adjacent to travelling stock reserves (TSR). Whilst not an objective of this study, it was evident that the condition of the riparian zone was higher in most TSR visited than it was for adjacent private land, primarily because of the fencing of the riparian zone and limited access by grazing stock. The value of TSR for fish has not previously been considered. However, we recommend that investigation be undertaken into the condition of the riparian zone at TSR versus privately-managed land to identify the value of TSR for protecting fish habitat.

4.3 The impact of flow variability on trout cod spawning and recruitment

Examination of hydrological data identified extreme variability and persistent oscillation in average daily discharge and water levels in reaches where trout cod were recorded, both for the upper Yanco Creek (gauged at the Yanco Creek offtake from the Murrumbidgee River) and upper Colombo Creek (gauged at Morundah). Water levels persistently oscillated by more than half of the available stream depth over the course of 7-10 days throughout the trout cod breeding period and for most of the study.

Altered hydrology would likely affect negatively trout cod spawning biology from spring when fish invest energy in eggs and move to spawning habitats. Trout cod are a nesting species. Therefore, ecological processes associated with spawning, such as nest selection and preparation, courtship, spawning and nest guarding could be interrupted when water levels oscillate unnaturally. Moreover, rapid drops in water level would regularly expose and reduce the number of available spawning sites (which typically include snag complexes, hard surfaces and hollow logs). This process would limit the number of spawning sites, causing reduced spawning potential for the population overall, and forcing "false starts" for spawning. Spawning requires a major biological investment from adult fish. False starts occur when hydrological conditions begin, but do not continue to support spawning requirements, resulting in the abandonment of or unsuccessful spawning.

Abnormal water level variability during the breeding period is likely to affect the spawning success by trout cod and other nesting species (e.g. Murray cod, freshwater catfish; Baumgartner et al. 2013; Sharpe et al. 2014) in Yanco and Colombo Creeks if nesting sites are intermittently exposed. Ultimately, under fluctuating levels the availability of spawning and nesting sites in Yanco and Colombo Creeks is greatly reduced compared to their likely availability under a more stable hydrological regime. While hydrological variability is crucial to the health of aquatic ecosystems (Mallen-Cooper and Stuart 2003; Bunn et al. 2006), persistent, extraordinary or extreme variability in discharge will affect critical life history processes for riverine fish, which can lead to localised extinctions of susceptible species (Lytle and Poff 2004).

Understanding of the impacts of the wide oscillations in discharge and water levels upon the ecology of spawning and recruitment is important for sustaining trout cod in Yanco and Colombo Creeks. While trout cod populations in both creeks consist of a wide range of age and size classes, a key knowledge gap lies in understanding the mode of population maintenance and ultimately the species' persistence. Possible scenarios for population maintenance include:

- The population is self-maintaining: spawning and recruitment occur regularly in Yanco and Colombo Creeks
- The population is maintained by downstream larval drift into Yanco and Colombo Creeks from the adjacent Murrumbidgee River population
- The population is maintained by active colonisation of juveniles and adults from the adjacent Murrumbidgee River population.

None of these scenarios are mutually exclusive and trout cod populations may be maintained by a combination of the above. However, larval drift is highly likely (Koehn and Harrington 2006) and fish may

move the short distance to and from the Murrumbidgee River, in spring and autumn. Fish movement between the two systems and their home range could be evaluated through an acoustic tagging study of trout cod.

Ultimately, for the BYC population to be self-sustaining, spawning and recruitment are required to occur within Yanco/Colombo Creek, semi-independently, or at least in synchrony, with processes occurring in the Murrumbidgee River. Understanding if spawning *and* recruitment regularly occur in Yanco and Colombo Creeks could inform management of regulated flows in this system. If spawning does not occur, or the success of spawning is limited, then options to mitigate persistent oscillations in water levels should be investigated, as these factors are likely to have the greatest potential negative impact upon spawning ecology. This investigation could be facilitated by delivering environmental water during periods of lower irrigation demand and thus low water levels, which may require close scrutiny and active adaptive management in planning for flow delivery. However, this option may be limited because of the lack of a structure to regulate flow at the Yanco offtake on the Murrumbidgee River. Consideration could be given to the value of an appropriately designed flow regulation structure at this site to achieve 'smoothing' of the hydrograph, considerate of the ecological requirements for trout cod spawning.

Murray LLS could consider several options for enhancing the trout cod population, including considering greater protection for the reach above Tarabah Weir with instream and riparian habitat restoration, restoration of spring spawning flows, winter base flows and restoration of hydrodynamic diversity. Also, we observed many signs of illegal fishing (e.g. numerous set lines) in the upper Yanco Creek. Greater control of poaching would be beneficial to the trout cod population.

It is important for future flow planning and investment in flow regulation infrastructure on Yanco/Colombo creeks to understand if the Yanco/Colombo Creek trout cod population is self-sustaining (i.e. spawning and recruitment occurs locally within the Yanco/Colombo system) or if the population is maintained by drift/colonisation from the Murrumbidgee River. We recommend that a spawning study be undertaken which examines the occurrence and spatial distribution of trout cod larvae in Yanco/Colombo Creeks in relation to larval drift into Yanco Creek from the adjacent Murrumbidgee River. Such a study would establish if the Yanco/Colombo Creek population is self-sustaining or reliant on colonisation from drifting larvae from the Murrumbidgee River, and inform knowledge of the impacts of the overt, persistent oscillations in water levels upon the status of trout cod in Yanco and Colombo Creeks.

Recommendations

1. Investigate if the trout cod population in BYC creeks is self-maintained from local spawning or dependent on movement of fish from the Murrumbidgee River as either larvae or dispersing sub-adult/adult fish (spawning/larval study and fish movement study).

2. Develop a trout cod spawning hydrograph for trial implementation in the upper Yanco Creek during spring 2015. The hydrograph would not affect irrigators as it would essentially smooth out spring water level oscillations without affecting downstream users while also maximising connectivity with the Murrumbidgee River. A specific trout cod hydrograph would maximise hydrodynamic complexity and flowing water velocities >0.3 m/s for the entire 40 km trout cod reach. The hydrograph would be a highly sensitive tool for evaluating the benefits of environmental water allocation to trout cod in the BYC system (requires spawning/larval study).

3. The present study has identified a major new trout cod population. We recommend consideration of greater protection of Yanco Creek above Tarabah Weir and Colombo Creek to ~10km downstream of Morundah with: instream habitat restoration, spring spawning flow restoration, winter base flows, maintenance of hydrodynamic diversity and hydraulic complexity, fencing riparian zones and regulation of illegal fishing.

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