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Drought contingency monitoring at Tumudgery Creek, New South Wales

Final report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre.

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Cover images: Site T2 at Tumudgery Creek in December 2009. Images by MDFRC.

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Executive summary

Tumudgery Creek is a wetland of 136 ha on the Edward–Wakool River system located 40 km north-west of Deniliquin, New South Wales. In 2007, it was selected for disconnection from the Edward River to achieve water savings as part of drought contingency planning. The former Murray–Darling Basin Commission (now the Murray-Darling Basin Authority) engaged the Murray–Darling Freshwater Research Centre (MDFRC) to monitor changes in the environmental condition of the wetland to detect and respond to risks of environmental damage. This report deals only with the outcomes and implications of this monitoring and does not present the broader details of the program.

Ecological indicators monitored at Tumudgery Creek included presence of sulfidic sediments, water levels and quality, blue-green algae, fish richness and abundance, river red gum condition, vegetation community, birds (waterbirds and terrestrial) and groundwater levels. Ten tri-monthly surveys were undertaken during the monitoring period of 6 September 2007 to 18 December 2009. Monitoring results were assessed against pre-determined 'trigger values' for management intervention based on Wallace et al. (2007) and NSW Department of Water and Energy (2007). These trigger values provided a point at which managers could assess if intervention was required.

Water levels and quality

Tumudgery Creek received four significant inflows during the sampling period. One inflow event occurred before and three occurred after the refurbishment of the Tumudgery Creek regulator in June 2008, with the largest inflow event occurring between September and December 2009.
The wetland contained surface water for the duration of the study period, although sections of the creek bed dried between sites T1 and T3 during periods of low water levels. Cross-sectional measurements of the creek bed taken in the single pool between sites T3 and T5 showed water depths of 1.0 to 2.4 m in October 2008 when water levels were at their lowest.

- The electrical conductivity of surface water ranged from 46 to 154 μS.cm-1 @ 25 °C and was therefore below the 5,000 μS.cm-1 trigger value of NSW Department of Water and Energy (2007) and the 1,000 mg.L-1 (≈ 1,500 μS.cm-1) trigger value of Wallace et al. (2007) at all times.
- Surface water pH mostly remained within the acceptable pH 6–9 range of NSW Department of Water and Energy (2007) and Wallace et al. (2007), but was outside this range at a single site in August 2008 (pH 9.10) and November 2008 (pH 5.95).
- Mean dissolved oxygen concentrations at the surface (0.2 m depth) ranged from 4.74 to 10.29 mg.L-1 and were above the 5 mg.L-1 threshold of NSW Department of Water and Energy (2007) on 26 of 28 sampling occasions, and were always above the 2 mg.L-1 threshold of Wallace et al. (2007). The lowest individual site recording for dissolved oxygen was 1.88 mg.L-1.
- Surface water temperatures ranged from 8.8 °C to 25.1 °C, and were within the NSW Department of Water and Energy (2007) acceptable range of 6–30°C at all sites and monitoring events. Turbidity levels ranged from 45 to 937 NTU, with most readings being <250 NTU.

Blue-green algae

Over the study period, 22 blue-green algae taxa were sampled. Counts exceeded the trigger value of15,000 cells.mL-1 of Wallace et al. (2007) for 15 of the 30 samples. Two potential toxin producers, Anabaena circinalis and Microcystis aeruginosa were sampled at concentrations above the 15,000 cells.mL-1 threshold at one site in March 2008. The remaining 14 samples exceeding 15,000 cells.mL-1 were of taxa not known as toxin producers.

Fish

In total, 12,391 fish comprising nine native and five exotic species were sampled. This included 922 fish caught with electrofishing (5 surveys) and 11,469 fish caught in fyke nets (10 surveys). Silver perch, Bidyanus bidyanus (n=3), listed as vulnerable under the New South Wales Fisheries Management Act 1994 and Murray cod, Maccullochella peelii peelii (n=10), listed as vulnerable under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999, were sampled in low abundance and by electrofishing only.

River red gum

The majority of river red gum Eucalyptus camaldulensis had a crown condition rating of 'moderate cover' on each sampling occasion. Trees at site T2 had a lower crown condition than those at sites T3 and T4. At site T2, three trees met the Wallace et al. (2007) trigger point for management notification when their crown condition deteriorated from category 4 (moderate foliage cover) to category 0 (sparse crown of dead leaves).

It was difficult to relate wetland disconnection to the decrease in tree condition given the wetland contained water throughout the monitoring period.

Vegetation community

Thirty-five plant taxa, including five introduced species, from eight functional groups were identified from nine surveys of vegetation community. The most abundant species sampled was common rush, Juncus usitatus, followed by river red gum, Eucalyptus camaldulensis and common sneezeweed, Centipedia cunninghamii. No rare or threatened plant species were recorded. The noxious weed arrowhead, Sagittaria platyphylla, was observed in March 2009 at site T1 and managers were notified of its occurrence.

Birds

A total of 180 waterbirds from 11 species were recorded at Tumudgery Creek from nine surveys. The richness of waterbird species was low, ranging from two to five species for each sampling event. The white-bellied sea-eagle was recorded at Tumudgery Creek on two surveys. This species is listed on the China–Australia Migratory Bird Agreement and as a migratory bird under the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999.

Forty-eight terrestrial bird species were recorded during the bird surveys. Species richness ranged from 12 to 25 for each survey. No species of conservation concerns were recorded, although five terrestrial bird species are considered to be declining in abundance in the region.

Groundwater

The influence of groundwater on Tumudgery Creek was based on interpretation of regional data. The closest monitoring site with recent groundwater level information was bore GW502020 located 4.5 km to the south-east of Tumudgery Creek. Regional groundwater levels declined during the drought period and were not expected to have any salinity impacts on Tumudgery Creek. Groundwater salinity in the region was 10,000 to 20,000 µS.cm-1. The resulting low electrical conductivity of surface water when the wetland was disconnected to achieve water savings supported the prediction that Tumudgery Creek would not intercept saline water.

Achievement of the study objective

The monitoring program was successful in achieving its objective of assessing the ecological condition of Tumudgery Creek following its disconnection from the Edward River. There was no evidence of a decrease in the ecological condition of Tumudgery Creek over the study period with the exception of some river red gums at site T2 and high blue-green algae counts from half of the samples. The general maintenance of ecological condition is primarily due to the wetland containing surface water throughout the monitoring period from the four separate inflow events. Monitoring results were evaluated against pre-determined trigger values and communicated regularly to the MDBA and New South Wales government agencies. This communication was important to ensure managers were able to make timely decisions, if required, based on recent and appropriate environmental data.

Future management and recommendations

The regular connection of Tumudgery Creek with the Edward River is important ecologically, as it allows the exchange of water, biota and nutrients between Tumudgery Creek, the wetland complex within the Werai State Forest and the Edward River. Given the relatively low commence-to-flow of this wetland, this exchange can occur at low river flows if the regulator is open. Based on the findings that Tumudgery Creek supports a significant fish community, that the authors believe the maintenance of ecological condition during the disconnection was primarily due to the creek not drying out, and the wetland has a natural water regime of 'permanent' (NSW MWWG 2008), the authors recommend that:

- Tumudgery Creek is managed to allow the two-way exchange of water between the wetland and the Edward River and to maintain sufficient aquatic habitat within the creek to support any isolated fish community.
- A management plan is developed for Tumudgery Creek to maximise the ecological values of the wetland, to develop operating rules around the closing of the regulator and to scope other issues important for the effective management of the site. The management plan should develop an optimal water regime for the wetland that accommodates the first recommendation.

Introduction

Background

In April 2007, the state governments of the Murray–Darling Basin undertook drought contingency planning following sustained low inflows into the system. One of the adopted measures included the temporary disconnection of wetlands from their main river channel to reduce evaporation losses. Tumudgery Creek was one such wetland selected by the New South Wales government for temporary disconnection to achieve water savings.

The former Murray–Darling Basin Commission (MDBC) engaged The Murray–Darling Freshwater Research Centre (MDFRC) to monitor Tumudgery Creek as part of drought water recovery measures (Contract no. MD962). On 15 December 2008, the new Murray–Darling Basin Authority (MDBA) absorbed all of the functions of the MDBC, which ceased to exist. The monitoring program and reporting requirements remained unchanged during this transition.

This report deals only with the outcomes and implications of the environmental monitoring at Tumudgery Creek and does not present the broader details of the wetland disconnection program.

Objective of study

The primary objective of the project was to assess the ecological condition of Tumudgery Creek following its disconnection from the Edward River, and for a minimum period of six months following refilling. In particular, the monitoring program sought to detect early changes that may lead to environmental damage at the wetland.

Monitoring strategy

The monitoring strategy involved assessing a range of physical and biological variables against pre-determined 'trigger values' or 'thresholds' for management intervention (Wallace et al. 2007; NSW Department of Water and Energy 2007). These trigger values reflected levels at which environmental damage to the wetland ecosystem may occur. Results were also evaluated against those from previous monitoring events to provide an indication of any changes in ecological condition. The monitoring team liaised closely with the MDBA and New South Wales government throughout the project and provided regular updates following each monthly sampling of water quality. Results from all ecological indicators were provided in tri-monthly update reports (Durant et al. 2008a,b,c,d, 2009a,b; Reid et al. 2009a,b).

Site description

Tumudgery Creek is a part of the Edward–Wakool River system and is located approximately 40 km north-west of Deniliquin, New South Wales. It connects directly to the Edward River downstream of Stevens Weir. Tumudgery Creek delivers floodwaters to Werai State Forest, which forms part of the New South Wales Central Murray State Forests Ramsar site. The surface area of Tumudgery Creek covers 136 ha and extends for 9 km. The water depth reaches a maximum of about 2.5 m at the western end of the creek during unregulated periods (**Figure 1**).

The land adjacent to Tumudgery Creek is mostly private property and the main land-uses are cattle farming and cropping. The site supports relatively low recreational activity.

Recent ecological condition

Before the project started, Durant and Nielsen (2007) conducted a desktop and field assessment of the ecological condition of Tumudgery Creek in March 2007. The assessment identified threatened species, populations and ecological communities of both flora and fauna known to (or have the potential to) occur in the region.

From this assessment, it was determined that 40 threatened fauna and two threatened flora species have been recorded, or had the potential to occur, in the region. It was also identified that three endangered ecological communities could potentially occur in this region, and one of these was confirmed to exist at Tumudgery Creek.

The Lower Murray River Catchment area, where Tumudgery Creek is located, is classified as an endangered aquatic ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* (Durant and Nielsen 2007). The endangered aquatic ecological community of the Lower Murray catchment includes all native fish and aquatic invertebrates within all natural creeks, rivers and associated lagoons, billabongs and lakes of the regulated Murray River below Lake Hume, including the Edward and Wakool rrivers.

Durant and Nielsen (2007) concluded that re-imposing a wetting and drying cycle has the potential to benefit many components of the ecological community of Tumudgery Creek if:

(i) wetting is undertaken at the appropriate time of year

(ii) water is held within the wetland for sufficient duration to allow flora and fauna to complete life cycles, and

(iii) water is allowed to naturally draw down (Durant and Nielsen 2007).

Recent wetland hydrology

A non-functioning regulator existed on Tumudgery Creek when this project commenced in September 2007. However, an upgrade of the regulator was completed in June 2008. Inflows to Tumudgery Creek occur when the regulator is open and discharge at Stevens Weir exceeds 730 $ML.d^{-1}$, or water level at the gauge downstream of Stevens Weir exceeds 1.0 m (New South Wales Murray Wetland Working Group 2008). The water regime of this wetland is considered 'permanent' (New South Wales Murray Wetland Working Group 2008) due to the relatively low commence-to-flow threshold (McCarthy and Durant 2008) and ability for the wetland to hold pools of water when disconnected from Edward River.

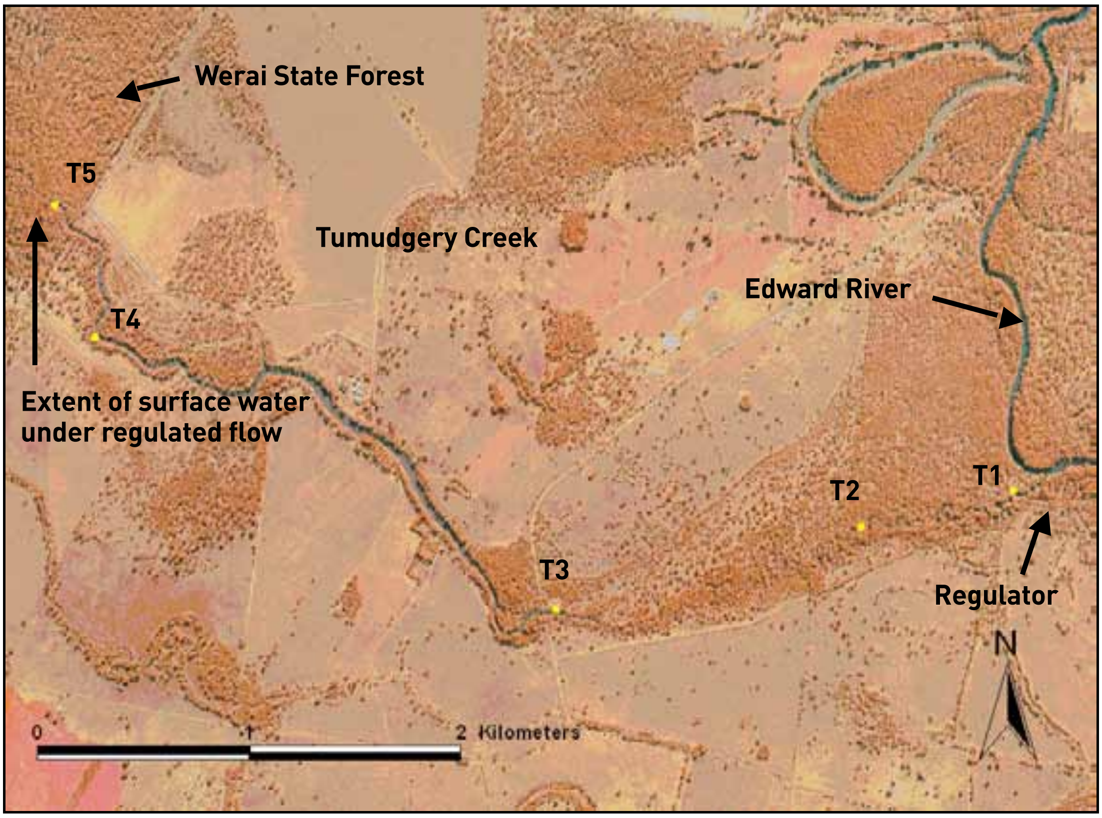

Figure 1. Sampling sites (T1-T5) at Tumudgery Creek

Methods

Ecological indicators and sampling schedule

The ecological indicators monitored during this study were determined by the protocol for assessing wetlands (Wallace et al. 2007) and additional input from New South Wales government agencies and the former MDBC. Monitoring commenced on 6 September 2007 with final sampling occurring 27 months later on the 18 December 2009 (**Table 1**). Ten tri-monthly surveys were completed during this time.

The locations of the five monitored sites at Tumudgery Creek were chosen to maximise the spatial coverage of the wetland and to ensure major habitat types were represented. Site T1 was selected because it was close to the existing regulator and site T5 was selected as it represented the extent of surface water under regulated flows. Given that no clear differences in vegetation community were observed along the creek, sites T2, T3 and T4 were selected in relation to geographic location and positioned at least 500 m apart along the creek (**Figure 1**) as recommended by Wallace et al. (2007).

Sulfidic sediments

Three sites were sampled in September 2007 to assess the likelihood of sulfidic sediment occurrence (and therefore risk of acidification) at Tumudgery Creek. The decision-support tool developed by Baldwin et al. (2007) was used, with the protocol incorporating desktop, field and simple laboratory analyses. Trigger values from Baldwin et al. (2007) are shown in **Table 2**.

Water levels and quality

Water levels were measured monthly from a gauge installed at site T3 in November 2007 by New South Wales Department of Environment and Climate Change (DECC). The gauge was referenced to Australian height datum (mAHD). The measured attributes for water quality were: dissolved oxygen ($mg.L^{-1}$), pH, electrical conductivity ($\mu S.cm^{-1}$ @ 25 °C), water temperature (°C) and turbidity (NTU). These attributes were measured *in situ* at three sites (T2,T3 and T4) on a monthly basis.

Table 1. Tumudgery Creek monitoring schedule

Tumudgery Creek	2007				2008												2009												2010
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Water level																													
Water quality																													
Blue-green algae																													
Fish																													
Understorey																													
Tree health																													
Photopoints																													
Waterbird																													
Acidification potential																													
Update Report					#1		#1	#2			#3			#4			#5			#6			#7			#8			
Final Report																													
KEY: Completed		Needed to reschedule																											

Table 2. Sulfidic sediments trigger values for management notification (from Baldwin et al. 2007)

Variable	Trigger value
Electrical conductivity of surface water	> 1,750 $\mu S.cm^{-1}$
Electrical conductivity of sediment	> 400 $\mu S.cm^{-1}$
pH of surface water	< 4
pH of sediment	< 4.5
Sulfate of surface water	> 10 $mg.L^{-1}$

Water quality trigger values were established by New South Wales Department of Water and Energy (2007) and Wallace et al. (2007), as shown in **Table 3**. Managers were advised when monitoring results met these trigger values.

Blue-green algae

A phytoplankton sample of 0.2 L was collected at 0.2 m water depth at each of three sites (T2, T3 and T4) every three months. Samples were preserved at the point of collection with the addition of 5 ml of Lugol's solution. Blue-green algae species known or suspected to produce toxins were identified to species level and their cell counts recorded. The remaining blue-green algae were identified to genus level and their cell counts recorded. Algae Test Consulting (Malgorzata Przybylska) conducted blue-green algae identification and cell counts. The trigger value for management notification was when BGA counts exceeded 15,000 cells.mL^{-1} (Wallace et al. 2007).

Fish

Fish were surveyed using a combination of fyke nets (fine and coarse mesh) and electrofishing at sites T2, T3 and T4, as described in Wallace et al. (2007). Fish were sampled using fyke nets every three months and by electrofishing every six months.

The netting technique involved two large coarse mesh and two small fine-mesh fyke nets being deployed overnight at each of the three monitoring sites. Nets were set in the afternoon and collected the following morning (typical soak time approximately 12 hours). Large fyke nets (28 mm stretched mesh) had a central wing (8 m x 0.65 m) attached to the first supporting hoop (∅ = 0.55 m) with a 0.32 m stretched mesh entry. Small fyke nets (2 mm stretched mesh) had dual wings (each 2.5 m x 1.2 m) with the first supporting hoop (∅ = 0.4 m) fitted with a square entry (0.15 m x 0.15 m) covered by a plastic exclusion grid with rigid square openings (0.05 m x 0.05 m) to exclude large fish.

Boat electrofishing (5.5 kW Smith-Root electrofisher model GPP 5.5 H/L) consisted of 12 x 90 second shots (power on) for each sampling time. Each shot consisted of intermittent or pulsed electrofishing to minimise the 'herding' of fish away from the effective sampling area of the boat. Electrofishing was undertaken on alternate banks and in open water areas in an attempt to effectively sample all available microhabitats. During each operation, sampled fish were spotted, removed with hand nets and placed in an aerated live-well for processing. Backpack electrofishing (LR-24 Smith-Root electrofisher) consisted of 8 x 150 second shots (power on) on each sampling occasion. Each shot consisted of wading through the water and directing intermittent pulsed current to all available and accessible habitats to sample the resident fish fauna. Backpack electrofishing was conducted when water depths were too shallow for boat electrofishing.

Captured fish were counted, measured and identified to species level (McDowell 1996; Lintermans 2007), with the exception of *Hypseleotris* spp. (Bertozzi et al. 2000). Large-bodied fish species were also weighed (to the nearest 1 gram). All native species were released at their point of capture immediately following processing, with exotic species euthanised as per ethics regulations. The standard length (to the nearest 1 mm) was recorded for all species. Where large catches of a species occurred, a sub-sample of at least 15 individuals (including the largest and smallest) was measured for each gear type.

The trigger value for notifying management was the occurrence of rare or threatened fish species (Wallace et al. 2007).

Table 3. Water quality trigger values for management notification

Variable	DWE (2007)	Wallace et al. (2007)
Temperature	< 6 / > 30 °C	-
Dissolved oxygen	< 5 mg.L-1	< 2 mg.L-1
pH	< 6 / > 9	< 6
Electrical conductivity	> 5,000 µS.cm-1	> 1,500 µS.cm-1
Turbidity	-	-

River red gum

Three transects each consisting of 10 river red gums (*Eucalyptus camaldulensis*) were established along the creek bank at sites T2, T3 and T4. Mature trees containing foliage (i.e. live leaves) were preferentially selected to allow the detection of a potential decline in tree condition. The GPS location of individual trees was recorded and trees were marked with cattle ear tags to assist in locating them at future monitoring times. The condition of the 30 trees was assessed every three months by measuring the variables of crown condition and new growth (Wallace et al. 2007).

Crown condition was assessed as the amount of foliage cover present on a tree relative to its hypothetical maximum given its existing branching structure. In the field, this entailed (a) viewing the branching structure of the tree, (b) visualising the maximum amount of foliage (100%) that could be supported by that branching structure assuming the tree was in full health, and (c) calculating the amount of existing foliage (%) relative to the carrying capacity of the tree. Independent scores to the nearest 5% interval were provided by two observers. From this, a mean score was calculated and the tree assigned to the appropriate category of **Table 4**.

The amount of new growth (new leaves including epicormic growth) on a tree was assessed relative to the amount of foliage present at the time of the survey. Independent scores to the nearest 5% interval were provided by two observers. From this, a mean score was calculated and the tree assigned to the appropriate category of **Table 5**.

A vertical photograph of each tree was obtained every three months to provide a temporal visual record of each tree. A marker peg was placed in the ground under each tree for the duration of the study. A Pentax Optio W30 camera was positioned in a specifically-designed wooden cradle containing a circular spirit level to maintain the camera in a horizontal plane to obtain a vertical photograph. The camera holder was placed on the marker peg, shaded to prevent glare on the image, and oriented relative to the base of the tree. The camera was set to infinity focus, fully wide angle, auto exposure and no flash.

The trigger value for management notification was a deterioration in river red gum crown condition from category 4 (moderate foliage cover) to a lower category (Wallace et al. 2007).

Table 4. Categories of crown condition (based on Wallace et al. 2007)

Category	Description and range	% cover
0	No crown or sparse dead leaves (dead or near dead)	0
1	Full or substantial crown of dead leaves (near dead)	0
2	Sparse crown of live leaves (highly stressed)	<10
3	Minimal cover (stressed)	10-25
4	Moderate cover (moderately stressed)	26-75
5	Full cover (healthy)	76-100

Table 5. Categories of new growth (based on Wallace et al. 2007)

Category	Description and range	% cover
0	None	0
1	Sparse	<10
2	Minimal cover	10-25
3	Moderate cover	26-75
4	Dense cover	76-100

Vegetation community

Vegetation was monitored on a tri-monthly basis at sites T2, T3 and T4 to identify changes to the vegetation community as a result of wetland disconnection. Vegetation was not sampled during the first monitoring event due to the addition of this ecological indicator to the contract after monitoring had commenced.

At each site, five fixed 15 x 1 m^2 quadrats (comprising 15 individual cells of 1 m x 1 m) were established perpendicular to the wetland at +60, +30, 0, -30 and -60 cm elevations from the initial waterline. The location of each quadrat was recorded by GPS and marked with a survey peg. The occurrence of each plant species that had live roots (including non-woody and woody vegetation) within each cell was recorded. Identifications of vegetation species were based on Cunningham et al. (2006), Moore (2005), and Sainty and Jacobs (1981, 2003).

Life cycle patterns and plant responses to the presence or absence of water are key factors in classifying wetland species into functional groups. The functional group categorisation aids in understanding community responses in relation to disturbance, rather than attempting to follow an individual species over time (Brock and Casanova 1997). Each understorey species sampled was assigned to one of the functional groups listed in **Table 6**.

The trigger value for management notification was the occurrence of rare or threatened vegetation species (Wallace et al. 2007).

Birds

Birds were surveyed by Ecosurveys Pty Ltd, Deniliquin (Rick Webster) every three months. Waterbird species, abundances and general activity were recorded. In addition, terrestrial bird species were recorded when observed. Bird surveys were not conducted during the first monitoring event because the addition of this ecological indicator to the contract occurred after monitoring had commenced.

Trigger values were not established for birds.

Photo points

Five photo points were established at Tumudgery Creek to document visual changes at the wetland. A landscape image was taken at each photo point every three months over the study period. The image obtained from the first sampling event was used to frame subsequent images. The camera was shaded to prevent glare on the image. Photographs were taken using the same camera and settings described for the river red gum vertical photo points. Trigger values were not established for photo points.

Groundwater

Groundwater data for Tumudgery Creek was provided by New South Wales Department of Water and Energy (DWE). The following information is based on advice provided to MDFRC from Mitchell (2008).

There were no groundwater monitoring sites close to Tumudgery Creek. Interpretations of groundwater in the vicinity of Tumudgery Creek were based on regional data. The closest sites were monitored by Murray Irrigation Limited and the most recent data on the State Groundwater Database were collected in 2005. The closest monitoring site with recent groundwater level information was bore GW502020 located 4.5 km to the south-east of Tumudgery Creek. Data is presented for this bore as the best available groundwater data for assessment. Trigger values were not established for groundwater.

Table 6. Classification of species functional groups (from Casanova and Brock 2000, Casanova 2007)

Primary category	Secondary category	Description
Terrestrial	Dry species: Tdr	Species that germinate, grow and reproduce where there is no surface water and the watertable is below the soil surface.
Terrestrial	Damp species: Tda	Species that germinate, grow and reproduce on saturated soil.
Amphibious fluctuation-tolerators	Emergent species: ATe	Species that germinate in damp or flooded conditions, that tolerate variation in water level, and that grow with their basal portions under water and reproduce out of the water.
Amphibious fluctuation-tolerators	Low-growing species: ATl	Species that germinate in damp or flooded conditions, that tolerate variation in water level, that are low-growing and tolerate complete submersion when water levels rise.
Amphibious fluctuation-tolerators	Amphibious flood tolerators: ATw	Woody species that tolerate flooded conditions.
Amphibious fluctuation – responders	Morphologically plastic species: ARp	Species that germinate in flooded conditions, grow in both flooded and damp conditions, reproduce above the surface of the water, and that have morphological plasticity (e.g. heterophylly) in response to water level variation.
Amphibious fluctuation – responders	Species with floating leaves: ARf	Species that germinate in flooded conditions, grow in both flooded and damp conditions, reproduce above the surface of the water, and that have floating leaves when inundated.
Submerged	Emergent species: Se	Species that germinate and reproduce under water and also grow above the surface of the water.
Submerged	r-selected species: Sr	Species with rapid growth, germinate and reproduce under water.
Submerged	k-selected species: Sk	Species that have slower growth, germinate and reproduce under water.

Results

Sulfidic sediments

Trigger values

Sediments at sites T2 (pH 3.65) and T4 (pH 3.80) were below the pH 4.5 threshold in the decision-support tool of Baldwin et al. (2007).

A subsequent and detailed analysis of sediment cores found only low levels of sulfidic materials at Tumudgery Creek, and therefore a low risk of acidification to the wetland if dried (Baldwin et al. 2008).

Results for several components of the decision-support tool in Baldwin et al. (2007) are presented in **Table 7**. The pH of the sediment was below the pH 4.5 threshold at sites T2 (pH 3.65) and T4 (pH 3.80). The protocol of Baldwin et al. (2007) consequently recommended that a more detailed investigation of the occurrence of sulfidic sediments be undertaken by directly analysing sediments.

In response to these findings, the former MDBC requested that the MDFRC directly analyse sediments at Tumudgery Creek for the presence of sulfidic materials. A brief overview of this separate study is provided in the discussion, and further details can be found in Baldwin et al. (2008).

Water levels

The water level in Tumudgery Creek ranged from 0.38 m (78.76 m AHD) to 2.69 m (81.07 m AHD) over the study period (**Figure 2**).

Tumudgery Creek contained surface water for the duration of the sampling period. In the reach between sites T3 and T5 the surface water consisted of a single waterbody for the duration of the study. However, in the reach between sites T1 and T3 some sections of the creek bed were exposed at low water levels and the surface water fragmented into a series of remnant pools.

Four significant inflows occurred at Tumudgery Creek during the sampling period (**Figure 2**). The increase in water level in February 2008 was unplanned and caused by an operational problem at Stevens Weir in late January 2008. The malfunction resulted in a decrease in water levels upstream of Stevens Weir and a consequent increase in water levels downstream of the weir. The elevated water level exceeded the commence-to-flow for Tumudgery Creek resulting in a brief inflow of water and increase in water level of 0.5 m at the wetland (the regulator was not functioning at that time).

Table 7. Measurements of variables at Tumudgery Creek to determine the risk of sulfidic sediments occurring at the wetland

Site	EC surface water (μS.cm^{-1})	EC →1750 μS.cm^{-1}?	EC of sediment (μS.cm^{-1})	EC→400 μS.cm^{-1}?	pH of surface water	Surface water pH←4?	pH of sediment	Sediment pH ←4.5?	Sulfate surface water (mgSO_4.L^{-1})	Sulfate →10mg.L^{-1}?
Site T2	50	No	9	No	6.64	No	**3.65**	**Yes**	1.9	No
Site T3	59	No	18	No	6.68	No	4.60	No	2.7	No
Site T4	64	No	15	No	7.11	No	**3.80**	**Yes**	2.1	No

The three remaining inflow events occurred after the refurbishment of the regulator was completed in June 2008, with the greatest increase in water level occurring between September and December 2009.

At the time of low water levels in October 2008, concerns were raised about whether the depth of surface water remaining within Tumudgery Creek was sufficient to support the isolated fish community.

On 14 October 2008, 13 cross-sectional depth profiles were obtained along the deeper section of the creek between sites T3 and T5. Most cross-sections had a maximum water depth of >1 m, with the deepest point recorded being 2.43 m (**Figure 3**). The findings indicated that the water depth would be sufficient to support the fish community in the short-term.

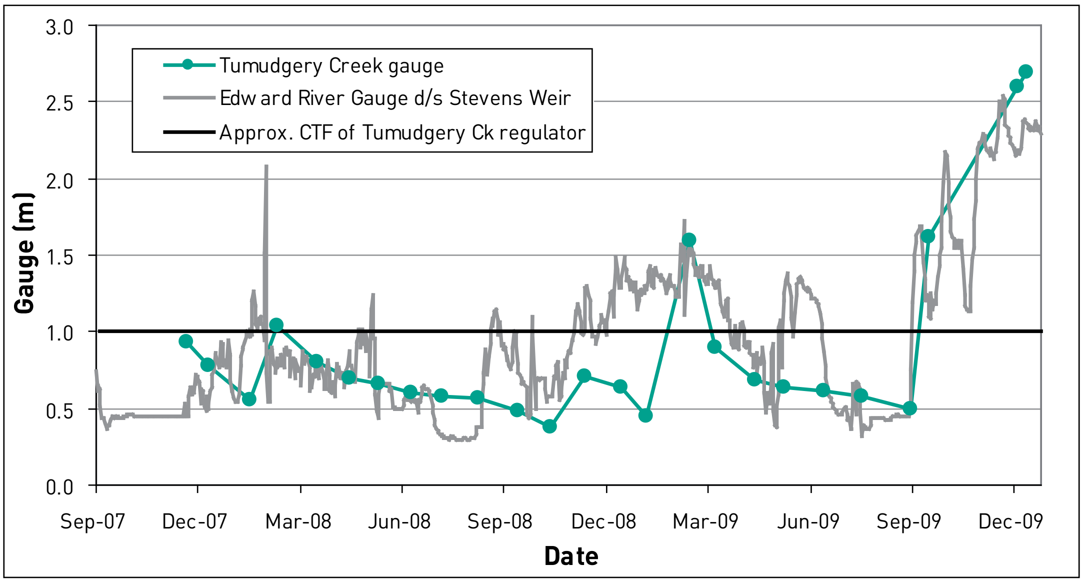

Figure 2. Water level at the established gauge (site T3) at Tumudgery Creek and the Edward River gauge downstream of Stevens Weir. The approximate commence-to-flow of the Tumudgery Creek regulator is shown

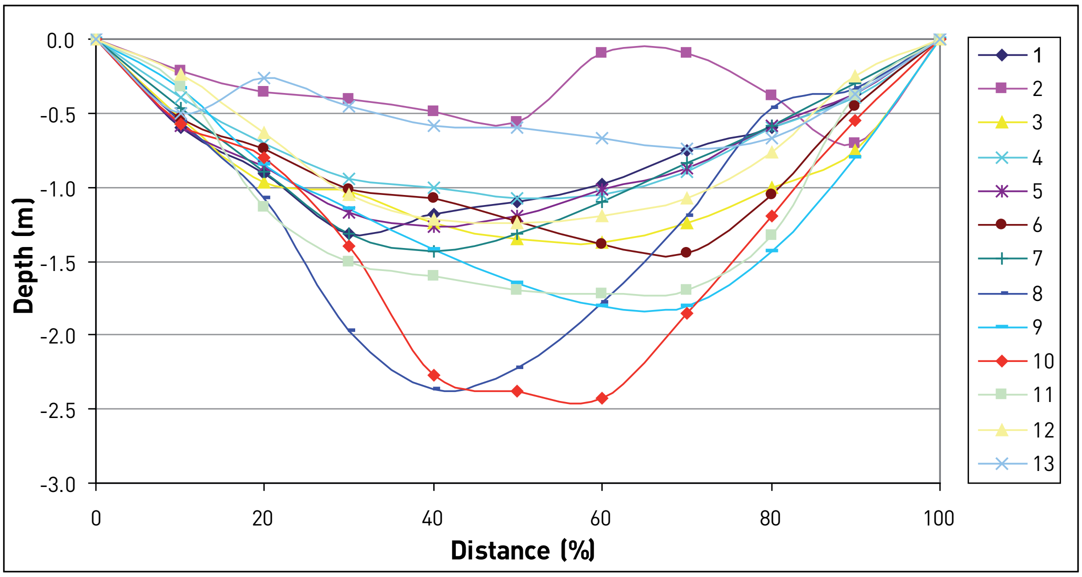

Figure 3. Water depth cross-sections obtained along a 2–3 km reach of Tumudgery Creek between sites T3 and T5 on 14 October 2008.

Water quality

Electrical conductivity

Trigger values

Electrical conductivity did not exceed the 5,000 μS.cm^{-1} trigger value of NSW Department of Water and Energy (2007) or the 1000 mg.L^{-1} (≈1,500 μS.cm^{-1}) trigger value of Wallace et al. (2007) during the monitoring period.

The electrical conductivity (EC) of surface water ranged from 46 to 154 μS.cm^{-1} @ 25 °C.

Mean surface water EC generally remained low (<100 μS.cm^{-1} @ 25 °C) throughout the study period (**Figure 4**). The lowest single-site EC value of 46 μS.cm^{-1} was recorded in December 2009 (site T2), with the highest value of 154 μS.cm^{-1} measured in January 2009 (site T2). The highest EC values generally corresponded with low water levels, and the lowest EC values corresponded with the highest water levels for the period of sampling.

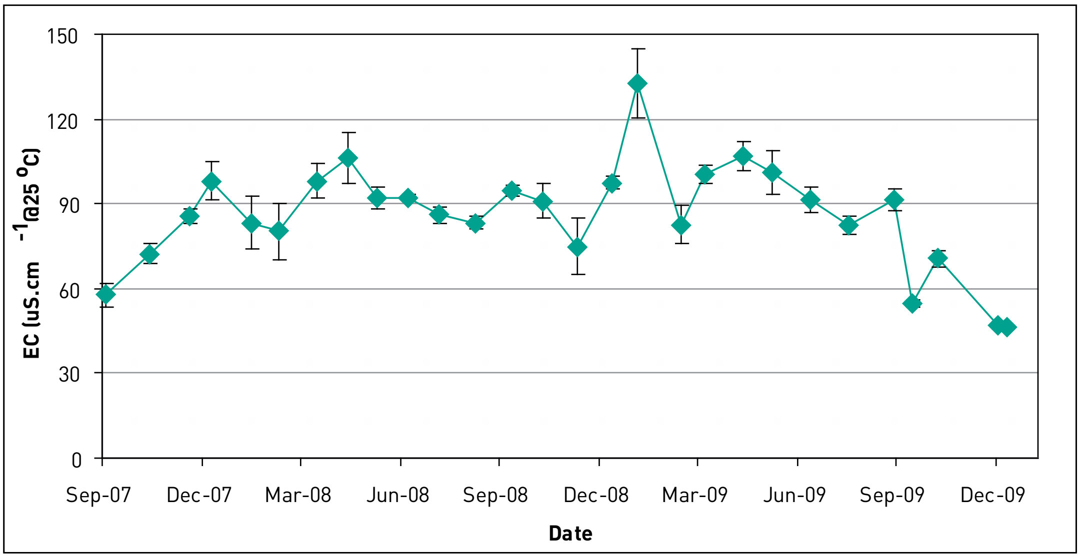

Figure 4. Mean (±1 S.E.) electrical conductivity (μS.cm^{-1}@25°C) of surface water at Tumudgery Creek.

pH

Trigger values

Mean surface water pH levels remained within the acceptable pH range of 6–9 as stipulated in NSW Department of Water and Energy (2007) and Wallace et al. (2007).

However, individual site pH levels were outside of this range at single sites in August 2008 (pH 9.10) and November 2008 (pH 5.95).

Mean surface water pH levels ranged from 6.04 to 8.12 (**Figure 5**) for the 28 sampling occasions.

Water temperature

Trigger values

Surface water temperatures remained within the NSW Department of Water and Energy (2007) acceptable range of 6–30°C at all sites and times.

Surface water temperatures fluctuated over the sampling period in response to seasonal conditions, with mean temperatures ranging from 8.8°C to 25.1°C (**Figure 6**).

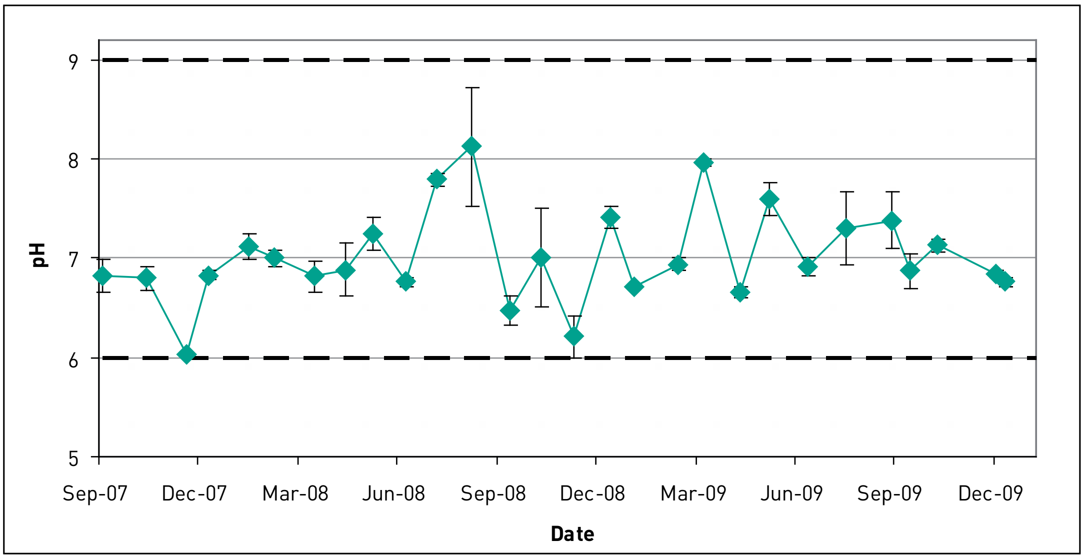

Figure 5. Mean (±1 S.E.) pH of surface water at Tumudgery Creek. The dashed lines represent the pH 6 and pH 9 trigger values.

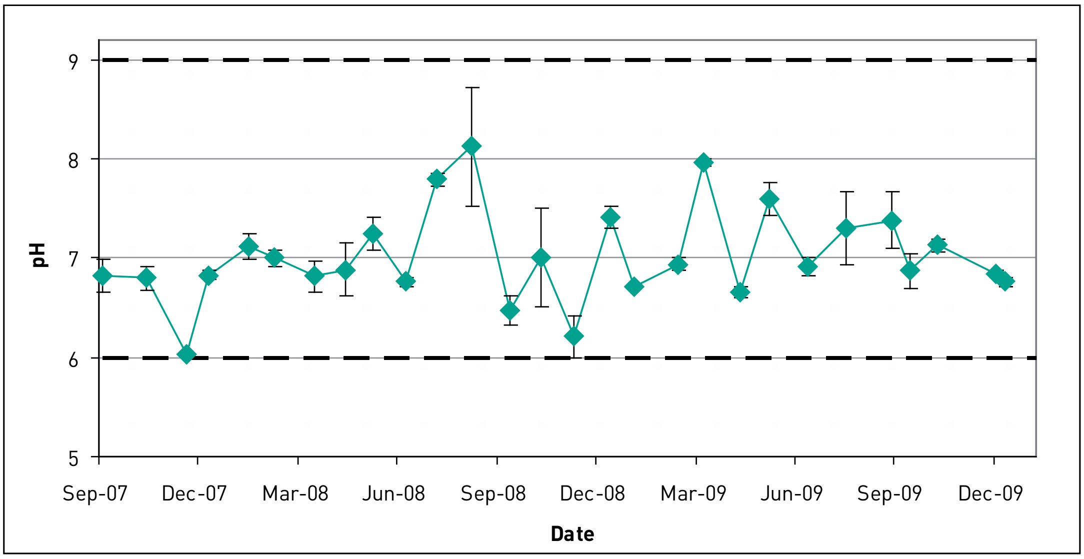

Figure 6. Mean (±1 S.E.) surface water temperature (°C) at Tumudgery Creek. The dashed lines represent the 6˚C and 30˚C trigger values

Dissolved oxygen

Trigger values

Mean dissolved oxygen concentrations at the surface (0.2 m depth) were above the 5 mg.L^{-1} threshold of NSW Department of Water and Energy (2007) on 26 of 28 sampling occasions, and always above the 2 mg.L^{-1} threshold of Wallace et al. (2007).

Mean dissolved oxygen concentrations at the bottom of the water column were above the 5 mg.L^{-1} threshold of NSW Department of Water and Energy (2007) on 20 of 24 occasions when sampled, and above the 2 mg.L^{-1} threshold of Wallace et al. (2007) on all 24 occasions.

The lowest individual site recording of dissolved oxygen was 1.9 mg.L^{-1} at site T3 in March 2009.

Mean dissolved oxygen concentrations at the surface (0.2 m depth) ranged from 4.7 to 10.3 mg.L^{-1} (**Figure 7**).

Mean dissolved oxygen concentrations at the surface (0.2 m depth) were above the 5 mg.L^{-1} threshold of NSW Department of Water and Energy (2007) on 26 of 28 sampling occasions. However, individual site measurements of dissolved oxygen at the surface of the water column were below the 5 mg.L^{-1} threshold of NSW Department of Water and Energy (2007) on 5 of 28 sampling occasions, and above the 2 mg.L^{-1} threshold of Wallace et al. (2007) at all sampling times.

Mean dissolved oxygen concentrations at the bottom of the water column were above the 5 mg.L^{-1} threshold of NSW Department of Water and Energy (2007) on 20 of 24 sampling occasions. However, individual site measurements of dissolved oxygen at the bottom of the water column were below the NSW Department of Water and Energy (2007) threshold of 5 mg.L^{-1} on 10 of 24 sampling occasions, and below the Wallace et al. (2007) threshold of 2 mg.L^{-1} once (1.9 mg.L^{-1} at site T3 on 27 March 2009).

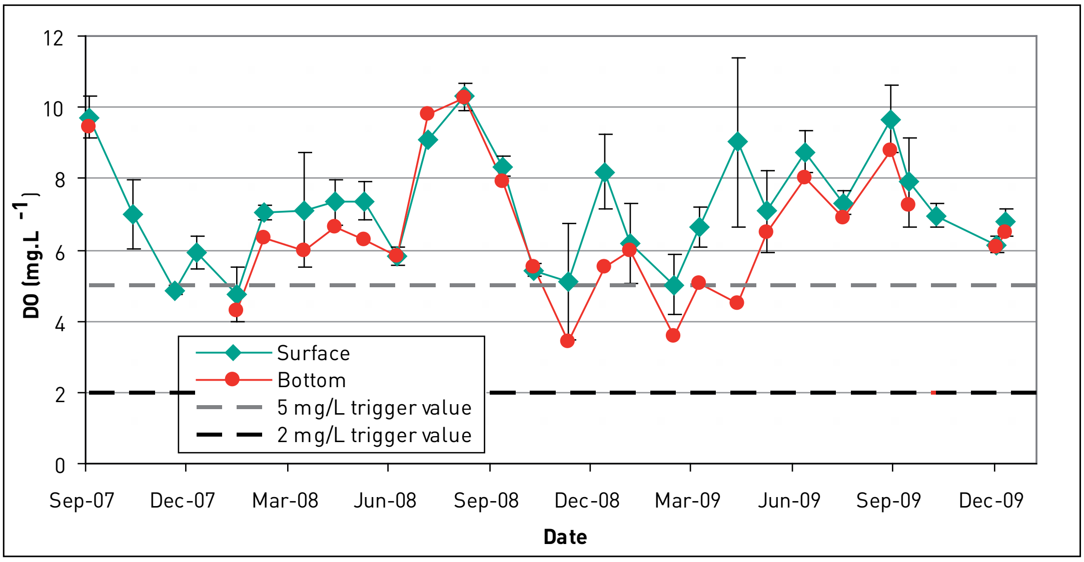

Figure 7. Mean (±1 S.E.) dissolved oxygen concentrations (mg.L^{-1}) at the surface and bottom of the water column at Tumudgery Creek. The dashed lines represent the 5 mg.L^{-1} and 2 mg.L^{-1} trigger values.

Turbidity

Trigger values

No trigger values were established for turbidity in NSW Department of Water and Energy (2007) or Wallace et al. (2007).

Mean turbidity levels ranged from 45–937 NTU.

The highest individual turbidity reading (1,845 NTU) was obtained in October 2008 and the lowest (19.5 NTU) in November 2008 (**Figure 8**). The high turbidity value occurred at site T2 where water depth was shallow (approximately 10 cm) and the lowest reading occurred at site T2 following an increase in water levels.

Blue-green algae

Trigger values

Blue-green algae counts exceeded the trigger value of 15,000 cells.mL^{-1} of Wallace et al. (2007) for 15 of 30 samples.

Two potential toxin producers, *Anabaena circinalis* and *Microcystis aeruginosa,* were sampled at concentrations above the 15,000 cells.mL^{-1} threshold at one site in March 2008.

A total of 22 blue-green algae taxa were recorded during the study period (Appendix A). Counts of blue-green algae exceeded the 15,000 cells.mL^{-1} threshold of Wallace et al. (2007) for 15 of the 30 samples (**Table 8**). However, the majority of these high cell counts belonged to the non-toxic genera *Aphanocapsa*.

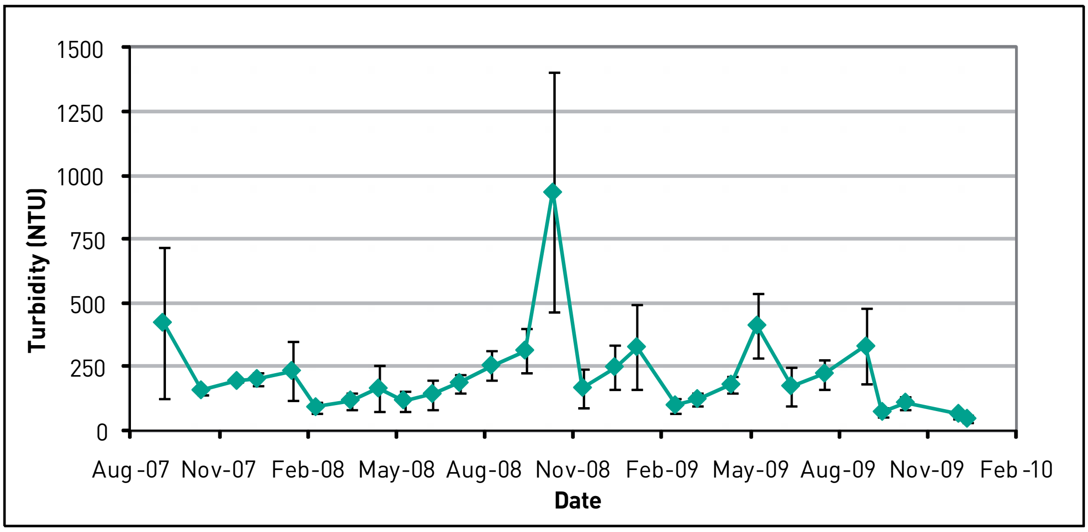

Figure 8. Mean (±1 S.E.) turbidity (NTU) at Tumudgery Creek

Table 8. Blue-green algal counts (most abundant species in parentheses) at Tumudgery Creek. Shading denotes when blue-green algae cell counts exceeded the 15,000 cells.mL^{-1} trigger value.

Date	Site T2 (cells.mL^{-1})	Site T3 (cells.mL^{-1})	Site T4 (cells.mL^{-1})
6 Sep 2007	20,260 (8,500 *Romeria* spp.)	24,256 (22,256 *Aphanocapsa* spp.)	22,280 (21,490 *Aphanocapsa* spp.)
12 Dec 2007	19,370 (18,430 *Aphanocapsa* spp.)	210 (80 *Merismopedia* spp. and 80 *Microcystis* spp.)	520 (440 *Aphanocapsa* spp.)
18 Mar 2008	67,850 (65,540 *Aphanocapsa* spp.)	164,470 (84,650 *Anabaena circinalis*)	38,420 (36,470 *Aphanocapsa* spp.)
12 Jun 2008	12,680 (11,890 Aphanocapsa spp.)	12,770 (12,760 Aphanocapsa spp.)	13,980 (13,660 Aphanocapsa spp.)
17 Sep 2008	1,540 (1,480 Aphanocapsa spp.)	1,030 (590 Aphanocapsa spp.)	790 (500 Aphanocapsa spp.)
17 Dec 2008	2,760 (1,210 Planktolyngbya subtilis)	5,230 (3,260 Aphanocapsa spp.)	3,720 (3,200 Aphanocapsa spp.)
12 Mar 2009	6,310 (5,090 Aphanocapsa spp.)	26,310 (25,370 Aphanocapsa spp.)	103,040 (64,080 Microcystis spp.)
18 Jun 2009	78,520 (47,570 Aphanocapsa spp.)	96,830 (80,870 Aphanocapsa spp.)	53,490 (40,430 Aphanocapsa spp.)
21 Sep 2009	4,370 (2,250 Anabaena spp.)	3,750 (1,660 Aphanocapsa spp.)	3,330 (1,920 Aphanocapsa spp.)
18 Dec 2009	20,530 (17,910 Aphanocapsa spp.)	18,840 (16,960 Aphanocapsa spp.)	24,210 (22,640 Aphanocapsa spp.)

Four potential toxin producers and two suspected, but unconfirmed, potential toxin producers were sampled from all three sites (**Table 9**). The potential toxin producers *Microcystis aeruginosa* (78,440 cells.mL^{-1}) and *Anabaena circinalis* (84,650 cells.mL^{-1}) were sampled in high abundance at one site (T3) in March 2008, with levels above the threshold stipulated in Wallace et al. (2007).

Fish

Trigger values

Nine native and five exotic fish species were sampled at Tumudgery Creek.

The native fish community contained Silver perch, *Bidyanus bidyanus,* and Murray cod, *Maccullochella peelii peelii*, two species of conservation concern. Therefore, the trigger value of Wallace et al. (2007), which involved a requirement for the maintenance of aquatic habitat as fish refuge, was met.

A total of 12,391 fish comprising nine native and five exotic species were recorded from 10 sampling events. 922 fish were caught with electrofishing (five surveys) and 11,469 fish were caught in fyke nets (10 surveys) (**Table 10**).

Native species comprised 96.4% and exotic species 3.6% of the total catch. However, exotic species comprised 78.2% of the 212 kg of large-bodied fish biomass sampled (common carp 72.6%, goldfish 4.7%, redfin perch 0.9%). The four native fish contributing to the 21.8% of native large-bodied fish biomass were golden perch (12.2%), Murray cod (8.8%), silver perch (0.4%) and bony bream (0.4%).

Silver perch, *Bidyanus bidyanus,* (n=3) listed as vulnerable under the New South Wales *Fisheries Management Act 1994* and Murray cod, *Maccullochella peelii peelii,* (n=10) listed as vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, were sampled in low abundance by electrofishing only.

The native *Hypseleotris* spp. (carp gudgeon) were the most abundant taxon sampled (n=10,984 or 89% of total catch) followed by flat-headed gudgeon, *Philypnodon grandiceps,* (n=513 or 4.1% of total catch). Common carp, *Cyprinus carpio,* (n=207 or 1.7% of total catch) was the most abundant exotic species sampled followed by eastern gambusia, *Gambusia holbrooki,* (n=168 or 1.4% of total catch).

Table 9. Blue-green algal counts for 'potential toxin producers' and 'suspected but unconfirmed potential toxin producers' at Tumudgery Creek. Shading denotes when blue-green algae cell counts exceeded the15,000 cells.mL^{-1} trigger value.

Date	Site T2 (cells.mL^{-1})	**Site T3** (cells.mL^{-1})	**Site T4** (cells.mL^{-1})
18 Mar 2008	60 Anabaena spiroides f spiroides[1] 420 Planktolyngbya subtilis[2]	84,650 Anabaena circinalis[1] 190 Anabaena spiroides f spiroides[1] 78,440 Microcystis aeruginosa[1]	1,240 Anabaena circinalis[1] 350 Microcystis aeruginosa[1] 40 Planktolyngbya subtilis[2]
12 Jun 2008			130 Anabaena circinalis[1]
17 Dec 2008	1,210 Planktolyngbya subtilis[2]		
12 Mar 2009		340 Microcystis aeruginosa[1] 60 Planktolyngbya subtilis[2]	380 Anabaena circinalis[1] 12,310 Microcystis aeruginosa[1]
21 Sep 2009	80 Anabaena spiroides f spiroides[1]	660 Anabaena spiroides f spiroides[1]	110 Anabaena circinalis[1] 490 Anabaena spiroides f spiroides[1]
18 Dec 2009	500 Anabaena affinis[2] 40 Anabaena circinalis[1] 540 Planktolyngbya subtilis[2]	440 Anabaena affinis[2] 50 Anabaena circinalis[1] 160 Planktolyngbya subtilis[2]	40 Anabaena affinis[2] 30 Anabaena circinalis[1] 140 Planktolyngbya subtilis[2]

[1] Potential toxin producer
[2] Suspected but unconfirmed potential toxin producer

Table 10. Fish species and their relative abundances from netting and electrofishing at Tumudgery Creek.
Exotic fish are highlighted with an asterisk. (+) indicates species was not captured but observed at time of sampling in the creek.

Common name	Scientific name	Sep07		Dec07	Mar08		Jun08	Sep08		Dec08	Mar09		Jun09	Oct09		Dec09
		Net	Elec	Net	Net	Elec	Net	Net	Elec	Net	Net	Elec	Net	Net	Elec	Net
Australian smelt	Retropinna semoni	36	32	3	3	1	1	8	5					1	1	
Bony bream	Nematalosa erebi											2				2
Carp gudgeon	Hypseleotris spp.	197	102	335	1602	196	1251	2381	15	689	976	100	812	190	15	2123
Flat-headed gudgeon	Philypnodon grandiceps	17	82	111	64	11	9	37	4	13	56	5	2	9		93
Fly-specked hardyhead	Craterocephalus stercusmuscarum fulvus		40	12	2	3	3		2	2	1	6	2	6		
Golden perch	Macquaria ambigua		2			2	1		3	1	3	3		1	2	1
Murray cod	Maccullochella peelii peelii		3			1			2			4			(+)	
Murray–Darling rainbowfish	Melanotaenia fluviatilis	1	15	4	32	3	16	1	2		31	46	55		1	33
Silver perch	Bidyanus bidyanus		1			2			+							
Common carp*	Cyprinus carpio		9	1	1	44		1	9	15	13	43	8	3	16	44
Eastern gambusia*	Gambusia holbrooki			6	41	36	24				3	2	1	1		54
Goldfish*	Carassius auratus		5			12	1	5	3	2	3	25	8		2	
Oriental weatherloach*	Misgurnus anguillicaudatus							1			2	2				
Redfin perch*	Perca fluviatilis	1						1								
	Richness	5	10	7	8	10	8	8	9	6	9	11	7	7	6	7
	Count	252	291	472	1747	309	1306	2435	45	722	1088	238	888	211	37	2,350
	Total richness	11		7	11		8	11		6	11		7	9		7
	Total count	543		472	2,056		1,306	2,480		722	1,326		888	248		2,350

River red gum

Trigger values

The majority of river red gum (*Eucalyptus camaldulensis*) had a crown condition rating of 'moderate cover' on each sampling occasion.

Three trees met the Wallace et al. (2007) trigger point for management notification when crown condition deteriorated from category 4 (moderate foliage cover) to lower categories.

Crown condition

The majority of river red gum on each sampling occasion were rated as category 4 (moderate cover) for their crown condition (**Figure 9**). Three trees were classified as category 0 (no crown or sparse dead leaves) on the final sampling occasion in December 2009.

The crown condition of the river red gum monitored at site T2 was lower than the river red gum at sites T3 and T4 (**Figure 10**). At site T2, all trees experienced fluctuations in their crown condition with two trees at category 2 and three trees at category 0 in December 2009. Four of these five trees rated as category 3 or 4 at the beginning of the study, with the remaining tree declining in condition from category 2 to 0 after 18 months of sampling.

Photographs of the three trees at site T2, which declined in condition to the extent that they no longer contained foliage (live leaves), are provided in **Figure 11**.

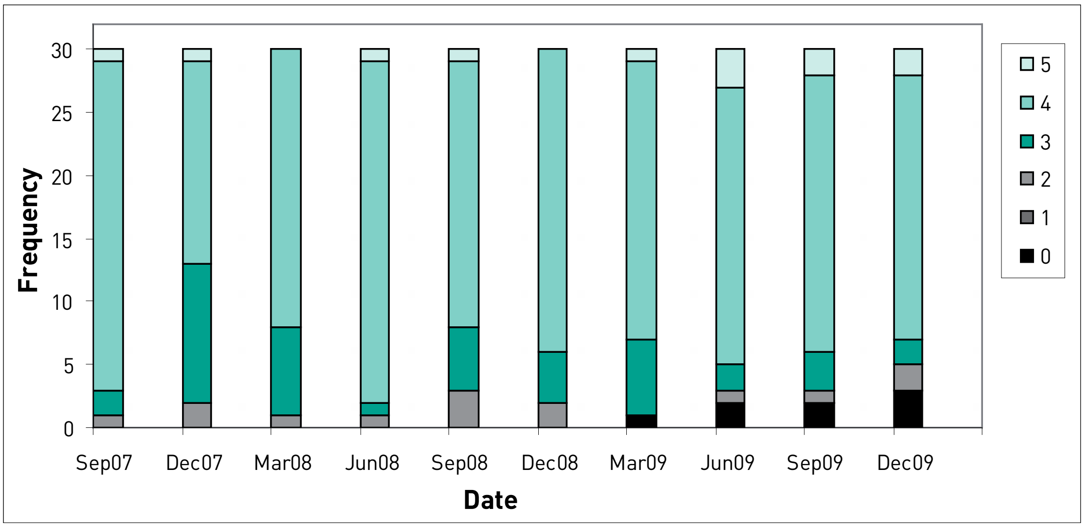

Figure 9. Crown condition of river red gum at Tumudgery Creek

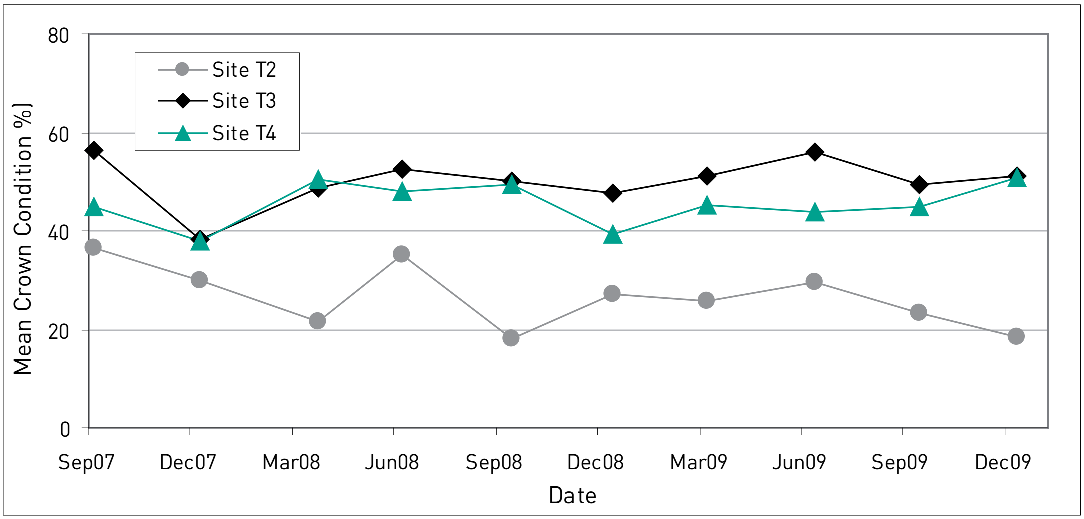

Figure 10. Mean crown condition scores (%) for river red gum at each of three transects (n=10 trees per transect) at Tumudgery Creek.

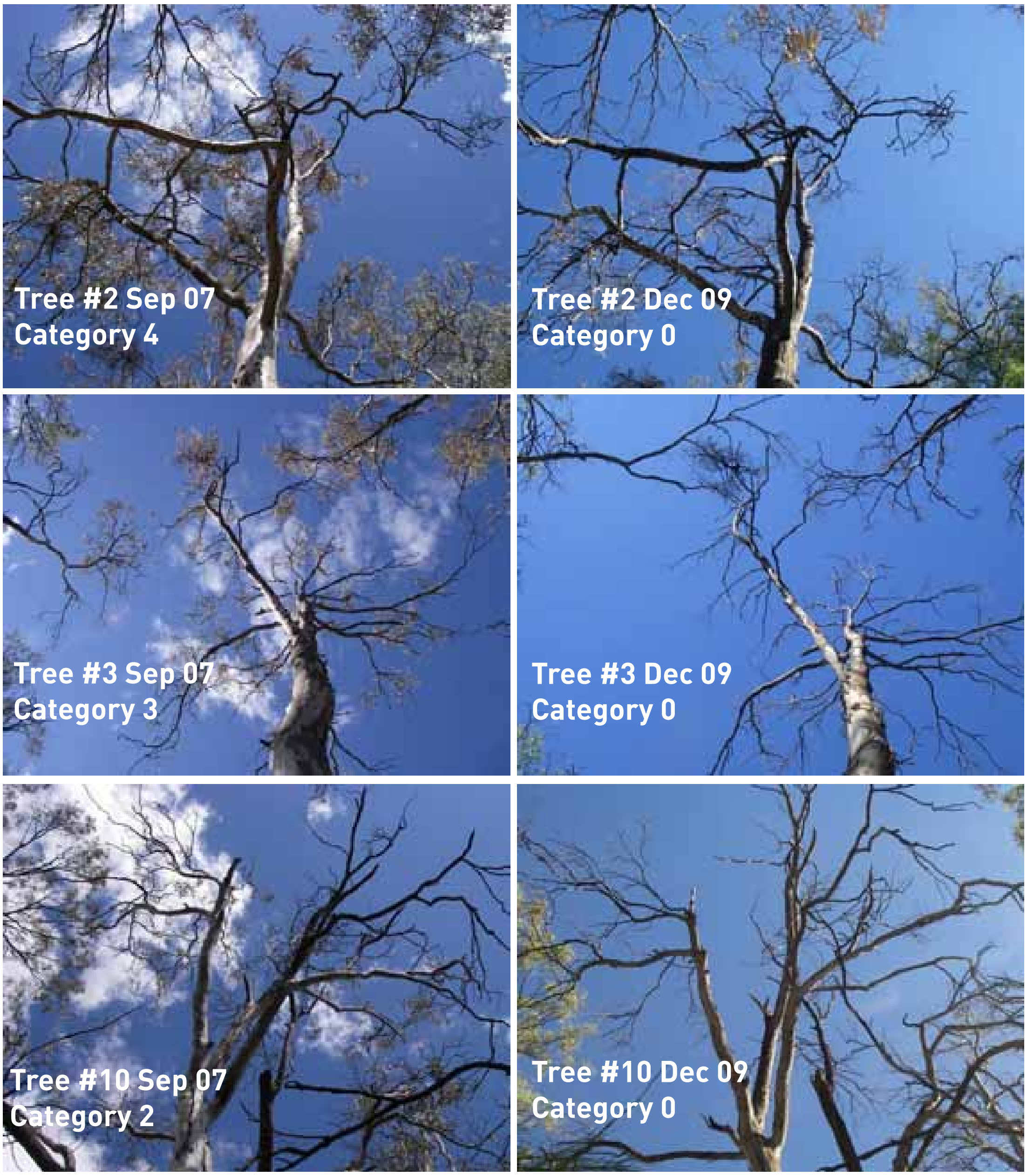

Figure 11. Photographs showing the complete loss of foliage (live leaves) from river red gum trees #2, #3 and #10 at Tumudgery Creek site T2. Images shown were obtained at the beginning of the study in September 2007 and the completion of the study in December 2009. Note that the crowns of adjacent trees also appear within the photographs.

New foliage

The greatest amount of new foliage growth occurred in December 2009, when 10 trees were recorded as having over 10% of their foliage as new growth (**Figure 12**).

Three trees displayed no new growth over the sampling period. These trees (#3, #4 and #10) were all located at site T2.

Vegetation community

Trigger values

No rare or threatened plant species were recorded in the vegetation community of Tumudgery Creek. Hence, the trigger point of Wallace et al. (2007) relating to the maintenance of aquatic habitat for rare or threatened vegetation species was not met.

The noxious weed arrowhead, *Sagittaria platyphylla,* was recorded at Tumudgery Creek.

Thirty-five plant taxa from eight functional groups were identified from nine surveys. The abundance of each taxon for each sampling occasion and its functional group are presented in **Table 11**. Abundances are the number of cells in which each taxon was recorded from a possible 225 cells (i.e. 3 sites x 5 elevations x 15 cells per quadrat).

Vegetation community richness ranged from seven to 20 taxa between surveys. The most abundant species sampled was common rush, *Juncus usitatus*, followed by river red gum, *Eucalyptus camaldulensis,* and common sneezeweed, *Centipedia cunninghamii*. In December 2009, all quadrats were completely inundated with the exception of the +60 elevation at site T2. This single quadrat was the only one sampled at this time.

The weed arrowhead, *Sagittaria platyphylla,* was observed growing in Tumudgery Creek at site T1 downstream of the regulator in March 2009. This species is declared in New South Wales under the *Noxious Weeds Act* 1993 (DPI 2005). It is known to form dense patches in waterways and can obstruct water flows. Without removal and/or control measures, there is the potential for this species to out-compete native water plants. Managers were notified of the occurrence of this declared noxious weed in the tri-monthly update reports (Durant et al. 2009b; Reid et al. 2009a,b).

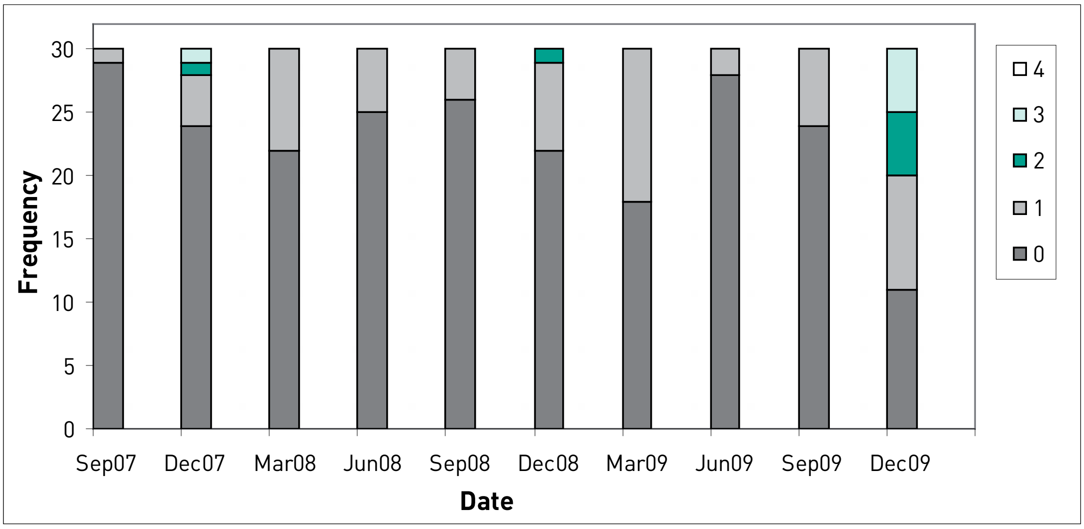

Figure 12. New growth of river red gum at Tumudgery Creek.

Table 11. Vegetation sampled at Tumudgery Creek on nine occasions. Functional groups and abundances are presented. The maximum possible abundance for each taxon at each time is 225 (i.e. 3 sites x 5 elevations x 15 cells per quadrat). Introduced species are highlighted with an asterisk.

Scientific name	Common name	Functional group	Abundance								
			Dec07	Mar08	Jun08	Sep08	Dec08	Mar09	Jun09	Sep09	Dec09
Alternanthera denticulate	Lesser joyweed	Tda		15	14	1	14	9	10	4	
Asteraceae family			1	2	7	15			1	3	
Bolboschoenus fluviatilis	Marsh clubrush	ATe			15			6	12	1	
Centipeda spp.		ATl		8	4			8			
Centipeda cunninghamii	Common sneezeweed	ATl	55	34	55	35	39		72		
Centipeda minima	Spreading sneezeweed	ATl				4	23				
Chamaseyce drummondii	Caustic weed	Tdr			2					1	
Chenopodium pumilio	Small crumbweed	Tdr	4	1					77		
Cucumis myriocarpus*	Paddy melon	Tdr						3	2		
Cyperus difformis	Dirty dora	ATe		2		2					1
Cyperus spp.		ATe			11	8					
Elatine gratioloides	Waterwort	ARp	9	9			15	17	31		
Eucalyptus camaldulensis	River red gum	ATw	47	35	46	36	39	121	118	52	1
Eucalyptus spp.		ATw		14		1					
Exocarpos cupressiformis	Cherry ballart	Tdr		2						2	
Glinus lotoides	Hairy carpet weed	Tda			7						
Immature dicot				19	49	26	28	39	66	27	1
Immature monocot					62	26	1	1	12		
Isolepis prolifera*	Budding clubrush	Arp						2			
Juncus spp.		Ate				7					
Juncus usitatus	Common rush	Ate	52	28	50	36	47	56	80	72	
Ludwigia peploides ssp. montevidensis	Water primrose	ARp						3	4	1	
Lythrum hyssopifolia	Hyssop loosestrife	Tda						4			
Malva parviflora*	Small-flowered mallow	Tdr			1	3	1				
Medicago spp.*		Tdr			25	23		6	24		
Nitella spp.	Stonewort	Sk		5							
Paspalum distichum	Watercouch	Tda						2	1		
Persicaria spp.	Knotweed	Ate	13	2	4		3		20		
Phragmites australis	Common reed	ATe			1						
Phyla nodiflora*	Lippia	Tda	18		11	22	17	7	10	15	11
Poaceae family			27	18	10	71	44	3	46	70	9
Polygonum plebium	Small knotweed	Tda		2							
Pseudognaphalium luteo-album	Jersey cudweed	Tda	32	19	43	61	22	7			
Senecio spp.			3	13	1	23	12	3	12	58	14
Wahlenbergia fluminalis	River bluebell	Tda	1	6			6	1	5	11	10
		Abundance	262	234	418	400	311	298	603	317	47
		No. taxa	12	19	20	18	15	19	19	13	7

The abundances of vegetation taxa at each elevation and monitoring time are presented in **Figure 13**. Abundances are the summed frequency of occurrence of plant species in the cells at each elevation. The graph shows a relatively high abundance of plants in June 2009 compared to other sampled months. The sampling in June 2009 occurred several months after all quadrats were inundated, and the increased soil moisture was providing conditions favourable for the germination of some plant species.

Only a single quadrat (+60 cm at site T2) could be sampled in December 2009 due to the increase in water level at Tumudgery Creek.

Richness of species ranged from four to 14 for each elevation and sampling occasion (**Figure 14**).

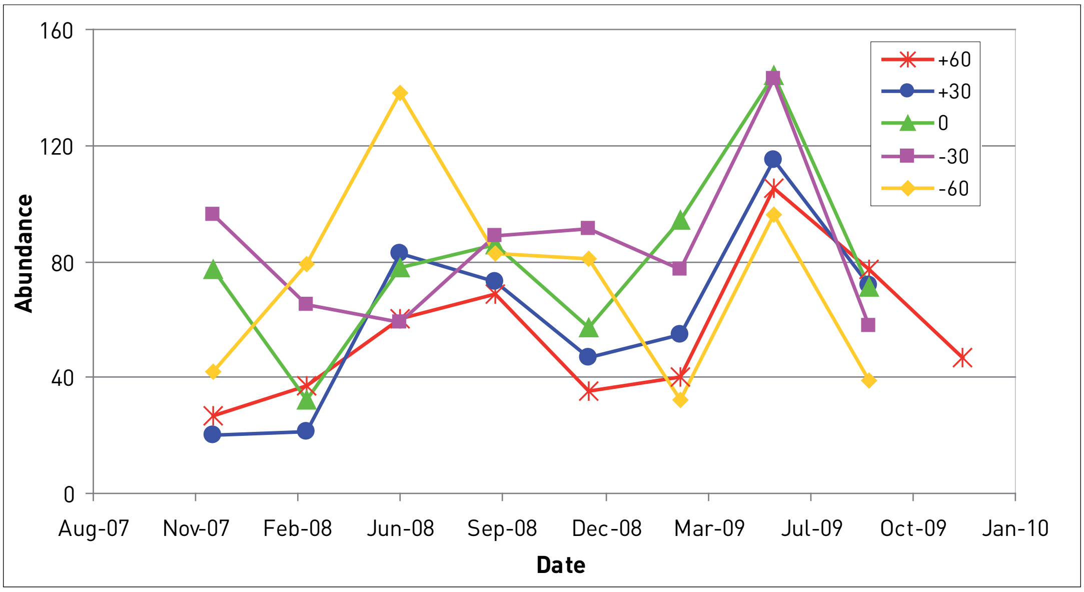

Figure 13. Abundance of vegetation from fixed 1 m x 1 m cells at Tumudgery Creek. Five elevations were surveyed nine times.

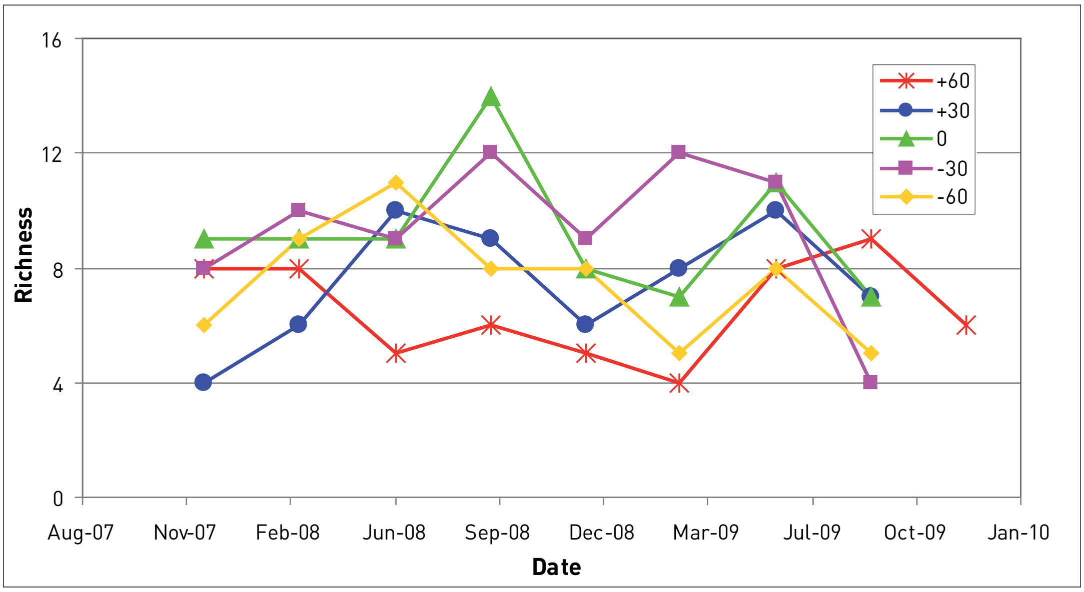

Figure 14. Richness of vegetation from fixed 1 m x 1 m cells at Tumudgery Creek. Five elevations were surveyed nine times.

The 35 plant taxa classified into seven of a possible 10 functional groups (**Figure 15**). One submerged (Sk) species (*Nitella* sp.) was recorded on one occasion in March 2008 at the -60 cm elevation. The functional group with the greatest richness on all but two sampling occasions was Tda (terrestrial damp). Amphibious species (Atl, Ate, Arp) were represented throughout the monitoring period. Species belonging to Tdr (terrestrial dry) were recorded on each sampling occasion with the single exception of December 2009. The low abundance and richness in December 2009 was due to the inundation of all sites with the exception of one quadrat at +60 cm elevation.

Birds

Trigger values

No trigger values were established for birds in Wallace et al. (2007) or NSW Department of Water and Energy (2007).

The white-bellied sea-eagle, *Haliaeetus leucogaster,* was recorded during the monitoring period and bred at Tumudgery Creek. This species is listed on the China–Australia Migratory Bird Agreement (CAMBA) and as a migratory bird under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*.

In addition, five terrestrial bird species are considered to be declining in numbers.

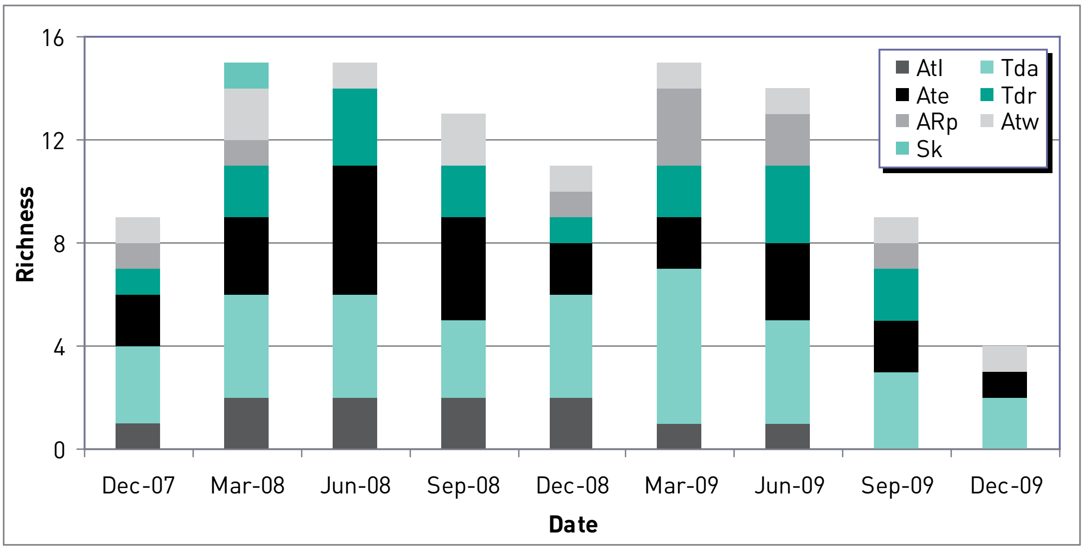

Figure 15. Species richness of vegetation by functional group at Tumudgery Creek at nine sampling times

Waterbirds

A total of 180 individual waterbirds from 11 species were recorded at Tumudgery Creek from nine surveys (**Table 12**). The white-bellied sea-eagle, *Haliaeetus leucogaster,* was recorded in December 2007 and September 2008. The three individuals recorded in December 2007 included one nestling, with the nest located near site T3. The species is listed on the China–Australia Migratory Bird Agreement (CAMBA) and as a migratory bird under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*.

The richness of waterbird species was low, ranging from two to five species for each sampling occasion. The highest abundance of waterbirds occurred in December 2008, when 46 individual waterbirds from five species were recorded.

Terrestrial birds

A total of 48 terrestrial bird species were recorded during the monitoring period (**Table 13**). Species richness ranged from 12 to 25 for each survey.

No threatened or rare terrestrial bird species were recorded at Tumudgery Creek. However, five terrestrial bird species recorded at Tumudgery Creek have declined in abundance in areas north-east of this study site (Reid 1999). These included the chestnut-rumped thornbill (*Acanthiza uropygialis*), Jacky winter (*Microeca fascinans*), red-capped robin (*Petroica goodenovii*), restless flycatcher (*Myiagra inquieta*) and rufous whistler. (*Pachycephala rufiventris*).

Table 12. Waterbirds recorded at Tumudgery Creek

Common name	Scientific name	Relative abundance								
		Dec 07	Mar 08	Jun 08	Sep 08	Dec 08	Mar 09	Jun 09	Sep 09	Dec 09
Australian pelican	Pelecanus conspicillatus						1			
Australian wood duck	Chenonetta jubata	1		4	8	25	7	21	14	15
Azure kingfisher	Alcedo azurea	2	1							
Black-fronted dotterel	Elseyornis melanops					1				
Grey teal	Anas gracilis				2	12	9	2	2	
Pacific black duck	Anas superciliosa		1	11	5	7	1	8	5	2
Pied cormorant	Phalacrocorax varius								1	
Whistling kite	Haliastur sphenurus		2			1				
Australian reed-warbler	Acrocephalus australis									2
White-bellied sea-eagle	Haliaeetus leucogaster	3			1					
White-faced heron	Egretta novaehollandiae		1		1			1		
	Richness	3	4	2	5	5	4	4	4	3
	Total count	6	5	15	17	46	18	32	22	19

Table 13. Terrestrial birds recorded at Tumudgery Creek

Common name	Scientific name	Occurrence								
		Dec07	Mar08	Jun08	Sep08	Dec08	Mar09	Jun09	Sep09	Dec 09
Australian magpie	Gymnorhina tibicen		X		X	X		X	X	
Australian raven	Corvus coronoides		X	X	X			X		X
Black-faced cuckoo-shrike	Coracina novaehollandiae	X	X		X	X			X	
Brown-headed honeyeater	Melithreptus brevirostris		X				X		X	X
Brown treecreeper	Climacteris picumnus picumnus	X	X	X	X	X	X		X	X
Buff-rumped thornbill	Acanthiza reguloides	X	X	X	X	X				
Chestnut-rumped thornbill[1]	Acanthiza uropygialis			X		X	X		X	X
Cockatiel	Nypmhicus hollandicus								X	
Crested pigeon	Ocyphaps lophotes					X				
Dollarbird	Eurystomus orientalis									X
Galah	Eolophus roseicapilla		X	X	X	X	X	X	X	X
Golden whistler	Pachycephala pectoralis			X						
Grey fantail	Rhipidura albiscapa	X		X	X	X	X	X	X	X
Grey shrike-thrush	Colluricincla harmonica		X			X	X			X
Jacky winter[1]	Microeca fascinans			X			X	X	X	
Laughing kookaburra	Dacelo novaeguineae		X						X	
Little friarbird	Philemon citreogularis		X							X
Long-billed corella	Cacatua tenuirostris		X		X				X	
Mistletoe bird	Dicaeum hirundinaceum		X			X				
Magpie-lark	Grallina cyanoleuca									X
Noisy friarbird	Philemon corniculatus					X				
Noisy miner	Manorina melanocephala				X					
Peaceful dove	Geopelia striata		X			X				
Pied butcherbird	Cracticus nigrogularis		X		X				X	
Red-capped robin[1]	Petroica goodenovii			X						
Red-rumped parrot	Psephotus haematonotus	X		X			X	X	X	X
Restless flycatcher[1]	Myiagra inquieta									X
Rufous whistler[1]	Pachycephala rufiventris			X	X	X				
Sacred kingfisher	Todiramphus sanctus					X				X
Scarlet robin	Petroica multicolor			X						
Silvereye	Zosterops lateralis		X							
Spotted pardalote	Pardalotus punctatus			X						
Striated pardalote	Pardalotus striatus		X	X	X	X			X	X
Striated thornbill	Acanthiza lineate			X						
Sulphur-crested cockatoo	Cacatua galerita		X	X	X	X		X	X	X
Superb fairy-wren	Malurus cyaneus	X	X	X	X	X	X	X	X	X
Tree Martin	Hirundo nigricans									X
Varied sittella	Daphoenositta chrysoptera	X		X						
Wedge-tailed eagle	Aquila audax			X	X	X				
Weebill	Smicrornis brevirostris	X	X	X	X	X		X		X
Welcome swallow	Hirundo neoxena	X	X			X	X		X	X
White-plumed honeyeater	Lichenostomus penicillatus	X	X	X	X	X	X	X	X	X
White-throated treecreeper	Cormobates leucophaeus	X			X	X	X	X		
White-winged chough	Corcorax melanorhamphos	X	X	X					X	
White-winged triller	Lalage sueurii									X
Willie wagtail	Rhipidura leucophrys		X	X	X	X	X		X	X
Yellow rosella	Platycercus elegens flaveolus	X	X	X	X	X		X	X	X
Yellow thornbill	Acanthiza nana		X	X	X	X	X		X	
	Richness	13	25	25	21	25	14	12	22	23

[1] Species proposed to be in decline (Reid 1999)

Groundwater

Regional groundwater levels declined during the drought with levels in the region unlikely to cause any salinity impacts on Tumudgery Creek. It is likely that if Tumudgery Creek dried for an extended period the groundwater levels surrounding the creek would decline (Mitchell 2008).

Groundwater at the monitoring site GW502020 is approximately 5 m below ground level (**Figure 16**). It is likely that in the Werai State Forest, where inundation from Tumudgery Creek occurs, that groundwater levels would be less than 5 m below ground level (Mitchell 2008).

Groundwater salinity tends to increase with distance to the west of Tumudgery Creek. The salinity of the local groundwater near Tumudgery Creek, which is in the central region of the Murray Geological Basin, was recorded at levels between 10,000 and 20,000 $\mu S.cm^{-1}$ by Murray Irrigation Limited (Mitchell 2008).

Photo points

Photographs from a single photo point from each established site are presented in Figures 17 to 21. These images provide a photographic history of the site and highlight changes in water levels and vegetation over time.

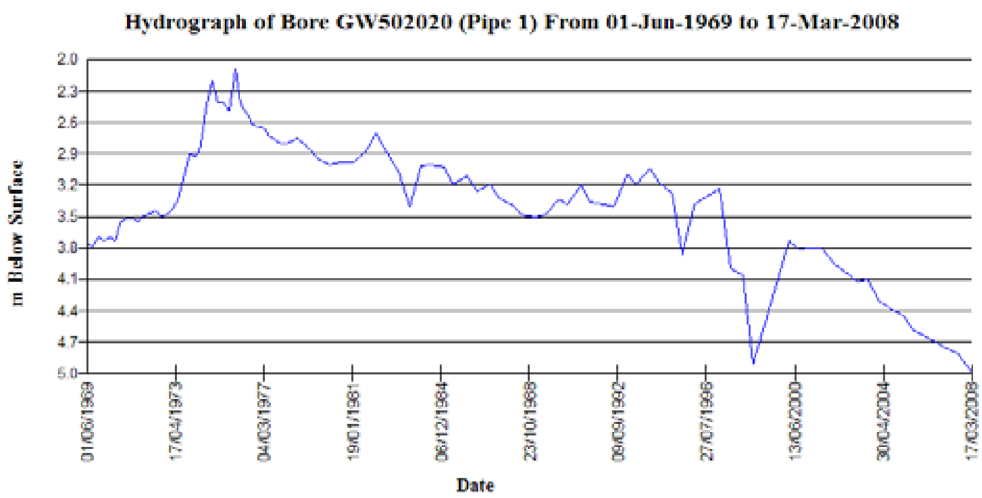

Figure 16. Groundwater level (m below surface) at GW502020 located 4.5 km to the southeast of Tumudgery Creek for the period 1969 - 2008.

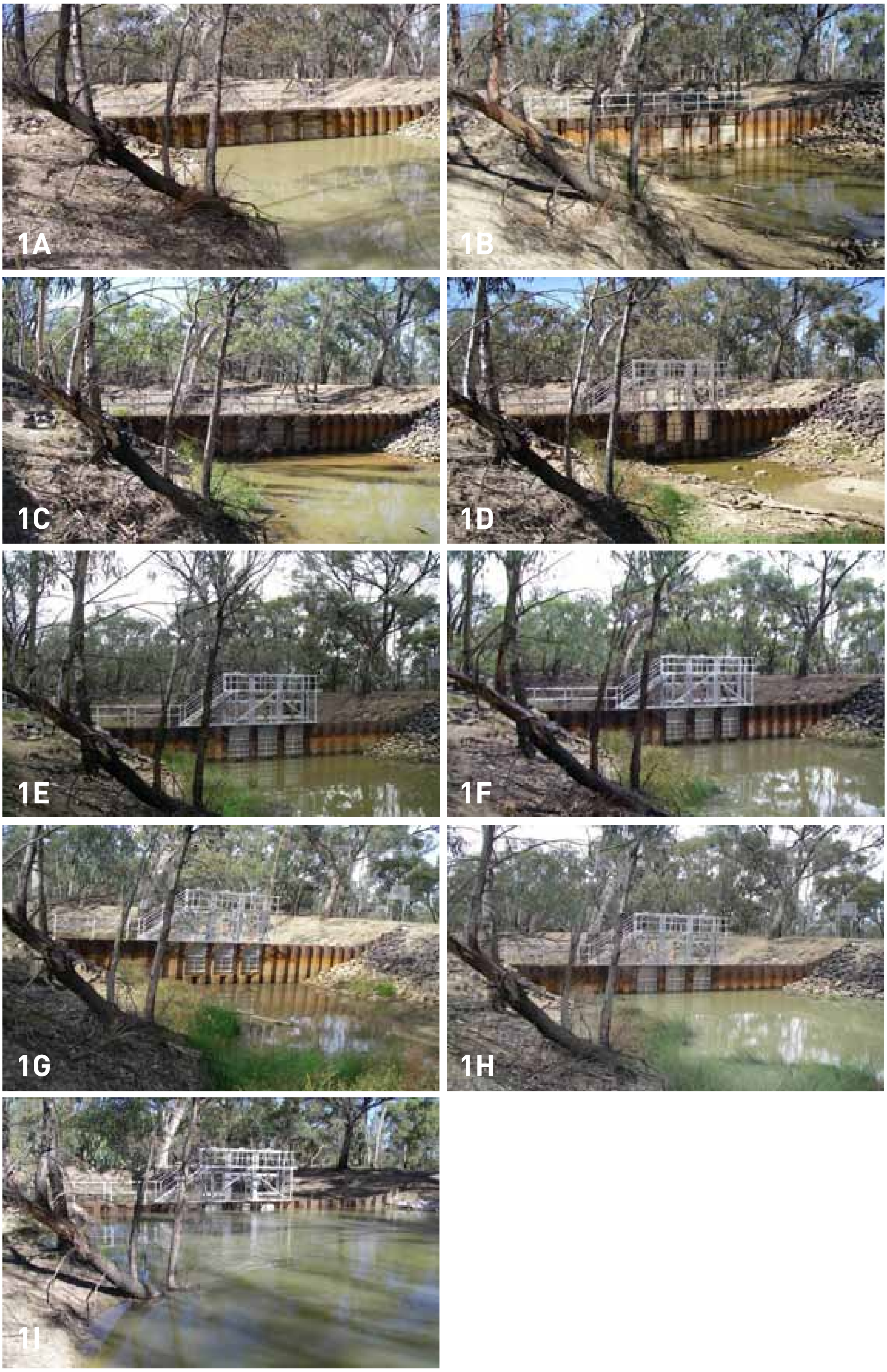

Figure 17. Photo points of Tumudgery Creek at Site T1 on (A) 6 September 2007, (B) 12 December 2007, (C) 28 March 2008, (D) 17 September 2008, (E) 17 December 2008, (F) 12 March 2009, (G) 18 June 2009, (H) 21 September 2009 and (I) 18 December 2009.

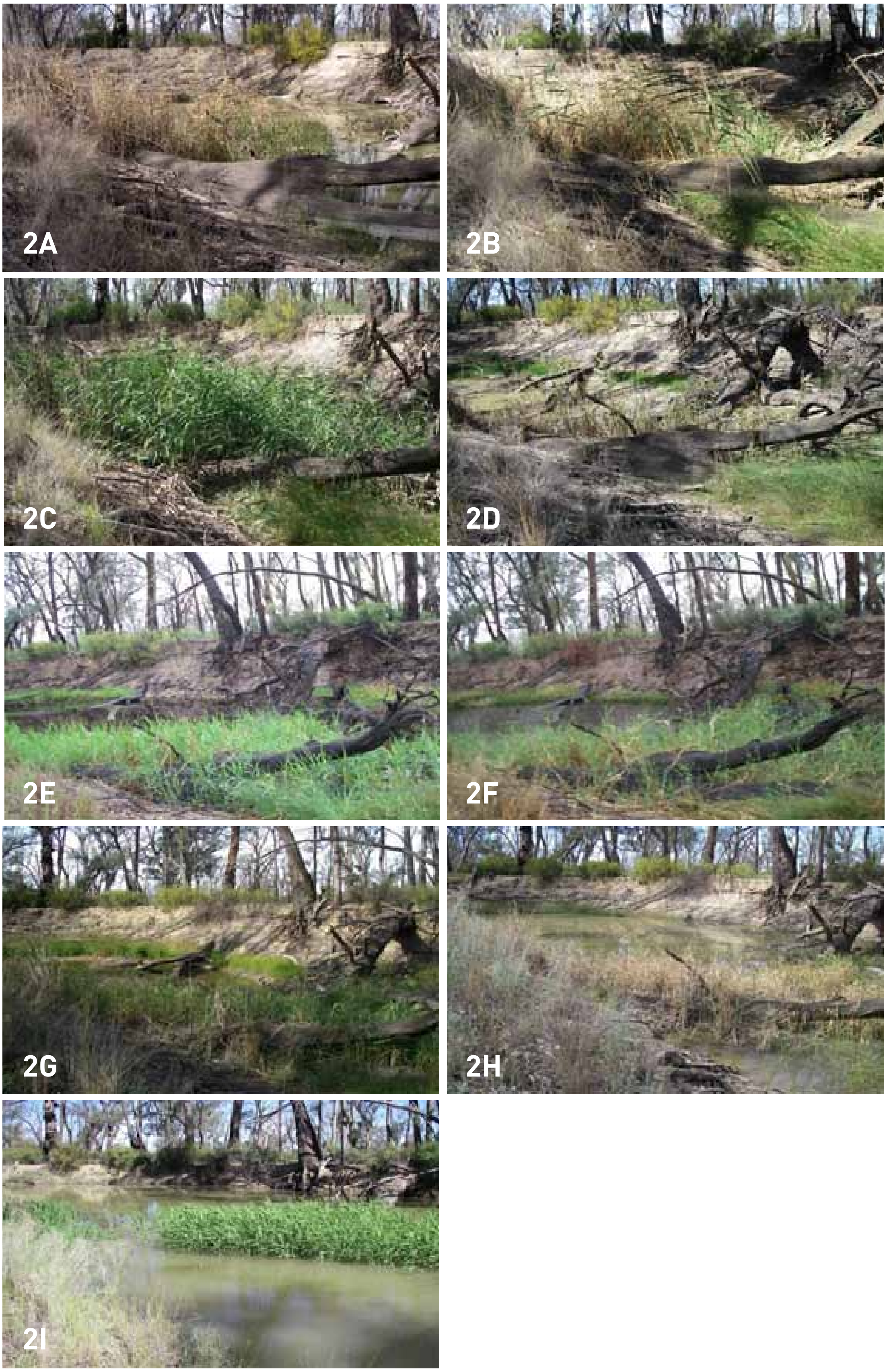

Figure 18. Photo points of Tumudgery Creek at Site T2 on (A) 6 September 2007, (B) 12 December 2007, (C) 28 March 2008, (D) 17 September 2008, (E) 17 December 2008, (F) 12 March 2009, (G) 18 June 2009, (H) 21 September 2009 and (I) 18 December 2009.

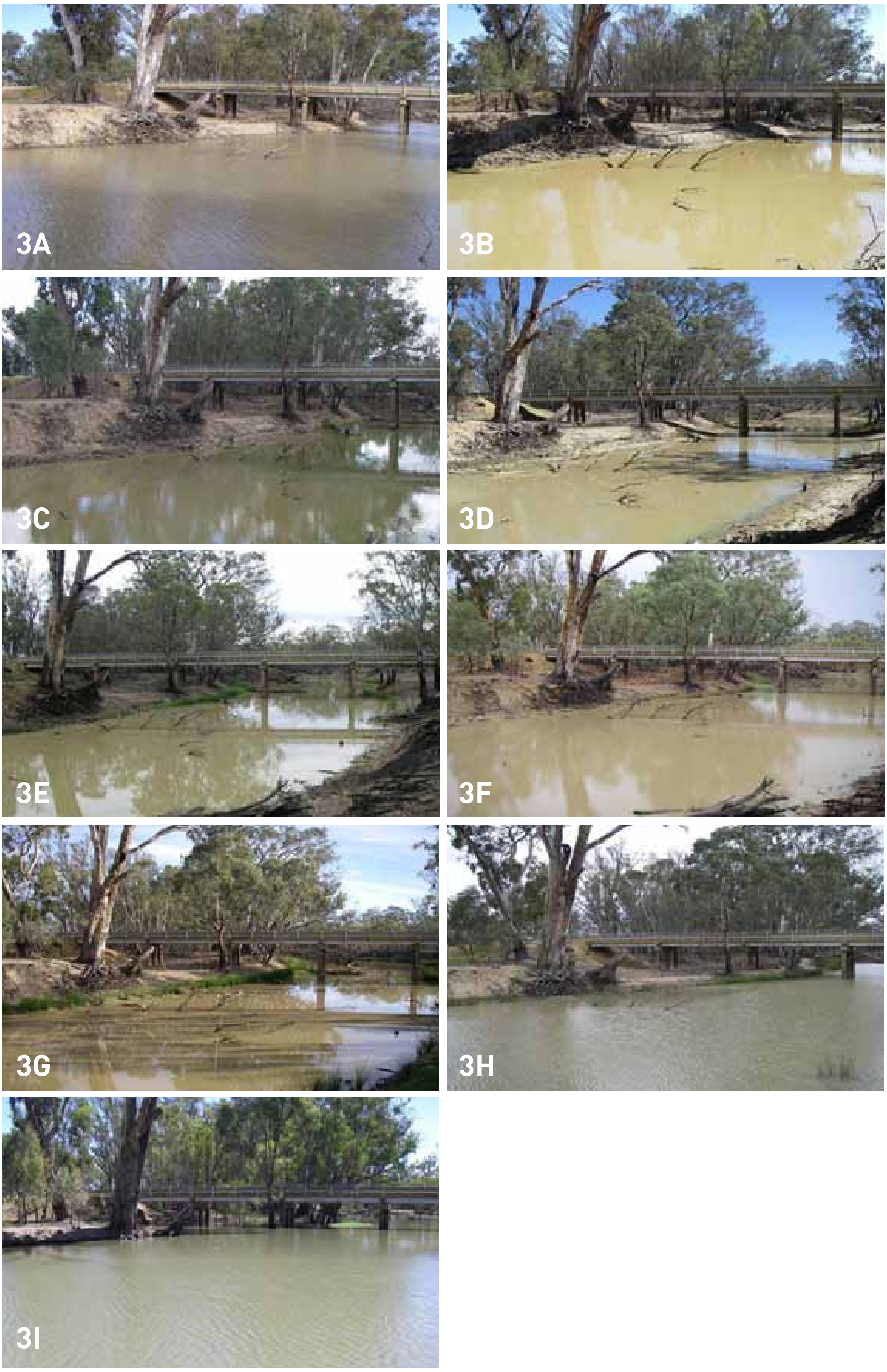

Figure 19. Photo points of Tumudgery Creek at Site T3 on (A) 6 September 2007, (B) 12 December 2007, (C) 28 March 2008, (D) 17 September 2008, (E) 17 December 2008, (F) 12 March 2009, (G) 18 June 2009, (H) 21 September 2009 and (I) 18 December 2009.

Figure 20. Photo points of Tumudgery Creek at Site T4 on (A) 6 September 2007, (B) 12 December 2007, (C) 28 March 2008, (D) 17 September 2008, (E) 17 December 2008, (F) 12 March 2009, (G) 18 June 2009, (H) 21 September 2009 and (I) 18 December 2009.

Figure 21. Photo points of Tumudgery Creek at Site T5 on (A) 6 September 2007, (B) 12 December 2007, (C) 28 March 2008, (D) 17 September 2008, (E) 17 December 2008, (F) 12 March 2009, (G) 18 June 2009, (H) 21 September 2009 and (I) 18 December 2009.

Discussion

The monitoring program met its objective of assessing the ecological condition of Tumudgery Creek during the study period. Monitoring results for the ecological indicators of sulfidic sediments, water quality and levels, blue-green algae, fish, river red gum, vegetation community, birds and groundwater were interpreted against pre-determined trigger values (Wallace et al. 2007; NSW Department of Water and Energy 2007) and communicated regularly to managers on a monthly to tri-monthly basis to ensure that management decisions could be based on recent and appropriate environmental data.

Sulfidic sediments

The pH of sediment at sites T2 (pH 3.65) and T4 (pH 3.80) was below the acceptable pH 4.5 threshold in the decision-support tool of Baldwin et al. (2007), raising concerns that the wetland may contain sulfidic materials at levels that may cause ecological damage if the wetland dried out. The protocol of Baldwin et al. (2007) recommended that a more detailed investigation of the occurrence of sulfidic sediments be undertaken by directly analysing sediments.

The subsequent analysis of sediment was presented as a separate report (Baldwin et al. 2008). In summary, Baldwin et al. (2008) analysed sediment cores from six sites of Tumudgery Creek using the methodology outlined in Hall et al. (2006). The study found only small amounts of chromium reducible sulfur at all sites of Tumudgery Creek. Baldwin et al. (2008) concluded that while there was high net acidity at most of the Tumudgery Creek sites, there was a low risk of net acidification related to the oxidation of sulfidic sediments if the creek was to dry for a period of time.

Water levels and quality

Tumudgery Creek retained surface water for the duration of the monitoring period between September 2007 and December 2009. However, the wetland became isolated from the Edward River for most of this time due to a combination of (a) low riverine flows and (b) the operation of the regulator. During periods of disconnection, water levels decreased in Tumudgery Creek and the surface water fragmented into a series of pools in the reach between sites T1 and T3. Cross-sections of the single deeper pool in the section of Tumudgery Creek between sites T3 and T5 showed that the remaining water was relatively deep (up to 2.4 m) and therefore likely to be sufficient in the short-term to support the fish community present in the wetland. Four discrete inflow events provided connectivity between the pools and also between Tumudgery Creek and the Edward River.

Water quality is an important determinant of the aquatic flora and fauna that can occur within a wetland. Several water quality variables were on occasion outside the acceptable ranges as stipulated by NSW Department of Water and Energy (2007) and Wallace et al. (2007). Given that monitoring of water quality occurred during the daytime and on a monthly basis, it is likely that water quality variables met the trigger values on more occasions than those detected within the monitoring program. However, in no instance did we record or observe any deleterious effects or significant decreases in abundances of aquatic biota such as fish.

The electrical conductivity of the surface water in Tumudgery Creek was low throughout the study period (46–154 $\mu S.cm^{-1}$ @ 25°C), with the most marked changes being decreases in EC following inflows from the Edward River. EC levels were well below the trigger values of 5,000 $\mu S.cm^{-1}$ and 1,500 $\mu S.cm^{-1}$ established by NSW Department of Water and Energy (2007) and Wallace et al. (2007) respectively, and consequently were not considered to have affected negatively the biota of Tumudgery Creek.

The pH of the surface water remained within the acceptable range of 6–9 as determined by NSW Department of Water and Energy (2007) and Wallace et al. (2007). The absence of very low pH values is evidence that any sulfidic sediment exposed and dried during periods of low water levels did not oxidise and liberate acid in quantities sufficient to cause acidification.

Dissolved oxygen concentrations in the water column varied over time and were occasionally recorded below the 5 mg/L threshold of NSW Department of Water and Energy (2007). Dissolved oxygen concentrations vary diurnally as they are the net product of oxygen generation within the water column through photosynthesis, diffusion of oxygen from the atmosphere and consumption of oxygen through metabolic demands. Hence, dissolved oxygen concentrations can decrease when decomposition processes are promoted, such as the microbial consumption of carbon sources following their inundation (e.g. Howitt et al. 2007).

The lowest dissolved oxygen levels recorded occurred in sections of the creek that had been recently inundated. Low dissolved oxygen concentrations may directly impact upon aquatic organisms such as fish, although we found no evidence for this during the monitoring period.

Water turbidity was variable, with high readings generally occurring in areas containing shallow water where the influence of wind and waves can resuspend wetland sediments into the water column. The lowest turbidity occurred following the large inflows from the Edward River in January 2009 and September 2009.

Blue-green algae

Blue-green algae are a natural feature of wetlands such as Tumudgery Creek and play an important role in food webs by converting sunlight energy into carbohydrate. However, high concentrations of some blue-green algae can have deleterious effects upon the health of people and livestock.

Anabaena circinalis (84,650 cells.mL^{-1}) and *Microcystis aeruginosa* (78,440 cells.mL^{-1}) were the only potential toxin producers sampled at concentrations above the 15,000 cells.mL^{-1} trigger value of Wallace et al. (2007). Both of these high concentrations occurred at Site T3 in March 2008. According to the National Health and Medical Research Centre guidelines, a cell count for *Microcystis aeruginosa* of >50,000 cells.mL^{-1} constitutes an action mode or red alert level for recreational use (National Health and Medical Research Centre 2008). If Tumudgery Creek was subject to recreational use, the National Health and Medical Research Centre (2008) guidelines recommend that the local authority and health authorities notify the public that the water body is unsuitable for primary contact recreation.

Fish

An abundant and relatively diverse native fish community occurred at Tumudgery Creek for the duration of the monitoring period. The use of small and large fyke nets was successful in sampling 12 of 14 taxa surveyed. The two species sampled only with boat electrofishing were Murray cod, *Maccullochella peelii peelii,* and silver perch, *Bidyanus bidyanus*. Murray cod was sampled in the first four of five boat electrofishing surveys and was observed in the final survey, and silver perch was sampled in the first two of five electrofishing surveys and sighted in the third survey. Electrofishing was also more effective than netting in sampling other large-bodied fish including golden perch, *Macquaria ambigua,* goldfish, *Carassius auratus,* and common carp, *Cyprinus carpio*, while netting was generally most effective at sampling the small-bodied fish species.

Native fish comprised 96.4% of the total abundance of fish sampled at Tumudgery Creek. However, the majority of the native fish were small-bodied. In terms of biomass, exotic species contributed 78.2% of the large-bodied fish biomass principally due to the occurrence of large common carp (72.6% of total biomass). Small-bodied fish were not weighed as part of the monitoring program so their contributions to the biomass figures were not evaluated.

The fish community of Tumudgery Creek was very similar to that recorded at Washpen Creek near Euston New South Wales following its disconnection from the main river channel. McCarthy et al. (2010) sampled 10 native and five exotic fish species in this 13 km creek system that forms part of the Euston Lakes system. The timing, frequency and methods of sampling were the same between the studies. At Washpen Creek additional species —freshwater catfish, *Tandanus tandanus,* and dwarf flat-head gudgeon, *Philypnodon macrostomus* — were sampled, while Murray cod was not recorded (McCarthy et al. 2010).

Two species of conservation concern were sampled in low abundance at Tumudgery Creek. Murray cod was sampled on four occasions and has a national status of vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Silver perch was sampled on two occasions and is listed as vulnerable under the New South Wales *Fisheries Management Act 1994*.

The occurrence of silver perch and Murray cod within Tumudgery Creek met the trigger value of Wallace et al. (2007), which requires the maintenance of aquatic habitat as fish refuge. In October 2008, the surface water in the wetland had decreased to its lowest level and there were concerns that water depth may be insufficient to provide refuge for fish. Cross-sectional profiles were obtained (see Results section) and revealed pools over 1 m deep with some areas over 2 m deep, indicating that good habitat for fish remained within sections of Tumudgery Creek. Water levels in Tumudgery Creek increased after this time. There was no evidence of any fish deaths within Tumudgery Creek during the study period based on the tri-monthly fish surveys and monthly observations at the site.

River red gum

River red gum was the dominant tree species adjacent to Tumudgery Creek. The 30 trees selected for inclusion in the monitoring program were alive at the commencement of the study and contained crown cover ranging from sparse to full, with the majority having moderate cover. Seasonal changes in the condition of river red gum (based on crown cover) were recorded throughout the study period, with condition increasing during the cooler months and decreasing over the summer period.

River red gum condition was generally maintained at sites T3 and T4 over the study period. However, there was a clear decrease in the condition of some trees at site T2, with three trees having no foliage at the end of the study period. It is unclear whether these trees were dead. It is difficult to assign causality between wetland disconnection and tree condition given that Tumudgery Creek contained surface water throughout the study period. At site T2, the area of surface water decreased but still occurred as small pools within the creek when the wetland was disconnected. The decrease in condition of trees at site T2 may be due to prolonged drought conditions and the considerable period since these trees were directly inundated by floodwaters, particularly given that the trees were located on a relatively high bank. Other related factors such as soil condition or groundwater levels and salinity may also have contributed to the decrease in condition of these trees over the period of this study.

Vegetation community

The plant species recorded at Tumudgery Creek are common to wetlands and river systems located within the Edward–Wakool River system. No rare or threatened plant species were recorded from the fixed quadrats at Tumudgery Creek or from general observations within the area surrounding the creek.

The vegetation community plays an important ecological role in primary production and by providing habitat for other organisms, trapping suspended sediments, binding soils and reducing erosion. The number of plant taxa recorded at Tumudgery Creek on each sampling occasion was relatively constant across the seasons. However, changes in species composition and abundance occurred that could be partly attributed to the life cycles of individual species. The local hydraulic conditions were also important in determining the composition of the vegetation community. Opportunities for amphibious and terrestrial species to germinate and establish were provided following decreases in water level and exposure of the quadrats.

The majority of vegetation sampled at Tumudgery Creek was native (86%). This relatively high proportion is similar to surveys at other wetlands selected for disconnection as part of this program including Back Creek (81%; Durant et al. 2010), Euston Lakes (77%; McCarthy et al. 2010) and Tareena Billabong (85%; McCarthy et al. 2009).

Birds

The abundance and richness of waterbirds was low throughout the study. No threatened bird species were observed, although the CAMBA-listed white-bellied sea-eagle was recorded on two occasions and observed to be breeding at the site.

Three duck species, the Australian wood duck, Pacific black duck and grey teal, comprised 90% of the total number of waterbirds surveyed at Tumudgery Creek. However, the abundances of all 11 waterbird species recorded were low (mean total of 20 individual waterbirds per survey). As a comparison, Washpen Creek was sampled with the same timeframes, methods and surveyor, and 28 waterbird species were sampled with a mean abundance of 128 individuals per survey (McCarthy et al. 2010).

A more diverse and abundant waterbird community may have been expected at Tumudgery Creek in response to changes in water level, such as when mud flats were exposed during wetland disconnection. One explanation may be that the narrow corridor of vegetation fringing some sections of Tumudgery Creek and the neighbouring farmland may limit the suitability of the wetland as habitat for some waterbird species. However, waterbirds are highly mobile and they utilise aquatic habitat at the landscape scale. Therefore, it is difficult to assign a level of condition to a wetland based on the recording of low waterbird abundance and diversity over a two-year period.

A study by Reid (1999) examined bushbirds of the New South Wales sheep-wheat belt, which included large parts of the interim biogeographic regionalisation of the Riverina where Tumudgery Creek is located. Five terrestrial bird species recorded at Tumudgery Creek were considered by Reid (1999) as species that were declining in the region, including chestnut-rumped thornbill (*Acanthiza uropygialis*), Jacky winter (*Microeca fascinans*), red-capped robin (*Petroica goodenovii*), restless flycatcher (*Myiagra inquieta*) and rufous whistler (*Pachycephala rufiventris*). A bird species was defined by Reid (1999) as declining if it was identified as being at risk from at least three studies in the region.

Reid (1999) also listed the brown treecreeper (*Climacteris picumnus*) as a declining species. However, Reid (1999) does not clarify to which subspecies he is referring. Based on the distribution range of the two subspecies, it is likely that Reid (1999) is referring to the subspecies *Climacteris picumnus victoriae* that is listed as vulnerable on the New South Wales *Threatened Species Conservation Act 1995*. The brown treecreeper recorded at Tumudgery Creek is the subspecies *Climacteris picumnus picumnus*, which is not listed on the *Threatened Species Conservation Act*.

Groundwater

Based on a review of groundwater in the region, it was predicted that the groundwater level would be unlikely to cause any salinity impacts on Tumudgery Creek (Mitchell 2008). This prediction was supported by the recording of very low electrical conductivity of the surface water within Tumudgery Creek throughout the monitoring period.

Mitchell (2008) also predicted that groundwater levels near Tumudgery Creek would decline if the wetland were to dry for an extended period, with potential impacts upon shallow-rooted vegetation reliant on the groundwater. Given that surface water was maintained within Tumudgery Creek throughout the monitoring period, and in the absence of detailed groundwater data close to the site, it is not possible to determine (a) the groundwater changes that occurred close to Tumudgery Creek or (b) their potential effects upon vegetation adjacent to the wetland.

Synthesis of ecological indicators

Based on the monitoring results of the above ecological indicators, the ecological condition of Tumudgery Creek was generally maintained during the 27-month study period. No significant ecological damage was recorded or observed in response to the wetland disconnection. These statements are based on the following:

- sulfidic sediments and groundwater interactions were not considered significant threats at Tumudgery Creek.
- water quality was generally good with variables mostly within acceptable ranges
- while half of the blue-green algal samples exceeded the threshold of 15,000 cells.mL^{-1}, the taxa recorded were not considered toxic with the exception of one sample
- a significant fish community was maintained within the wetland for the duration of the monitoring period.

One exception to the maintenance of ecological condition was the decrease in river red gum condition for some trees (see details above).

The general maintenance of ecological condition is primarily due to the wetland containing surface water throughout the monitoring period from the four separate inflow events. These inflows maintained a large area of relatively deep surface water throughout the period of study that supported aquatic biota such as fish.

Future management and recommendations

An understanding of the natural water regime of a wetland provides managers with a guide for developing a management plan for that wetland. One approach may be to attempt to mimic the natural water regime to best support the flora and fauna adapted to that particular environment.

The water level of Tumudgery Creek is responsive to changes in the water level downstream of Stevens Weir on the Edward River and can also be modified through the operation of the regulator. Based on the hydrograph below Stevens Weir, Tumudgery Creek would have received regular and variable inflows from the Edward River. High water levels would inundate more elevated sections of Tumudgery Creek, and would connect this creek system to many other wetlands that extend into the Werai State Forest (Green and Alexander 2006). Tumudgery Creek would also have retained a considerable volume of water following its isolation from the Edward River due to deeper pool sections along the creek.

The regular connection of Tumudgery Creek with the Edward River is important ecologically, as it allows for the exchange of water, biota and nutrients between Tumudgery Creek, the wetland complex within the Werai State Forest and the Edward River. Given the relatively low commence-to-flow of Tumudgery Creek, this exchange can occur at low river flows if the regulator is open. Wetlands of this type are important because, at a system scale, river regulation has reduced connectivity between many wetlands and their river channels.

Based on the findings that Tumudgery Creek supports a significant fish community, that the authors believe the maintenance of ecological condition during the disconnection was primarily due to the creek not drying out, and the wetland has a natural water regime of 'permanent' (NSW MWWG 2008), the authors recommend that:

- Tumudgery Creek is managed to allow the two-way exchange of water between the wetland and the Edward River, and to maintain sufficient aquatic habitat within the creek to support any isolated fish community
- a management plan is developed for Tumudgery Creek to maximise the ecological values of the wetland, to develop operating rules around the closing of the regulator and to scope other issues important for the effective management of the site. The management plan should develop an optimal water regime for the wetland that accommodates the first recommendation.

References

Baldwin, DS, Fraser, MA and McCarthy, B 2008, Assessment of sulfidic sediments at Tumudgery Creek, NSW. Report to the Murray–Darling Basin Commission. The Murray–Darling Freshwater Research Centre.

Baldwin, DS, Hall, KC, Rees, GN and Richardson, AJ 2007, Development of a protocol for recognising sulfidic sediments (potential acid sulphate soils) in freshwater wetlands.*Ecological management and restoration* **8**, 56–60.

Bertozzi, T, Adams, M and Walker, K 2000, Species boundaries in carp gudgeons (Eleotridae: *Hypseleotris*) from the River Murray, South Australia: Evidence for multiple species and extensive hybridisation. *Marine and freshwater research* **51**, 805–815.

Brock, MA and Casanova, MT 1997, Plant life at the edge of wetlands: ecological response to wetting and drying patterns. *Frontiers in ecology: building the links*. 181–192.

Casanova, MT 2007, Plant functional groups: where to from here? Water: an inconvenient truth. Joint conference of the New Zealand Sciences Society and Australian Society for Limnology. Queenstown, New Zealand, 2–7 December.

Casanova, M and Brock, M 2000, How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? *Plant ecology* **147**, 237–250.

Cunningham, GM, Mulham, WE, Milthorpe, P L and Leigh, J H 2006, *Plants of Western New South Wales*. Elsevier Australia. Marrickville, New South Wales.

Department of Primary Industries 2005 *Noxious Weeds Act 1993* No. 11. New South Wales Department of Primary Industries.

Department of Primary Industries 2009, New South Wales Department of Primary Industries website: http://www.dpi.nsw.gov.au/agriculture/pests-weeds/weeds/noxweed/noxious-app?sq_content_src=%252BdXJsPWh0dHAlM0ElMkYlMkZ3d3cuYWdyaWMubnN3Lmdvdi5hdSUyRnRvb2xzJTJGdmlld3dlZWQuaHRtbCZhbGw9MQ%253D%253D&weed_id=117 Accessed 28 April 2009.

Durant, R, McCarthy, B, Reid, C and Vogel, M 2010, Drought contingency monitoring at Back Creek, New South Wales. Final report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre, September, 44pp.

Durant, R, McCarthy, B, and Vogel, M 2008a, *Drought contingency monitoring Tumudgery Creek – Three month report*. Internal report prepared for the Murray–Darling Basin Commission by The Murray–Darling Freshwater Research Centre, March, 14pp.

Durant, R, McCarthy, B, and Vogel, M 2008b, *Drought contingency monitoring Tumudgery Creek – Six month report*. Internal report prepared for the Murray–Darling Basin Commission by The Murray–Darling Freshwater Research Centre, March, 17pp.

Durant, R, McCarthy, B, and Vogel, M 2008c, *Drought contingency monitoring Tumudgery Creek – Nine month report*. Internal report prepared for the Murray–Darling Basin Commission by The Murray–Darling Freshwater Research Centre, March, 18pp.

Durant, R, McCarthy, B, and Vogel, M 2008d, *Drought contingency monitoring Tumudgery Creek – 12 month report*. Internal report prepared for the Murray–Darling Basin Commission by The Murray–Darling Freshwater Research Centre, March, 18pp.

Durant, R, McCarthy, B, and Vogel, M 2009a, *Drought contingency monitoring Tumudgery Creek – 15 month report*. Internal report prepared for the Murray–Darling Basin Commission by The Murray–Darling Freshwater Research Centre, March, 21pp.

Durant, R, McCarthy, B, Vogel, M and Reid, CJ 2009b,) *Drought contingency monitoring Tumudgery Creek – 18 month report*. Internal report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre, April, 23pp.

Department of Water and Energy 2007, New South Wales Department of Water and Energy. Review of environmental factors. Temporary disconnection of wetlands within Lower Murray and Edward–Wakool River systems – Stage 2 Euston Lakes. New South Wales Department of Water and Energy.

Green, D and Alexander, P 2006, River Murray Wetland Database: New South Wales, Victoria. Wetland commence-to-flow levels: June 2006. New South Wales Murray Wetlands Working Group.

Hall, KC, Baldwin, DS, Rees, GN and Richardson, AJ 2006, Distribution of inland wetlands with sulfidic sediments in the Murray–Darling Basin, Australia, *Science of the total environment* **370**, 235–244.

Howitt, JA, Baldwin, DS, Rees, GN and Williams, JN 2007, Modelling blackwater: predicting water quality during flooding of lowland river forests. *Ecological modelling* **203**, 229–242.

Lintermans, M 2007,. *Fishes of the Murray–Darling Basin: An introductory guide*. MDBC Publication No. 10/07.

McCarthy, B, Chapman, D, Walters, S, Rehwinkel, R and McGuffie, P2010, Drought contingency wetland monitoring: Euston Lakes 27-month report. Internal report to the Murray–Darling Basin Authority. The Murray–Darling Freshwater Research Centre.

McCarthy, B and Durant, R 2008, Drought contingency wetland monitoring – refilling advice for Back Creek, Tumudgery Creek and Tareena Billabong. Internal report prepared for the Murray–Darling Basin Commission by The Murray–Darling Freshwater Research Centre, October, 16pp.

McCarthy, B, McGuffie, P, Walters, S, Chapman, D and Rehwinkel, R2009, Drought contingency monitoring at Tareena Billabong, New South Wales. Final report to the Murray–Darling Basin Authority. The Murray–Darling Freshwater Research Centre, June, 35pp.

McDowell, R 1996, *Freshwater fishes of south-eastern Australia* (Reed Books: Chatswood, New South Wales).

Mitchell 2008,. Groundwater impacts of no water being available for Tumudgery Creek, Back Creek and Tareena Billabong. Advice to The Murray–Darling Freshwater Research Centre. New South WalesDepartment of Water and Energy.

Moore, P2005, *A guide to plants of inland Australia*. Reed New Holland. Sydney, New South Wales.

National Health and Medical Research Council 2008, Guidelines for managing risks in recreational water. National Health and Medical Research Council. Canberra, ACT.

New South Wales Murray Wetlands Working Group2008, River Murray Wetland Database – electronic data. New South Wales Murray Wetlands Working Group.

Reid, CJ, Durant, R, McCarthy, B and Vogel, M2009a, *Drought contingency monitoring Tumudgery Creek – 21 month report*. Report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre, July, 24pp.

Reid, CJ, Durant, R, McCarthy, B and Vogel, M (2009a). *Drought contingency monitoring Tumudgery Creek – 24 month report*. Report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre, October, 25pp.

Sainty, GR and Jacobs, SWL 1981, *Waterplants of New South Wales*. Water Resources Commission New South Wales.

Sainty, GR and Jacobs, SWL 2003, *Waterplants in Australia*. Sainty and Associates Pty Ltd, Potts Point, New South Wales.

Wallace, T, Gawne, B, Baldwin, D, McCarthy, B, Nielsen, D and Vilizzi, L2007, A standardised protocol for assessing the suitability of permanent wetlands for disconnection. Report to the Murray–Darling Basin Commission. The Murray-Darling Freshwater Research Centre. May.

Appendix B—Blue-green algae taxa recorded at Tumudgery Creek.

Anabaena affinis !!

Anabaena circinalis !!!

Anabaena spiroides f spiroides !!!

Anabaena sp.

Aphanizomenon sp.

Aphanocapsa sp.

Aphanothece sp.

Arthrospira sp.

Coelosphaerium kuetzingianum

Cyanodictyon sp.

Komvophoron sp.

Leptolyngbya sp.

Merismopedia sp.

Microcystis aeruginosa !!!

Microcystis sp.

Oscillatoria sp.

Phormidium sp.

Planktolyngbya subtilis !!

Planktolyngbya sp.

Pseudanabaena sp.

Romeria sp.

Trichodesmium sp.

!! Suspected but unconfirmed potential toxin producer

!!! Potential toxin producer

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