Identification of the aquatic vertebrate values and their hydrological requirements for input into the Environmental Watering Plan for the Lake Moodemere-Sunday Creek wetland complex

The Murray-Darling Freshwater Research Centre

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The Murray-Darling Freshwater Research Centre

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Final Report prepared for the North East Catchment Management Authority by The Murray-Darling Freshwater Research Centre.

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Photographer: Rick Stoffels

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Executive summary

- Significant changes to the hydrology of the Lake Moodemere–Sunday Creek wetland complex have been proposed. To save water, a regulator may be built between Lake Moodemere and Sunday Creek such that: (a) Sunday Creek could be operated as a reservoir for extraction by neighbouring irrigators; (b) water could be pumped directly into the northern end of Sunday Creek from the Murray River; and (c) Lake Moodemere hydrology could be restored to a more 'natural' regime of increased within- and between-year variability.
- Given this wetland complex is the largest between lakes Hume and Mulwala, there is concern about the biodiversity consequences of proposed interventions. The general objective of the present work is to survey the aquatic vertebrates (turtles and fish) of this wetland complex and discuss the risks and potential benefits associated with the intervention. The Lake Moodemere–Sunday Creek complex is a significant wetland for freshwater turtles and all three Murray-Darling Basin turtles were recorded in the wetland complex. The two most common species were the southern broad-shelled turtle (*Chelodina expansa*) and the Murray River turtle (*Emydura macquarii*), while the eastern long-necked turtle (*Chelodina longicollis*) was relatively rare, but present. *C. expansa* is listed as 'threatened' under the *Flora and Fauna Guarantee Act 1998* (FFG).
- Five native and five introduced fishes were recorded, with only one species listed under the FFG as 'threatened': the fly-specked hardyhead, *Craterocephalus stercusmuscarum fulvus*. Species listed under the *Environment Protection and Biodiversity Conservation Act 1999* were not recorded.
- Although we have very limited information about the fish and turtle biodiversity of floodplain wetlands between lakes Hume and Mulwala, it appears that the Lake Moodemere–Sunday Creek complex currently contains a fauna that is either equally, or more, diverse than in other floodplain wetlands along this reach of the Murray River.
- The littoral macrophytes (primarily *Juncus ingens*) beds currently comprise a significant habitat for native aquatic vertebrates in the wetland; most of the native biodiversity was concentrated in this narrow zone.
- **<u>The proposed intervention results in two broad outcomes.</u>** First, the potential to restore Lake Moodemere to a 'more natural' hydrology is created. Second, the hydrology of Sunday Creek could be managed in isolation from Lake Moodemere: in particular, high water levels from late spring to autumn can be maintained by direct feeding of water into its northern end from the Murray River.
- Both of these outcomes have their own set of risks and potential benefits to the aquatic vertebrate fauna. *We caution that assessment of risks and potential benefits is largely speculative, and should be viewed as hypotheses to be scientifically tested as part of an adaptive management program.*
- **The primary risks associated with alteration of Moodemere's hydrology include**:
    - Greater ephemerality may be to the detriment of regionally-rare turtles *C. expansa* and *E. macquarii*, which are associated with more permanent wetlands.

- The giant juncus beds of Lake Moodemere may be an important breeding habitat for the threatened *C. s. fulvus*. Loss of extensive juncus beds may be detrimental to this species.

- **The primary benefits associated with alteration of Moodemere's hydrology include**:
    - The turtle *C. longicollis* is generally associated with ephemeral wetlands, so it may benefit from increased ephemerality.
    - Any increase in the diversity of submerged and floating macrophytes may encourage the colonisation of certain fishes, such as the southern pygmy perch (*Nannoperca australis*) and the flat-headed galaxias (*Galaxias rostratus*).
- **The primary risks associated with alteration of Sunday Creek's hydrology include**:
    - Fragmentation of the wetland complex may result in a decline in fish biodiversity in Sunday Creek, by hampering population recovery following local disturbances.
    - Pumping water directly into Sunday Creek may increase the threat of cold-pollution during summer and is therefore a risk to certain fishes and turtles.
- **The primary benefit associated with alteration of Sunday Creek's hydrology include**:
    - If low water quality is characteristic of Sunday Creek then direct pumping into the north end from the Murray River may improve our ability to manage and restore water quality in Sunday Creek. In turn, improvement in water quality may reduce the abundance of noxious pest fish that are tolerant of such conditions (e.g. carp and goldfish), while increasing the abundance of native fishes.
- **The key knowledge gaps that hinder our ability to minimise deleterious effects and maximise benefits of any proposed interventions include:**
    - Our poor understanding of how biodiversity is distributed throughout floodplain networks in north-east Victoria. Investment in regional-scale biodiversity surveys and monitoring needs to happen if we are to provide scientifically-defensible solutions to the problems addressed here.
    - We need to determine how sustained and severe the low water quality of Sunday Creek is and the effects hypoxia has on key fishes of conservation concern.
- **We strongly recommend that: (a) the knowledge gaps highlighted above are addressed; and (b) any significant changes to the hydrology of the Lake Moodemere–Sunday Creek complex are scientifically monitored.** Indeed, an adaptive management approach to significant interventions such as the one proposed here is an imperative if we are ever to learn how to manage floodplains to achieve optimal outcomes for all stakeholders.

Introduction

Lake Moodemere and Sunday Creek are essentially two components of the same oxbow wetland complex. They are joined by a narrow channel and situated approximately 5 km west of the Victorian township of Rutherglen (Figure 1). Under natural flooding, Lake Moodemere fills when flows in the Murray River reach a discharge of 16 000 ML/day, and water enters the southern end of Sunday Creek via the lake. When discharge in the Murray River reaches 25 000 ML/day, Sunday Creek commences to flow from the northern end via Sandy Creek and its direct connection to the river (Green & Alexander 2006).

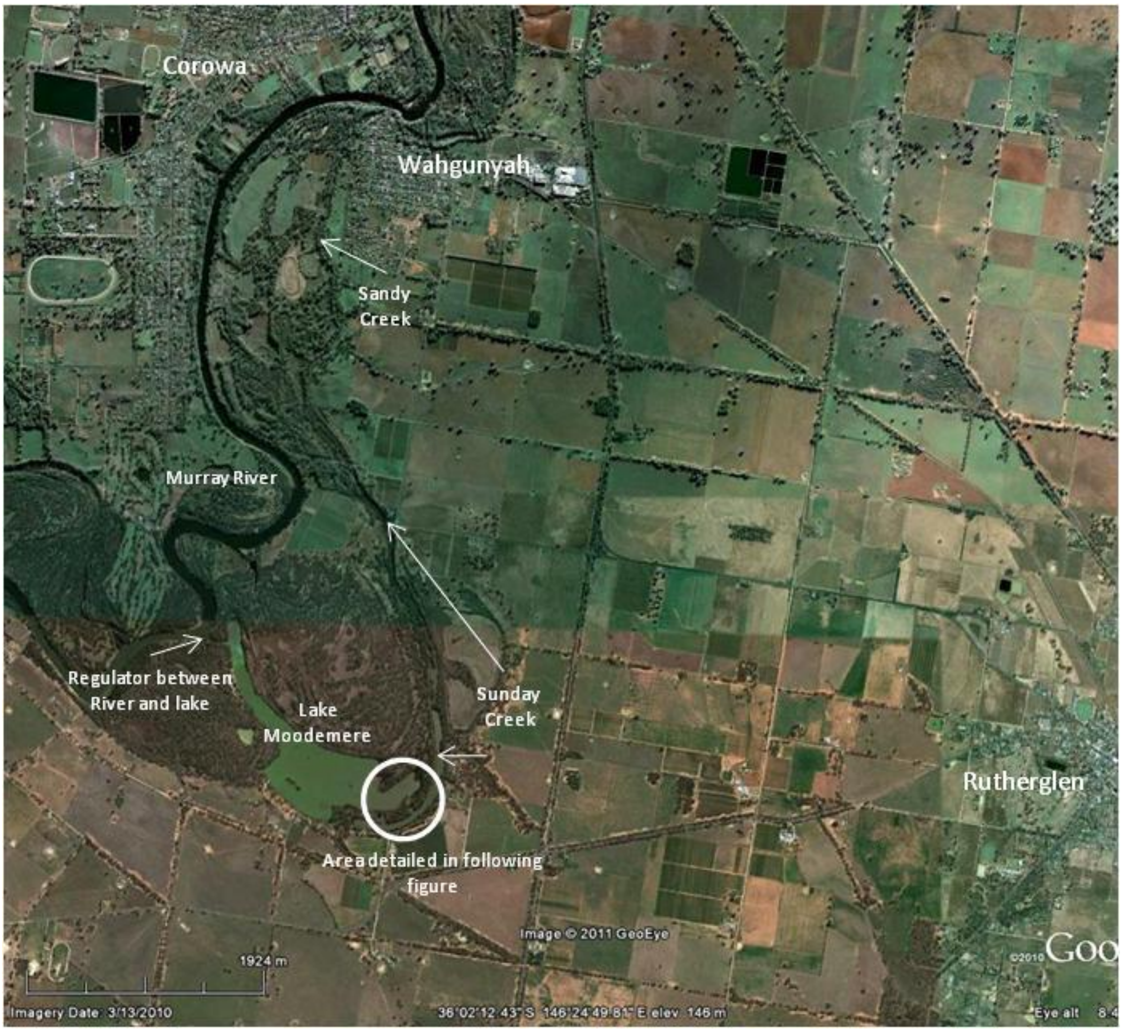

Figure 1. The Lake Moodemere–Sunday Creek wetland complex from Google Earth™ showing its proximity to the Murray River and neighbouring towns, the location of the current regulator, and the isthmus separating Sunday Creek and Lake Moodemere.

Although only differentiated from Lake Moodemere by a small isthmus approximately 150m wide, which itself is truncated by a small channel of less than 200 metres in length (Figure 2), the uses of Sunday Creek are quite different from those of the lake. Whereas Lake Moodemere is utilised for a variety of recreational purposes (waterskiing, rowing, fishing, bird watching, day picnic, for example), and there are facilities to accommodate such activities (vehicle access, boat ramps, etc.), Sunday Creek is used predominantly as a reservoir for irrigating the neighbouring vineyards and access is restricted — the only obvious recreational use is the floating golf green behind the Lake Moodemere Winery. A number of permanent water pumps are located along Sunday Creek.

Figure 2. The isthmus separating Sunday Creek from Lake Moodemere and the small channel that connects them (Google Earth™).

For irrigation purposes, water is currently gravity fed through the Lake Moodemere–Sunday Creek wetland complex through a regulator located on a small channel connecting the Murray River in the north-western corner of the lake (Figure 1). Lake Moodemere is then filled to such a height that water then fills Sunday Creek, where it is extracted by irrigators through the metered pumps located along the creek. Therefore, in order to obtain water for irrigation along Sunday Creek, Lake Moodemere needs to fill first. This indirect route to filling Sunday Creek was deemed inefficient by the Sunday Creek Irrigators Syndicate (SCIS), who requested that Goulburn–Murray Water investigate alternative water delivery arrangements such that water — and hence money — might be saved.

Sinclair Knight Mertz (SKM) was commissioned to investigate alternative water delivery arrangements and, in consultation with the SCIS, concluded that the preferred mode of operations was to: a) construct a regulator between Sunday Creek and Lake Moodemere so their water levels can be independently controlled; and b) pump water directly from the Murray River into northern Sunday Creek where it can be extracted for irrigation.

These proposed changes to water delivery may impact the aquatic vertebrate fauna (fish and turtles) in the Lake Moodemere–Sunday Creek wetland complex in several ways:

1. Loss of thermal refuge in Sunday Creek — anecdotal evidence (Robert Steele, DSE, personal observation) suggests that water temperatures in Sunday Creek are greater than those experienced at the western end of Lake Moodemere and the Murray River. Cold water pollution in the Murray River may be a significant impairment to the viability of certain freshwater ectotherms particularly during spring/summer when irrigation releases from upstream impoundments occur (e.g. Todd *et al.* 2005). It is possible that water warms in the wide and relatively shallow Lake Moodemere *en route* to Sunday Creek. If water is pumped directly into Sunday Creek from the Murray River then its potential as a thermal refuge is lost.
2. Increased fragmentation of wetland habitat — a regulator positioned between Sunday Creek and Lake Moodemere will further fragment freshwater fish populations which may, in turn, lower their long-term viability.
3. Alteration of Lake Moodemere hydrology— if water levels in Lake Moodemere do not need to be maintained to facilitate the delivery of water to irrigators in Sunday Creek, then its hydrology may be significantly altered. An earlier investigation demonstrated that Lake Moodemere may be an important habitat for certain threatened species, which may be affected by changes to the current hydrological regime (Richardson & Stoffels 2011). Changes to Lake Moodemere's hydrology, such as introducing wetting and drying phases or restoring natural seasonal cycles, has both inherent risks and potential benefits.

The specific objectives of the present investigation are:

- To determine the aquatic vertebrate biodiversity (fish and turtles) value of Sunday Creek.
- To compare and contrast the aquatic vertebrates of Sunday Creek with that of Lake Moodemere (Richardson & Stoffels 2011).
- To characterise the water quality gradient (water temperature, pH, dissolved oxygen and conductivity) between the current regulator connecting the Murray River to Lake Moodemere and the northern end of Sunday Creek.
- To discuss the potential impacts of the proposed alterations to water delivery on the fishes and turtles of the Lake Moodemere–Sunday Creek wetland complex.
- To discuss the key knowledge gaps that hinder our ability to minimise deleterious effects and maximise benefits of any proposed interventions.

Figure 3. Sunday Creek in winter 2011— dark water, instream woody debris and overhanging redgums (Stoffels).

Materials and Methods

Sunday Creek

A preliminary examination of Sunday Creek, prior to the determination of an appropriate sampling regime, found that Sunday Creek is a long (app. 3.5km) and narrow (app. 5–80m width throughout) wetland of highly heterogeneous habitat for freshwater fish. Sunday Creek is widest (20–80m) towards the southern end near its connection channel with Lake Moodemere. This wider section of the wetland continues northward for about 1.5 kilometres until it reaches a narrow (app. 5m) and shallow (<1m depth) pass called 'the narrows'. From this point to near its terminus, Sunday Creek is characterised by a wetland width of 10–20 metres, increased water depth, steeper banks and many large overhanging red gums (*Eucalyptus camaldulensis*). The northern extremity of the wetland is approximately 500m north of the Sunday Creek Bridge at Pfieffer's Winery, at which the wetland flattens and a gravel road crosses the dry 'creek line'.

As well as varying considerably in depth and width, there was a high degree of variability in the instream arrangement of woody debris, the macrophytic community and the littoral zone gradient of Sunday Creek. At the time of the preliminary examination, 5 May 2011, Sunday Creek was a very different wetland habitat than the largely homogenous Lake Moodemere, and it appeared more likely to contain rare or threatened species — such as southern pygmy perch (*Nannoperca australis*) or freshwater catfish (*Tandanus tandanus*).

Sunday Creek is likely to have experienced inflows at the northern end direct from the Murray River — as opposed to only filling via Lake Moodemere — from high flows in the Murray River during spring and early summer 2010/11. The commence-to-flow of Sunday Creek at the Murray River (25 000 ML/day) was exceeded during November 2010, during which discharges of greater than 30 000 ML/day were recorded twice; and in December 2010, during which a discharge greater than 60 000 ML/day was recorded — discharge figures for the Murray River at Doctor's Point below Lake Hume (http://riverdata.mdba.gov.au/sitereports/409017/mdba_409017_site_report.html). The December high flow event resulted in substantial inundation of the forest surrounding Lake Moodemere and Sunday Creek (Richardson & Stoffels 2011).

Lake Moodemere

The basic physical characteristics of Lake Moodemere were described in detail in an earlier report (Richardson & Stoffels 2011). Between the final sampling event of that previous aquatic survey (January 2011) and the commencement of the present survey (June 2011), little had changed with regard to surrounding vegetation, the location of reed beds and the amount of woody debris in the lake. The most noticeable physical change was the repair to the regulator at the connection to the Murray River such that water depth in Lake Moodemere was independent of the height of the Murray River — the lake was considerably higher than the river during the present winter survey (personal observation).

Sampling Design

The methodology used here follows that of Richardson & Stoffels (2011) so that comparisons can be made between the two studies. Two major habitat types were sampled in Sunday Creek — littoral and pelagic. A transect with points at 250 metre intervals was established starting from the Murray River (MR1), through Lake Moodemere to Sunday Creek (LM1–LM8), and along the entire wetted length of Sunday Creek (SC1–SC15) (Figure 4). The co-ordinates of each point were downloaded onto a GPS and each of these points was used for the characterisation of the water quality gradient.

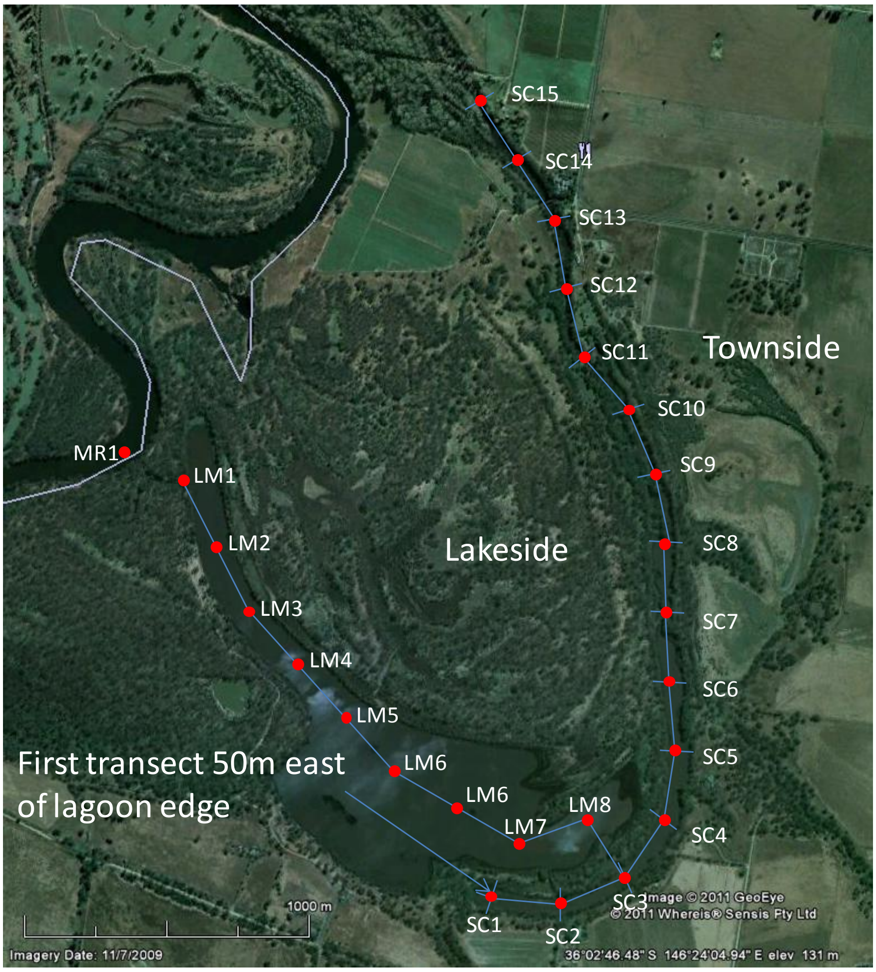

Figure 4. Map showing location of transect points at 250 metre intervals from the Murray River (MR1) through Lake Moodemere (LM1–LM8) and Sunday Creek (SC1–SC15). Points used for water quality measurements and location of sampling efforts.

The fifteen points along Sunday Creek (SC1–SC15) were also used for randomising sampling efforts. Each point represented a pelagic site (15 pelagic sites) and two littoral sites (Lakeside or Townside; 30 littoral sites). Positioning of nets and electrofishing shots within this grid was determined using a random number generator.

For sampling of aquatic vertebrate fauna in Lake Moodemere we followed the same protocol established in our earlier study (Richardson & Stoffels 2011), albeit with a reduced sampling effort. Exactly the same protocol was followed in regard to the establishment, location and randomisation of sampling sites. This permitted conversion of sampling catch to Catch Per Unit Effort (CPUE) and legitimate statistical comparisons with the previous summer's results.

We conducted the winter sampling of Sunday Creek and Lake Moodemere on 15-17 June 2011 and 6–8 July 2011, and the following sampling effort was repeated during both sampling events;

- 20 coarse-mesh fyke nets set at randomly selected sites (10 pelagic and 10 littoral) overnight in Sunday Creek to sample large-bodied fish and turtles.
- 6 coarse-mesh fyke nets set at randomly selected sites (3 pelagic and 3 littoral) overnight in Lake Moodemere to sample large-bodied fish and turtles.
- 10 fine-mesh fyke nets set at randomly selected sites (5 pelagic and 5 littoral) overnight in Sunday Creek to sample small-bodied fish.
- 6 fine-mesh fyke nets set at randomly selected sites (3 pelagic and 3 littoral) overnight in Lake Moodemere to sample small-bodied fish.
- 20 × 1 minute of electrofishing 'on' time (10 minutes pelagic and 10 minutes littoral) in Sunday Creek to sample large-bodied fish.
- Water quality measurements with a Quanta Hydrolab (water temperature, specific conductivity, dissolved oxygen, pH and turbidity) at each of the 25 transect points from the Murray River to the northern end of Sunday Creek.

As the northern end of Sunday Creek was particularly shallow (0.5m), an LR-24 backpack electrofishing unit was used at this location and a boat electrofisher was used elsewhere.

To reduce diurnal bias associated with some water quality parameters — dissolved oxygen concentrations increase during the day, for example — the order in which measurements were taken was reversed during the second trip. On June 17, we commenced taking water quality measurements at SC15 at 1110hrs and concluded at MR1 at 1508hrs. On July 17, we commenced recording water physico-chemical measurements at MR1 at 1315hrs and completed at SC15 at 1700hrs.

Treatment of catch data

All large-bodied fish captured were identified and enumerated, but only the first ten (chosen at random) of each species from each coarse-mesh fyke net had their standard and total length measured. All small-bodied fish sampled were identified and enumerated. All turtles captured were identified, enumerated and had their (straight) carapace length and width measured. As the set times for all nets set during sampling were recorded and electrofishing was conducted as a factor of fishing time, it was possible to convert all abundances to Catch Per Unit Effort (CPUE).

All analyses of spatial and temporal univariate and multivariate patterns are based on fyke net data only. Electrofishing (boat and backpack) data were excluded primarily because very few fish were recorded from both Lake Moodemere (previous study — Richardson & Stoffels 2011) and Sunday Creek (current study) using electrofishing, but also because the CPUE units of fyke nets (individuals per net, per hour of soak-time) and electrofishing (individuals per hour of on-time) are not comparable and cannot, therefore, be easily combined.

Data from the three sampling events in the previous aquatic vertebrate survey of Lake Moodemere (Richardson & Stoffels 2011) were combined and total CPUEs for animals sampled in that survey represent results of 'summer' sampling. Data from the present survey – events in June and July — are combined and CPUEs represent results of 'winter' sampling. This approach allows for seasonal comparisons in Lake Moodemere and permits the winter survey results from Sunday Creek to be placed into a seasonal perspective.

Analysis

The level of significance for hypothesis tests was $\alpha = 0.05$ unless otherwise stated.

Testing for seasonal differences in the Lake Moodemere aquatic vertebrate assemblage.
Two-factor permutational analysis of variance (PERMANOVA) was used to test for changes in fish and turtle assemblage structure between seasons (summer vs. winter) and habitats (littoral vs. pelagic). Both 'season' and 'habitat' were fixed factors and PERMANOVAs were conducted on Bray-Curtis similarities calculated on *ln*(CPUE +1)-transformed abundances. The log-transformation results in rare species having a significant influence on the spatial and temporal structure of the assemblage, which is appropriate given the nature of the investigation — biodiversity assessment. A dummy variable of ones was added to both the fine- and coarse-mesh fyke data to overcome the problem of undefined similarities between samples containing only zeros (nets yielding no fish). Two-factor PERMANOVAs were conducted for abundances from fine- and coarse-mesh fykes separately.

Habitat associations — littoral vs. pelagic assemblages.
Single-factor PERMANOVA was used to test for differences in assemblage structure between littoral and pelagic habitats. Separate habitat association analyses were conducted for Lake Moodemere and Sunday Creek, due to the fact they were sampled at different times of the year — we tested for habitat-specific assemblage structure in Lake Moodemere using the summer data only (most robust data set — more samples and species), while we tested for similar structure in Sunday Creek using the winter data (only data available). We calculated Bray-Curtis similarities on fourth-root transformed data for both the Lake Moodemere and Sunday Creek data sets. A dummy variable of ones was added to eliminate the problem of similarity calculation across two samples yielding no turtles or fish.

Effects of water quality on fish assemblage structure.
Although the random sampling protocol was appropriate for the purpose of biodiversity assessment of Lake Moodemere and Sunday Creek, it is not ideal for gradient analysis. The problem was that by using coarse- and fine-mesh fykes we targeted two subsets of the broader fish assemblage — large-bodied and small-bodied species — and our sampling was stratified by habitat (littoral vs. pelagic). In order to obtain an unbiased representation of the fish assemblage with respect to distance from the Murray, each spatial unit must have at least one sample of each of the following sample types: fine-mesh littoral, coarse-mesh littoral, fine-mesh pelagic, coarse-mesh pelagic. This was not the case at each transect point because nets were positioned at a random subset of all possible transects points (Figure 3).

Following the above criterion, it was possible to utilise the data for gradient analysis by grouping transects points (Figure 3) into 'areas' (Table 1). Mean CPUE of each species within each area was obtained by first calculating the mean CPUE across samples within each sample type, then summing the total CPUEs across different sample types. As water quality measurements were taken at each transect point, mean values for each water quality variable were also obtained for each area.

Table 1. The grouping of twenty-five transect points into 8 'areas' with the corresponding location of each transect point to area, and the number of each sample type taken from within each area. See Figure 4 for the physical locations of each transect point. Water quality measurements taken at each transect point.

Area	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Transect points	LM1, LM2, LM3	LM4, LM5	LM6, LM7, LM8	SC1, SC2, SC3	SC4, SC5, SC6, SC7	SC8, SC9	SC10, SC11, SC12	SC13, SC14, SC15	**N**
N fine littoral	2	2	2	5	4	3	4	2	**25**
N coarse littoral	2	2	2	1	3	3	1	3	**17**
N fine pelagic	1	1	4	4	4	4	2	2	**24**
N coarse pelagic	1	4	1	3	2	2	1	1	**15**
N	**6**	**9**	**9**	**13**	**13**	**9**	**8**	**8**	

Bray-Curtis similarities were calculated on fourth-root-transformed fish CPUEs from each area, while Euclidean distances were determined between normalised *ln*(x+1)-transformed water quality samples from the corresponding areas. The correlation between fish assemblage structure and water quality was then determined using DISTLM (Legendre & Anderson 1999; McArdle & Anderson 2001). Our emphasis here was on the correlation between fish assemblage structure and water quality as defined by temperature, dissolved oxygen (DO) and conductivity (SpC) — other water quality variables did not vary sufficiently to have an effect on the biology of the fishes. We used the BEST variable selection procedure and corrected Akaike Information Criteria (AICc) for selection of the most parsimonious model. When modelling the multivariate relationship between water quality and fish assemblage structure we forced inclusion of temperature, DO and SpC, but allowed BEST to search the model space defined by these first three variables and all combinations of additional polynomial terms (temperature x DO; temperature x SpC; SpC x DO; temperature x SpC x DO).

Results

Aquatic vertebrates in the Lake Moodemere–Sunday Creek wetland complex — species present and CPUE

Table 2. Aquatic vertebrates (CPUE) sampled at Lake Moodemere and Sunday Creek. Data presented by method and season (summer 2010/2011 and winter 2011) and effort for each method in each season given. Conservation status as listed under the Victorian *Flora and Fauna Guarantee Act 1988* (October 2010). No species were listed under the *Environment Protection and Biodiversity Conservation Act 1999.* NS=Not Sampled

Method: Coarse-mesh fyke nets (CPUE = animals per net per hour)

	Lake Moodemere		Sunday Creek		Conservation
	Summer	Winter	Summer	Winter	Status
Effort (net hours)	1008	242	0	234	
Species					
Broad-shelled turtle (*Chelodina expansa*)	0.0306	0.0039	NS	0.0013	Threatened
Eastern long-necked turtle (*Chelodina longicollis*)	0.0047	0	NS	0	
Murray River turtle (*Emydura macquarii*)	0.0753	0	NS	0	Data deficient
Goldfish (*Carassius auratus*)	0.0457	0.0163	NS	0.0338	
Common carp (*Cyprinus carpio*)	0.1318	0.1071	NS	3.4396	
Golden perch (*Macquaria ambigua*)	0	0.0082	NS	0.0013	
Redfin (*Perca fluviatilis*)	0.0018	0.0458	NS	0.0211	

Method: Fine-mesh fyke nets (CPUE = animals per net per hour)

	Lake Moodemere		Sunday Creek		Conservation
	Summer	Winter	Summer	Winter	Status
Effort (net hours)	602	234	0	364	
Species					
Australian smelt (*Retropinna semoni*)	0.0864	0.3391	NS	0.0218	
Goldfish (*Carassius auratus*)	0.0574	0.0046	NS	0.0220	
Common carp (*Cyprinus carpio*)	0.5243	0	NS	1.0309	
Oriental weatherloach (*Misgurnus anguillicaudatus*)	0.0853	0	NS	0	
Eastern Gambusia (*Gambusia holbrooki*)	0.1388	0.0599	NS	0.1005	
Flyspecked hardyhead (*Craterocephalus stercusmuscarum*)	0.1111	0.0758	NS	0.0083	Threatened
Redfin (Perca fluviatilis)	0.0134	0.0039	NS	0	
Flathead gudgeon (*Philypnodon grandiceps*)	0.0829	0	NS	0	
Carp gudgeon (*Hypseleotris* spp.)	7.9746	2.0083	NS	0.8986	

The large-bodied aquatic vertebrate communities were mostly similar between Lake Moodemere and Sunday Creek, with, however, a few notable differences (Table 2 and Figure 5). In coarse-mesh fyke nets, the same suite of species occurred in both major components of the same wetland complex — broad-shelled turtles (*Chelodina expansa*), goldfish (*Carassius auratus*), common carp (*Cyprinus carpio*), golden perch (*Macquaria ambigua*) and redfin (*Perca fluviatilis*). The occurrence of common carp in much greater abundance in Sunday Creek (CPUE = 3.4396) than Lake Moodemere (CPUE = 0.1071) was the major difference between the wetlands. In fine-mesh fyke nets, Australian smelt (*Retropinna semoni*), goldfish, eastern Gambusia (*Gambusia holbrooki*), flyspecked hardyhead (*Craterocephalus stercusmuscarum*) and carp gudgeons (*Hypseleotris* spp.) were collected from both wetlands, but common carp were only collected from Sunday Creek and redfin were only collected from Lake Moodemere. CPUEs for Australian smelt, flyspecked hardyhead and carp gudgeons were considerably greater in Lake Moodemere than Sunday Creek (Table 2).

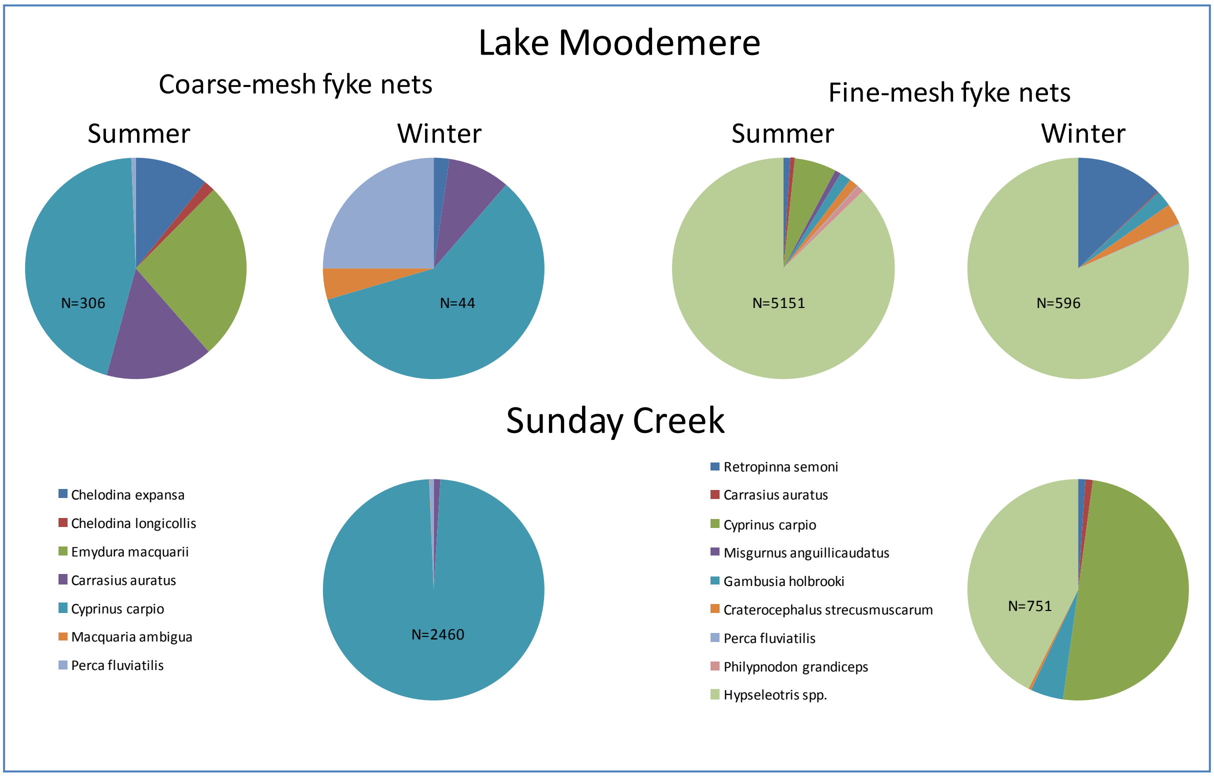

Figure 5. Turtles and fish sampled in coarse-mesh and fine-mesh fykes in Lake Moodemere in summer and winter and Sunday Creek in winter. Three sampling events pooled for summer and two sampling events pooled for winter.

There were also notable differences between the summer and winter sampling events in Lake Moodemere (Table 2 and Figure 5). There were clearly less turtles collected during winter sampling (one broad-shelled turtle) compared with summer (33 broad-shelled turtles, five eastern long-necked turtles and 80 Murray River turtles). Also, golden perch was collected for the first time in the lake during winter sampling (CPUE = 0.0082) and redfin abundance was considerably greater in winter (CPUEs of 0.0018 in summer and 0.0458 in winter). In fine-mesh fyke nets, less species were collected from Lake Moodemere in winter.

Sampling by electrofisher (boat and backpack) only detected two species in Sunday Creek — three goldfish and nine common carp were collected. For this reason, electrofishing data is excluded from further analysis.

Size-frequency distributions of common carp in Sunday Creek

Common carp was clearly the most common large-bodied fish species collected from Sunday Creek and the only species caught in great enough abundance to produce a meaningful size-frequency distribution (Figure 6). Here, we have presented the catch data from coarse-mesh fyke nets only — by far the most efficient sampling method. Only four size classes were represented in Sunday Creek during winter sampling. Individual common carp in the 51–100 mm standard length (SL) size class represented over 85% of the total catch, almost 14% were in the 101–150 SL size class and less than 1% was in each of the 151–200 SL and 201–250 SL size classes, respectively.

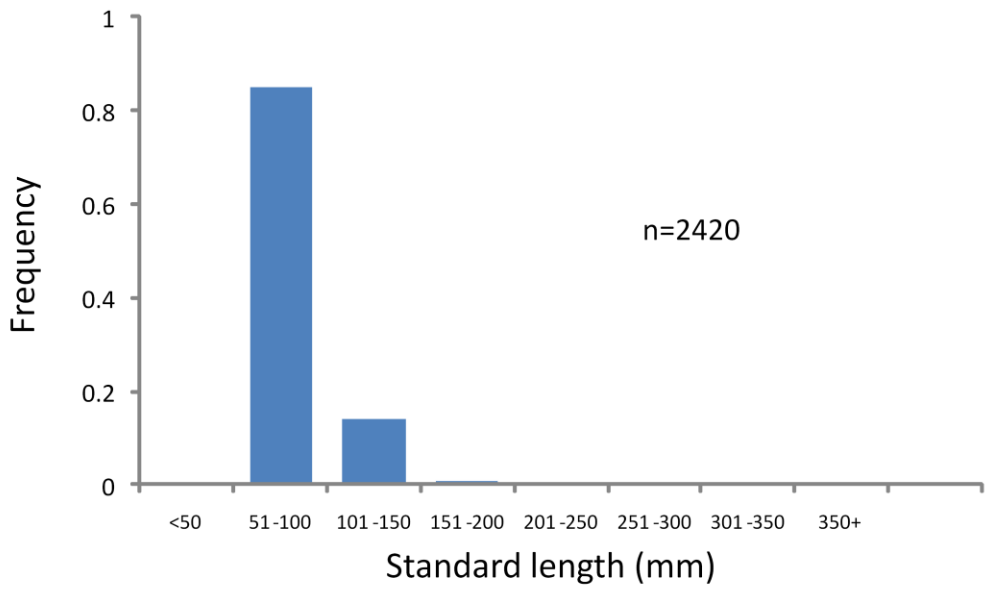

Figure 6. Size-frequency distributions of all common carp collected at Sunday Creek during winter sampling (coarse-mesh fyke net data only)

Seasonal differences in the Lake Moodemere vertebrate assemblage

Fine-mesh fykes

The structure of the fish assemblage sampled by fine-mesh fykes varies significantly between seasons (winter vs. summer: Pseudo-F = 9.3906, P = 0.001) and habitats (littoral vs. pelagic: Pseudo-F = 7.9398; P = 0.001). The distribution of fishes between the littoral and pelagic zones is not dependent on season (Pseudo-F = 1.0431, P = 0.377). SIMPER analysis showed that Australian smelt, carp gudgeons, common carp, flathead gudgeons and Gambusia were the species contributing most to seasonal changes in the assemblage (Figure 7A). In particular, carp gudgeons, common carp, flathead gudgeon and eastern Gambusia all declined significantly in winter, while Australian smelt increased in abundance. SIMPER also showed that Australian smelt, carp gudgeons, fly-specked hardyhead, eastern Gambusia and weatherloach (*Misgurnus anguillicaudatus*) were significantly more abundant in the littoral zone, while common carp were more abundant in the pelagic.

Coarse-mesh fykes

The structure of the vertebrate assemblage sampled by the coarse-mesh fykes differed significantly between seasons (summer vs. winter: Pseudo-F = 4.3, P = 0.0189) and the differences in vertebrate assemblage structure between habitats is dependent on season (season x habitat interaction: Pseudo-F = 4.4315, P = 0.0184; 'Habitat' main effect was not significant). The significant interaction term resulted from there being significant differences in the vertebrate assemblages sampled from the two habitats in summer, but not in winter. SIMPER analysis revealed that broad-shelled and Murray River turtles were significantly more abundant in summer, while redfin were significantly more abundant in winter (Figure 7B).

Due to the significant seasonal changes in the aquatic vertebrate assemblage, we cannot use the summer samples to make valid comparisons of assemblages between Lake Moodemere and Sunday Creek. We therefore treat the Lake Moodemere and Sunday Creek data separately when analysing the littoral and pelagic assemblages.

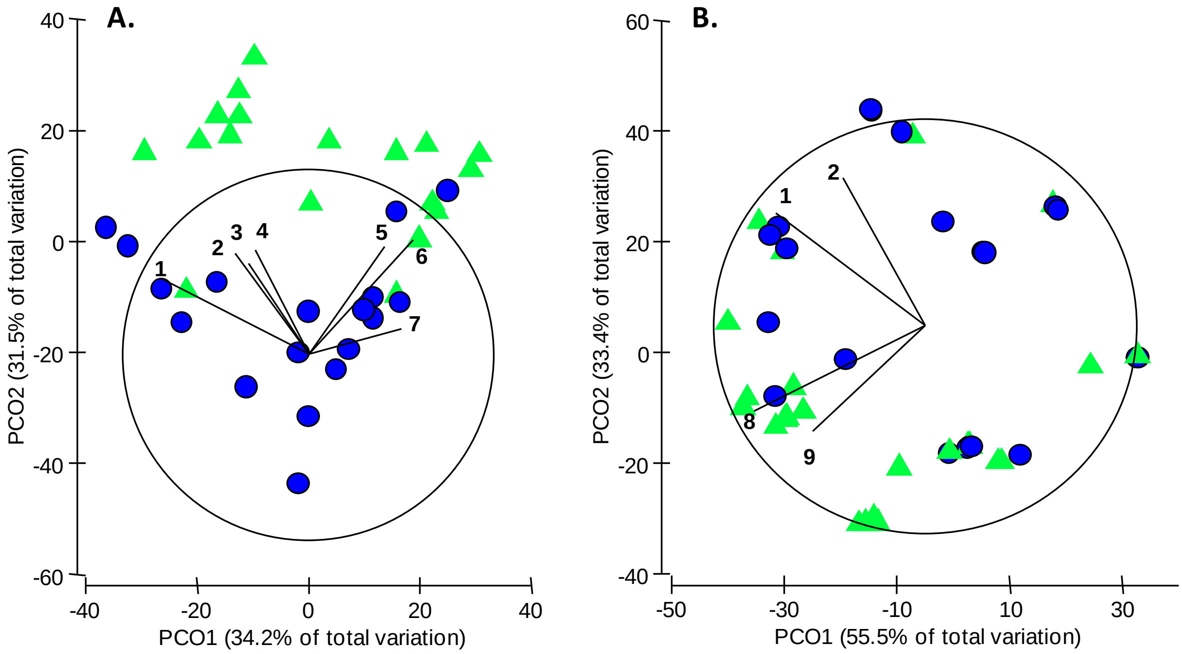

Figure 7. Principal coordinate plots (PCO) of (**A**) fine-mesh and (**B**) coarse-mesh fyke assemblage samples from the littoral (green triangles) and pelagic (blue circles) zones of Lake Moodemere in the summer. Distance between points is proportional to their dissimilarity of assemblage structure. Vector overlay indicates correlations species abundances have with principal coordinates, such that lines point to the region of 'ordination space' associated with higher abundances of that species. Vectors: 1. *C. carpio*; 2. *C. auratus*; 3. *G. holbrooki*; 4. *C. stercusmuscarum*; 5. *M. anguillicaudatus*; 6. *Hypseleotris*; 7. *P. fluviatilis*; 8. *E. macquarii*; 9. *C. longicollis*.

Habitat associations of aquatic vertebrates

Lake Moodemere

There was a significant difference in assemblage structure between littoral and pelagic habitats within Lake Moodemere in the summer, for both fine-mesh (Pseudo-F = 7.7095, P = 0.0001) and coarse-mesh fyke (Pseudo-F = 6.4512, P = 0.0027) data. Principal co-ordinates (PCO; Figure 7) plots demonstrate these clear differences and show that the littoral zones are characterised by increased abundances of carp gudgeons, fly-specked hardyhead, weatherloach, Murray River turtles and broad-shelled turtles, in particular. Australian smelt were more evenly dispersed across both pelagic and littoral habitats.

Sunday Creek

There was a significant difference in assemblage structure between the littoral and pelagic habitats in Sunday Creek during the winter, but only for the fine-mesh fyke data (Fine-mesh: Pseudo-F = 4.5403, P = 0.0029; Coarse-mesh: Pseudo-F = 1.893, P = 0.1589; Figure 8). The PCO plot for fine-mesh fyke data shows the clear differences in assemblage structure between littoral and pelagic habitats (Figure 8A). Common carp, Australian smelt, carp gudgeons and eastern Gambusia all contribute strongly to differences in assemblage structure between habitats — common carp and Australian smelt are associated with pelagic habitats in Sunday Creek in winter, while carp gudgeons and eastern Gambusia are associated with the littoral habitats (Figure 8A).

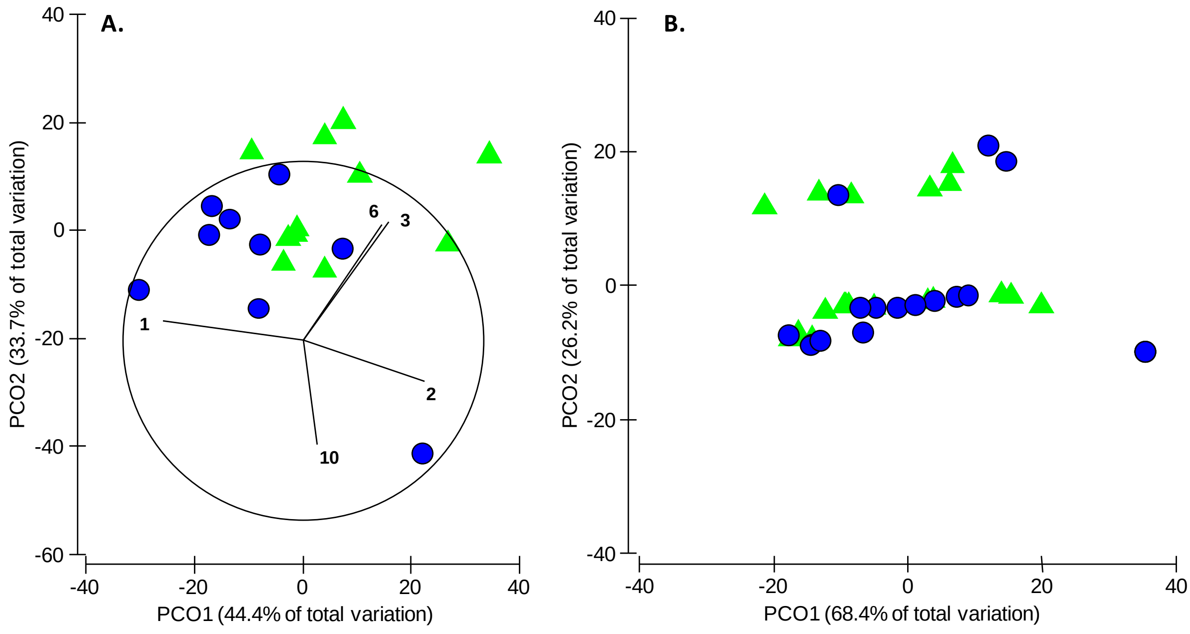

Figure 8. Principal coordinate plots (PCO) of (**A**) fine-mesh and (**B**) coarse-mesh fyke assemblage samples from the littoral (green triangles) and pelagic (blue circles) zones of Sunday Creek in the winter. Distance between points is proportional to their dissimilarity of assemblage structure. Vector overlay indicates correlations species abundances have with principal coordinates, such that lines point to the region of 'ordination space' associated with higher abundances of that species. Vectors: 1. *C. carpio*; 2. *C. auratus*; 3. *G. holbrooki*; 4. *C. stercusmuscarum*; 5. *M. anguillicaudatus*; 6. *Hypseleotris*; 7. *P. fluviatilis*; 8. *E. macquarii*; 9. *C. longicollis*; 10. *R. semoni*. Vector overlay in B not included as there was no significant difference in the assemblage structure between habitats.

Gradients in water quality and relations with the fish assemblage in winter

Water quality

Temperature, pH, dissolved oxygen (DO) and specific conductivity were all related with distance from the Murray River (Figure 9). Temperature declined with distance from the Murray and the maximum difference between the Murray River and Sunday Creek temperatures was 2.8 °C (Figure 9(a)). Both Lake Moodemere and Sunday Creek are slightly more acidic than the Murray River, with a maximum decline of 0.78 units between the Murray channel and Sunday Creek after the narrows (Figure 9(b)) — the narrows are located at approximately SC7 (Figure 1). Areas 4 and 5 on Sunday Creek are downstream of the narrows and areas 6–8 upstream (Table 1). Dissolved oxygen and conductivity exhibited the strongest changes with distance from the Murray channel. Dissolved oxygen dropped from over 10 mg/L in the Murray to below 2 mg/L at the far end of Sunday Creek, while conductivity increased from 0.06 mS/cm to 0.23 mS/cm along the same gradient (Figure 9(c) & 4(d)).

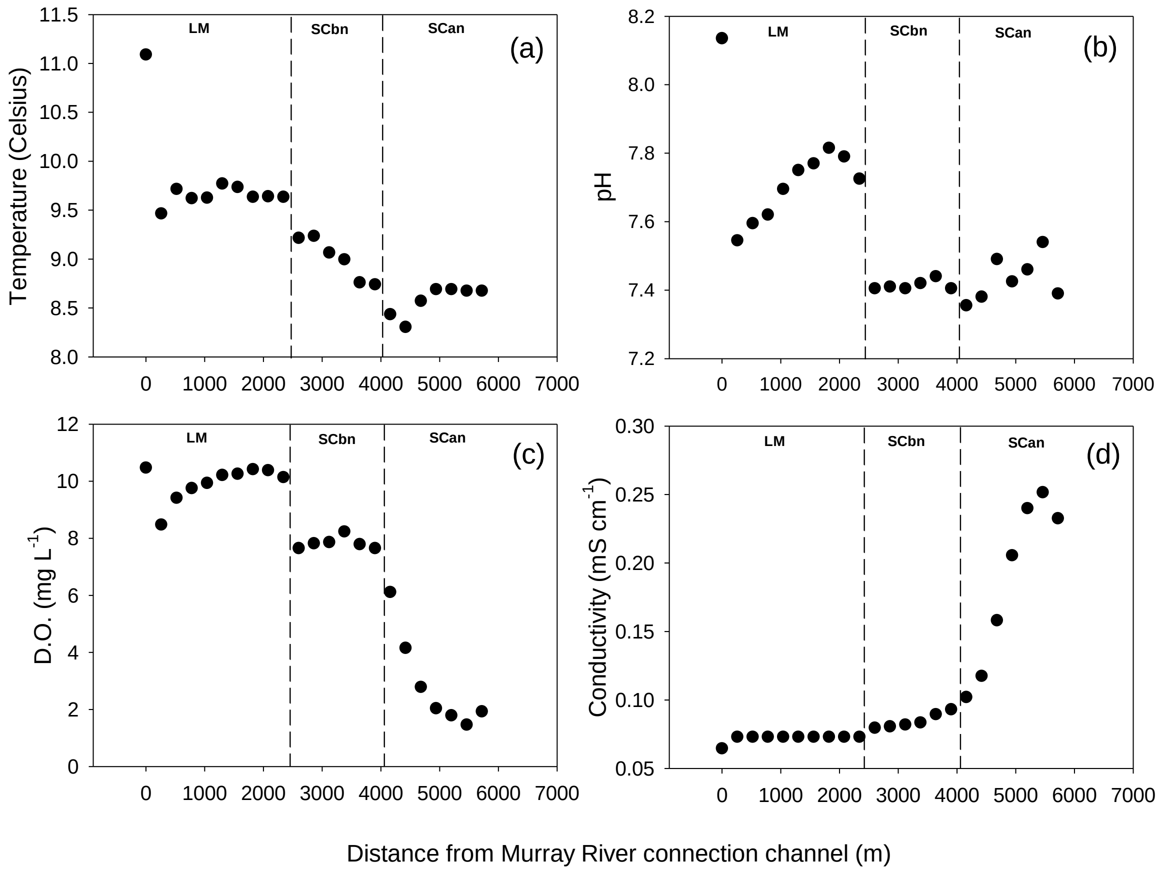

Figure 9. Longitudinal patterns in key (mean) water quality parameters throughout the Lake Moodemere-Sunday Creek wetland complex in winter. Relationship between distance from the connection with the Murray River and (a) temperature, (b) pH, (c) dissolved oxygen, and (d) conductivity. LM = Lake Moodemere; SCbn = Sunday Creek before narrows; SCan = Sunday Creek after narrows. The first point in all graphs is taken from the Murray River itself.

Effects of water quality on fish assemblage structure

There was a significant relationship between water quality variables and fish assemblage structure within the Lake Moodemere–Sunday Creek wetland complex. The most parsimonious model was one that described fish assemblage structure as a non-polynomial function of temperature, DO and specific conductivity (AICc = 61.458; R^2 = 0.62916). Figure 10A shows how well these three water quality variables are correlated with the gradient in fish assemblage structure along PCO1 in particular. Figure10B shows that very active natives — fly-specked harydhead (*C. stercusmuscarum*) and Australian smelt (*R. semoni*) — and the introduced redfin (*P. fluviatilis*) are associated with higher DO and higher temperature, but lower conductivity (Murray end of Lake Moodemere), while pest species common carp (*C. carpio*) and goldfish (*C. auratus*) are associated with the far end of Sunday Creek, which had low temperature and low DO, but high conductivity.

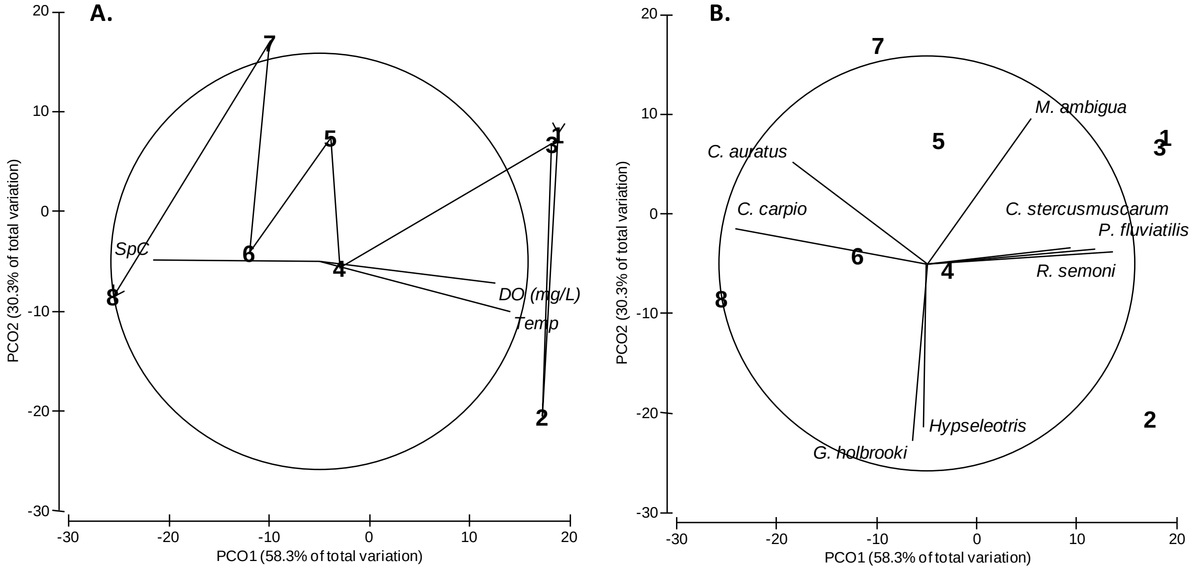

Figure 10. Principal Coordinate (PCO) plots of fish assemblage samples from each of the eight areas along the water quality gradient with (A) vector overlay of water quality relationships with principal coordinates and (B) vector overlay of fish species' relationships with principal coordinates. Vectors point to regions of ordination space that are best categorised by the corresponding variable, be it water quality or fish species.

Figure 11. The surprisingly tranquil Hell's Gate — the connecting channel between Lake Moodemere and Sunday Creek.

Discussion

Objective 1: Determine the aquatic biodiversity value of the Lake Moodemere–Sunday Creek wetland complex

The complete species list of the Lake Moodemere–Sunday Creek wetland complex was increased by one, golden perch, by winter sampling — all other species collected were present during summer sampling (Richardson & Stoffels 2011). This detection of golden perch, in both Lake Moodemere and Sunday Creek, is a notable addition to the species list given that it is the only large-bodied native fish collected from the wetland complex. Native aquatic vertebrates totalled eight species including the three turtles (broad-shelled turtle, eastern long-necked turtle and Murray River turtle), golden perch and four small-bodied fish species (Australian smelt, flyspecked hardyhead, flathead gudgeon and carp gudgeon). Five exotic pest species were collected including three large-bodied fishes (goldfish, common carp and redfin) and two small-bodied fishes (Oriental weatherloach and eastern Gambusia). Of all species collected from Lake Moodemere–Sunday Creek, only the broad-shelled tortoise and flyspecked hardyhead are listed as 'threatened' under the *Flora and Fauna Guarantee Act 1998*. No species recorded are listed under the *Environment Protection and Biodiversity Conservation Act* (1999; EPBC).

Aquatic biodiversity in a regional context

Is the species list assembled herein and by Richardson and Stoffels (2011) sufficient to suggest that the Lake Moodemere–Sunday Creek complex is a regionally-significant wetland with respect to aquatic vertebrates? Beesley *et al.* (2011) used a combination of seine and fine-mesh fyke netting to sample small-bodied fish species at a number of wetlands adjacent to the Murray River between Cobram and Howlong including Quat Quatta, Banyandah, Snake Island, Dairy, Golf Course and Cottadidda. These surveys, repeated eight times between January 2008 and April 2010, yielded similar results to Lake Moodemere–Sunday Creek (fly-specked hardyhead, carp gudgeon, flathead gudgeon and Australian smelt were present in each wetland surveyed). Beesley *et al.* (2011) did not however sample turtles. In 1996/97 Balcombe and Closs (2004) examined the fish assemblage of a Murray River wetland between lakes Hume and Mulwala. They showed that the fish assemblage was dominated by *Hypseleotris*, Australian smelt and common carp, with only two other (exotic) species recorded (redfin and goldfish). Similar to Beesley *et al.* (2011), they did not sample turtles. Both studies, Balcombe and Closs (2004) and Beesley *et al.* (2011), used different sampling protocols to the present and earlier investigations by Richardson and Stoffels (2011). It is clear that determining the biodiversity value of the Lake Moodemere-Sunday Creek complex is not an easy task. Variable sampling protocols and efforts across studies, as well as inadequate investment in regional biodiversity surveys hampers our ability to draw any conclusions about the biodiversity significance of this large wetland.

Despite the problems associated with rating the biodiversity value of the Lake Moodemere–Sunday Creek wetland system, the present work, including Richardson and Stoffels (2011), implies that the biodiversity value may be high within a regional context — it contains a diverse turtle community, including a threatened species, and the small-bodied fish community is at least the equal of other wetlands situated between lakes Hume and Mulwala. Also, given that it is the largest wetland between lakes Hume and Mulwala (Green & Alexander 2006), the regional importance of the Lake Moodemere–Sunday Creek complex is expected to be considerably greater during dry periods.

Importance of littoral zone macrophytes

Littoral zones in the Lake Moodemere–Sunday Creek complex support most of the native biodiversity and significantly higher abundances of native fish and turtles than the pelagic areas. The dense macrophyte beds (primarily giant juncus, *Juncus ingens*) that characterise the littoral zone of this system probably are a significant habitat to aquatic vertebrates. Three hypotheses are presented to explain the importance of the littoral zone to endemic fishes and turtles:

1. The rich epiphyton that covers the stems of giant juncus (Figure 12) supports a productive prey community for native, small-bodied fishes. Indeed, Balcombe *et al.* (2007) showed that giant juncus supports high densities of invertebrate prey for native fishes in Murray River wetlands (see also Balcombe & Humphries 2006). High abundances of small-bodied fishes may, in turn, provide nutrition for carnivorous turtles such as the threatened broad-shelled turtle. Hence the littoral juncus beds may support rich food chains for endemic fauna, from microinvertebrates to large ambush predators. Further, aquatic plants may be an important component of the diet of Macquarie turtles (Chessman 1986; Meathrel *et al.* 2002).
2. Giant juncus is an important breeding habitat for certain species of small-bodied fish. For example, fly-specked hardyhead, which were significantly more abundant within the littoral

zones, spawn within beds of macrophytes where they lay adhesive eggs on the plants themselves (Pusey *et al.* 2004).

3. Giant juncus beds provide an important refuge for small-bodied fishes from redfin, a voracious, introduced piscivore.

Figure 12. *Juncus ingens* beds in Lake Moodemere, showing the rich epiphyton coverage of stems.

Objective 2: Compare and contrast the aquatic fauna of Sunday Creek with that of Lake Moodemere

It is difficult to compare the relative biodiversity value of Lake Moodemere and Sunday Creek. Although we detected a significant difference in the structure of their aquatic vertebrate assemblages, these differences may have been driven by the hypoxic blackwater present in Sunday Creek, following the flood that preceded sampling. Moreover, we could not come to any conclusions concerning the turtle diversity of Sunday Creek because these animals are very difficult to sample during the winter as they become less active as water temperature cools (Chessman 1988). Whilst it is highly likely that Sunday Creek supports very similar aquatic fauna to Lake Moodemere, including the threatened broad-shelled turtle, we do not have data to support this.

Summer sampling in the Lake Moodemere–Sunday Creek wetland complex would permit legitimate comparisons of the two wetland components.

Objective 3: Characterise the water quality gradient between the current regulator connecting the Murray River to Lake Moodemere and the northern end of Sunday Creek.

Water quality clearly deteriorated with distance from the Murray River with virtually all measured parameters changing along a gradient. Lake Moodemere itself was characterised by high water quality — slightly alkaline, low conductivity, 8–11 mg/L dissolved oxygen — with values for parameters falling within the broad guidelines for 'Freshwater Lakes & Reservoirs' detailed in the Australian and New Zealand Guide for Fresh and Marine Water Quality (Australian New Zealand Environment and Conservation Council 2000). The quality of water began to deteriorate in Sunday Creek near its connection to Lake Moodemere — dissolved oxygen dropped slightly, as did pH, and conductivity rose slightly. Beyond the narrows (Figure 3) water quality was poor, with dissolved oxygen, in particular, dropping to levels detrimental to many fish species. This hypoxia was most likely due to large concentrations of organic matter being flushed into the northern end of Sunday Creek by the flood of Dec 2010-Jan 2011 (localised hypoxic blackwater event). However, it is possible that such conditions are typical of Sunday Creek — further water quality monitoring is required.

Effects of hypoxia on fish distributions in Lake Moodemere–Sunday Creek

The strong changes in fish community structure throughout the wetland complex correlate very well with water quality variables. Dissolved oxygen has a major limiting effect on fish physiology (Fry 1971), which in turn can drive behaviour and productivity (Richards *et al.* 2009). The changes in fish assemblage structure are predictable based on what we know about the relative hypoxia tolerance of the species concerned. That is, common carp and goldfish are two of the most hypoxia tolerant freshwater fishes in the world (Nilsson & Renshaw 2004; Fu *et al.* 2011) and these two species were most abundant at the hypoxic end of the wetland complex, at the northern end of Sunday Creek. By contrast, Australian smelt and fly-specked hardyhead are very active, schooling fishes (Pusey *et al.* 2004) and species with this lifestyle often have high oxygen requirements and poor hypoxia tolerance (Wells *et al.* 2005). Accordingly, these species were associated with water rich in dissolved oxygen at the western end of Lake Moodemere. Hence, the frequency, magnitude and extent of water exchange between the wetland and the Murray River may all be important drivers of water quality in the Lake Moodemere–Sunday Creek complex which, in turn, may shape the structure of the fish assemblage.

Sunday Creek as a thermal refuge

The magnitude of fluctuations in temperature of an aquatic system will be negatively related to the volume of the water body, but positively related to the degree of mixing. Because the water in the Murray River adjacent to Lake Moodemere is being discharged from a very large body of water — Lake Hume — its temperature will be buffered from ambient fluctuations, relative to the Lake Moodemere–Sunday Creek wetland complex. That is, water temperature in the Murray River below Lake Hume should be cooler in summer, but warmer in winter, relative to Lake Moodemere–Sunday Creek.

The temperature data we collected is concordant with the above reasoning, in that there is a negative relationship between distance from the Murray River and winter water temperature throughout the wetland complex (Figure 4a). It follows, however, that summer water temperature will be higher in the Lake Moodemere–Sunday Creek complex than that found in the Murray River. If this is indeed the case, then the wetland complex could be a particularly productive habitat for fishes and turtles in the summer. However, more work is required to test this hypothesis.

Management implications

Objective 4: Discuss the potential impacts of the proposed alterations to water delivery on the fishes and turtles of the Lake Moodemere–Sunday Creek wetland complex.

By constructing a regulator between Sunday Creek and Lake Moodemere and delivering irrigation water directly to Sunday Creek two broad outcomes result: Firstly, the potential to restore Lake Moodemere to a 'more natural' hydrology is created. Secondly, the hydrology of Sunday Creek can be managed in isolation from Lake Moodemere — in particular, high water levels from late spring to autumn can be maintained by direct feeding of water into its northern end from the Murray River. Both of these outcomes come with their own set of potential consequences (risks and benefits) to the aquatic vertebrate fauna, which we now discuss below:

Restoration of Lake Moodemere hydrology

Altering Lake Moodemere's hydrology to a more natural one is likely to result in the following scenario:

I. A more natural, seasonal hydrology potentially involving reduced water levels in late summer and autumn, higher levels in late winter/early spring, increased variability (hence shifting littoral zone) and increased ephemerality. Further, the timing and duration of connectivity with the Murray River may also be reduced, particularly in summer.

II. A more variable macrophyte community. Currently dominated by emergent macrophytes (in particular giant juncus), variable water depths and a shifting littoral zone might result in a macrophyte community that is more variable in both space and time, and one that potentially includes submerged and floating vegetation.

Risks

A deleterious effect on native aquatic vertebrates currently in Lake Moodemere is the major risk associated with such an intervention. The potential risks for three species of turtles, one large-bodied fish, and four small-bodied fish are discussed below:

- Broad-shelled turtle — May be at risk of a reduction in numbers as it prefers permanent waterbodies (Cann 1998). Preferred diet consists of live aquatic prey (yabbies, prawns, small fish etc.) and this species' relative success in the lake may be linked to the large beds of emergent macrophytes and the high abundance of small fish therein (Chessman 1983).

- Eastern long-necked turtle — Currently occurs in low numbers but may be advantaged (see 'Benefits' below). Increased numbers of this common turtle may impact on the two other rarer species.
- Murray River turtle — May be at risk of a reduction in numbers as preferred habitat tends toward large permanent waterbodies. Diet consists mostly of plant-based material such as filamentous algae (Chessman 1986) and this species' success in the lake may be linked to the extensive emergent macrophyte beds.
- Australian smelt — No obvious risk.
- Flyspecked hardyhead — Reduced access to wetland macrophytes during breeding period (shrinking wetland) as well as the loss of an important spawning habitat (giant juncus beds). This species lays eggs with adhesive strands that attach to vegetation, and survival of eggs in vegetated areas is higher (Llewellyn 1979; Milton & Arthrington 1983a).
- Golden perch — No obvious risk.
- Flathead gudgeon — No obvious risk.
- Carp gudgeons — No obvious risk.

A positive effect on the exotic species currently in Lake Moodemere should also be viewed as a risk. Our surveys detected the presence of five species of non-native fish and the risk that they would benefit from an altering the lake's hydrology are:

- Goldfish — May benefit from summer conditions if lake retreats and is not connected to river (low DO, high temp, hypoxic).
- Common carp — May benefit from summer conditions if lake retreats and is not connected to river (low DO, high temp, hypoxic). Shallow and warm waters are ideal habitat for carp spawning.
- Oriental weatherloach —May benefit from ephemeral conditions given ability to tolerate poor water quality and aestivate during dry periods. Particularly prevalent in rice fields in native range (see Keller & Lake 2007).
- Redfin — No obvious benefit.
- Eastern Gambusia —May benefit as reproductive activity linked to higher water temperatures (Milton & Arthrington 1983b) and is a rapid coloniser of freshly inundated wetlands (pers. obs.)

Benefits

Some of the potential benefits for the aquatic vertebrates in Lake Moodemere are difficult to assess for each individual species as the effect (of altered hydrology) is likely to have implications throughout the food web. For example, ephemeral wetlands, and indeed ephemeral areas within wetlands, are known to be more productive than permanently inundated wetlands in terms of zooplankton (Nielsen *et al.* 2000; Nielsen *et al.* 2002). Zooplankton is an important food source for most small native fishes (Pusey *et al.* 2004). Turtles are likely to benefit from the expected resultant increase in small fish and macroinvertebrate productivity. The timing of wetting/flooding events will be critical such that peak zooplankton abundance coincides with spawning events of small native fish (Humphries *et al.* 2008). Following are the likely benefits of a more natural hydrology in Lake Moodemere:

- Broad-shelled turtle — This species is a carnivorous ambush predator, so it may benefit from increased abundance of prey (e.g. small fish and crustaceans) associated with a (potentially) more diverse macrophyte assemblage.
- Eastern long-necked turtle — May benefit from increased zooplankton productivity. It is generally associated with ephemeral wetlands, so it may benefit from increased ephemerality.
- Murray River turtle — No obvious benefit.
- Australian smelt — May benefit from increased zooplankton productivity.
- Flyspecked hardyhead — May benefit from increased zooplankton productivity.
- Golden perch — May benefit from increased abundance of small fish and crustaceans
- Flathead gudgeon — May benefit from increased zooplankton productivity.
- Carp gudgeons — May benefit from increased zooplankton productivity.

The potential benefits to the aquatic vertebrate community of Lake Moodemere extend beyond the species currently found there. Any increase in the diversity of submerged and floating macrophytes, as a result of restoring a more natural hydrology to the lake, may encourage the colonisation of certain fishes. For example, southern pygmy perch (*Nannoperca australis*) and the flat-headed galaxias (*Galaxias rostratus*) may benefit from restoration of the submerged and floating macrophyte community. Note, however, that for this to happen a supply of colonists must exist somewhere else in the riverine network between lakes Hume and Mulwala.

Maintaining Sunday Creek as an irrigation reservoir

The proposed change to current water management involves constructing a regulator at Hell's Gate, the point of connection between Lake Moodemere and Sunday Creek, and pumping water directly into the northern end of Sunday Creek from the Murray River. This will effectively result in the following scenario:

I. Wetland fragmentation — The frequency, duration and timing of connection between Lake Moodemere and Sunday Creek may be altered.

II. Changed water quality — The data collected here shows that the magnitude of change in water quality variables increases with distance from the Murray River connection. Assuming that this pattern is common throughout the wetland complex (this assumption needs testing), pumping water directly into Sunday Creek's northern end may change water quality. Sunday Creek's water temperature, for example, may more closely approximate that of the Murray River.

III. Habitat *status quo* —the most basic habitat features of Sunday Creek — water depths, in-channel structure, macrophytic community, etc. — will experience little, if any, change.

Risks

Fragmentation of the wetland complex may result in a decline in fish biodiversity in Sunday Creek. For example, if episodes of low water quality (such as the hypoxia event encountered as part of this study) result in localised extinction of a species, re-colonisation and population recovery may be hampered by reduced connectivity with Lake Moodemere.

Clearly, if Sunday Creek acts as a thermal refuge from cold water releases from Lake Hume into the Murray River during spring/summer, then pumping water directly into Sunday Creek is a risk to certain fishes and turtles.

Benefits

It is not clear, at this stage, how frequent and/or sustained the hypoxia event we encountered in Sunday Creek is. If low water quality is characteristic of Sunday Creek, then direct pumping into the north end from the Murray River may improve our ability to manage and restore water quality in Sunday Creek. In turn, improvement in water quality may reduce the abundance of noxious pest fish that are tolerant of such conditions (e.g. common carp and goldfish), while increasing the abundance of native fishes.

An opportunity that may be considered once water quality in Sunday Creek has been improved — and one which would be considered a benefit at a regional scale — is the possible re-introduction of native species. Sunday Creek is a long and narrow wetland with a relatively diverse macrophytic community and considerable and complex patches of instream woody debris. In short, Sunday Creek presents a habitat suitable for the re-introduction of rare species such as freshwater catfish (*Tandanus tandanus*).

Objective 5: Discuss the key knowledge gaps that hinder our ability to minimise deleterious effects and maximise benefits of any proposed interventions

Several key knowledge gaps hinder our understanding of the whole Lake Moodemere–Sunday Creek wetland complex and the likely effects of the proposed changes to water delivery. These are as follows:

1. Regional context — poor knowledge of the aquatic vertebrate fauna in other regional wetlands, particularly along the Murray River between lakes Hume and Mulwala, make it difficult to properly determine the biodiversity value of Lake Moodemere. Also, we have little knowledge of the likely sources from which new species may re-colonise Lake Moodemere. <u>Aquatic vertebrate surveys of regional wetlands required to address this knowledge gap.</u>
2. Sunday Creek aquatic vertebrate assemblage — as our only survey was conducted in winter, we probably only know a subset of the species that inhabit this wetland. <u>Summer sampling is required and expected to result in a larger species list.</u>
3. Effects of summer 2010/11 flooding — this knowledge gap pertains to both the observed aquatic vertebrate assemblages in Lake Moodemere–Sunday Creek and to the hypoxic blackwater event in the northern end of Sunday Creek. Was what we observed 'normal' of any given year, or as a result of the flooding event? <u>Continued monitoring of aquatic vertebrates in Lake Moodemere–Sunday Creek is required to address the first question. A summer characterisation of the water quality gradient and aquatic vertebrate assemblage in Lake Moodemere–Sunday Creek is required to answer the second.</u>
4. Is Sunday Creek a thermal refuge — characterising the water quality gradient in winter did not adequately address this knowledge gap. Whilst we could demonstrate that the distributions of

aquatic vertebrates in Lake Moodemere–Sunday Creek are linked to water quality, we could not determine how variable water temperature in the wetland complex is in comparison with the Murray River. A summer characterisation of the water quality gradient in Lake Moodemere–Sunday Creek is required to address this knowledge gap.

Recommendations

The Lake Moodemere–Sunday Creek wetland complex, and the proposed changes in water delivery thereto, present a rare suite of opportunities for irrigators, water resource managers and scientists. For irrigators, there is the possibility of reducing the cost of their water supply and improving the quality of water in Sunday Creek. For water resource managers, there is also the opportunity to return a large lake to a more natural hydrology which will, hopefully, lead to a more diverse and productive wetland that may be colonised by other native flora and fauna. There is also an opportunity to re-introduce rarer fish species. For scientists, there are numerous opportunities to improve the understanding of, and therefore the management of, these wetland complexes associated with major rivers. Some of these opportunities include the study of threatened broad-shelled turtles, hypoxia tolerance of native fishes and the re-establishment of native fish species.

Given the opportunities created by the proposed changes to Lake Moodemere–Sunday Creek, it is vital that the key knowledge gaps highlighted in the previous section are addressed. And if steps are made to isolate Sunday Creek from Lake Moodemere and/or alter the hydrology of Lake Moodemere, it is critical that responses to these changes are adequately monitored so that management of the wetland complex can be adapted to changing environmental states and improved scientific knowledge. Indeed, an adaptive management approach to significant interventions such as the one proposed here is an imperative if we are ever to learn how to manage floodplains to achieve optimal outcomes for all stakeholders.

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