The decommissioning of Lake Mokoan: Effects on water quality and fishes of the Broken River

Prepared by: Rick Stoffels and Kyle Weatherman

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The decommissioning of Lake Mokoan: Effects on water quality and fishes of the Broken River

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

Goulburn-Broken Catchment Management Authority
PO Box 1752
Shepparton Vic 3632
Ph: (03) 5820 1100

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For further information contact:

Dr Rick Stoffels

The Murray-Darling Freshwater Research Centre
PO Box 991
Wodonga VIC 3689
Ph: (02) 6024 9665

Email: rick.stoffels@csiro.au
Web: www.mdfrc.org.au
Enquiries: info@mdfrc.org.au

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Author affiliation(s): The Murray-Darling Freshwater Research Centre; [2] CSIRO Land and Water

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Executive summary

- Two river segments of the Broken River were monitored annually for six years to determine how the decommissioning of Lake Mokoan has affected (1) turbidity and nutrient levels; (2) fish community structure.
- Segment A (Benalla to Casey's Weir) is above the discharge point of Lake Mokoan effluent, while Segment B (Casey's Weir to Gowangardie Weir) is below this point and has received effluent from Lake Mokoan until January 2009.
- This report adds a further year of monitoring to that of Stoffels and Weatherman (2013), which provides a more comprehensive account and conceptualisation of Mokoan impacts. Briefly, operation of Lake Mokoan had the following impacts on the Broken River:
    - Diversion of water from the Broken River into Lake Mokoan has resulted in Segment A incurring a higher probability of prolonged zero-flow events from 1990-2010;
    - Highly turbid discharge from Lake Mokoan has resulted in sustained elevated turbidity within Segment B of the Broken River. Turbidity below Lake Mokoan input was particularly high, averaging 173 NTUs over several years, compared to only 33 NTUs above Lake Mokoan inputs;
    - Discharge from Lake Mokoan has resulted in sustained elevated total nitrogen (TN) and total phosphorus (TP) levels within Segment B of the Broken River;
    - The fish community in Segment A was significantly and strongly different to that of Segment B. The fish community in Segment A was characterized by high abundances of small-bodied fishes, few Murray cod and more alien species such as carp and mosquitofish. In contrast, Segment B was characterised by Murray cod and fewer small-bodied and alien fishes;
- We hypothesised that Lake Mokoan decommissioning would have the following effects:
    - The difference in turbidity, TN and TP levels between Segments A and B would converge to zero. In other words, turbidity, TN and TP of Segment B would all decline to match levels in Segment A;
    - Murray cod abundance in Segment A would gradually recover, following the restoration of flows to that segment, which would in turn reduce the abundance of small-bodied and alien fishes. Accordingly, we hypothesised that the fish community structure of Segment A would converge to that of Segment B, not vice versa.
- Concordant with our hypothesis, decommissioning of Lake Mokoan has significantly and strongly reduced turbidity and total nutrient levels in Segment B of the Broken River, below Casey's Weir. This is a good outcome from a socio-ecological point of view as these effects improve the aesthetics of the Broken River and, we speculate, should also result in a more 'desirable' aquatic plant community downstream of Casey's Weir.
- Concordant with our hypothesis, decommissioning of Lake Mokoan has resulted in the fish community of Segment A converging to that of Segment B, such that Segment A is now experiencing strong recruitment of Murray cod into the 1+, 2+ and 3+ cohorts. Unfortunately, stocking of Murray cod from hatcheries has made it very difficult to disentangle the mechanisms underlying change in the fish community.
- Irrespective of the precise causal mechanisms underlying the fish community dynamics, we speculate that the abundance of spawning cod, as well as individuals of a desirable size to

sportfisherman, will increase substantially upstream of Casey’s Weir over the next 5-10 years, now that this river segment is not experiencing such strong diversion of flows.

- We conclude that, in addition to substantial water savings, the Decommissioning of Lake Mokoan has changed the Broken River to a more desirable state from a social, ecological and economic point of view.

END OF EXECUTIVE SUMMARY

1 Introduction

Geomorphological, biogeochemical and population processes of a majority of the world's large riverine ecosystems are affected deleteriously by dams and river regulation (Ward and Stanford 1983, Ligon et al. 1995, Bunn and Arthington 2002, Hart et al. 2002, Nilsson et al. 2005). To ameliorate these effects, in some cases dams are being removed (Gregory et al. 2002, Hart et al. 2002, Service 2011), and in others dams are being used to deliver "environmental flows" to restore critical components of the natural flow regime (Poff et al. 2003). However, neither dam removal nor delivery of environmental flows occurs without significant cost to stakeholders (Poff et al. 2003). To an irrigator, for example, dams may ensure a more reliable water supply, as well as dampen the frequency and/or magnitude of floods, which may cause erosion and damage irrigation infrastructure. Provision of environmental flows can be made possible through government buy-backs of water entitlements, which would have historically been owned by irrigators who compete with the environment for water. This competition for a limited resource has resulted in stakeholders seeking scientific evidence for both the effects of regulation on riverine ecosystems and improvements to the structure and function of riverine ecosystems when dams are removed or environmental flows released (Poff et al. 2003, see also Wilby et al. 2010).

With regard to fish communities, flow alteration may change the distribution, accessibility and abundance of in-stream physical habitat for fish (Ligon et al. 1995, Power et al. 1995). Dams also obstruct the migration and dispersal of fishes, interrupting life-histories and compromising the resilience of populations to disturbance (Hart et al. 2002). More broadly, if fishes have evolved life histories, behaviours or physiologies in response to a natural flow regime, alteration of the flow regime may impair fitness (the natural flow regime paradigm; Lytle and Poff 2004). By extension, replacing the natural flow regime with an altered one may favour invasion by non-endemic fishes (Marchetti and Moyle 2001, Valdez et al. 2001).

The most comprehensive way of ameliorating the effects of dams is to remove them altogether. This may seem like an extremely costly and therefore unlikely method of river restoration, but the truth is many dams in North America and Europe are now being removed (Hart et al. 2002, Poff and Hart 2002, Service 2011). Indeed, the cost:benefit ratio associated with the maintenance of certain dams may be far greater than the cost:benefit ratio of removing them altogether (Bednarek 2001, Gregory et al. 2002). However, our understanding of the impacts of dam removal is in its nascence and there is a great need for investigations of dam removal impacts in a broad range of contexts (Poff and Hart 2002).

The present work concerns the decommissioning of an off-channel dam, Lake Mokoan. Our specific objectives and hypotheses concerning the impacts of Mokoan decommissioning are best interpreted in light of a sound understanding of Lake Mokoan itself. Accordingly, we provide a brief background of Lake Mokoan operations and their impacts before presenting objectives and hypotheses.

<u>Lake Mokoan—background</u>

The Broken River Basin is a sub-catchment of the southern Murray-Darling Basin, and has a mean annual discharge of approximately 325 GL (Cottingham et al. 2001). The Broken River itself is a small, lowland river with a mean annual discharge below Casey's Weir of 236 GL (Cottingham et al. 2001) and is a tributary of the Goulburn River, which, in turn, flows into the Murray River. The river experiences relatively moderate levels of regulation, imposed by four major regulation structures: Lake Nillahcootie and Lake Mokoan, Casey's Weir and Gowangardie Weir. The present study is directly concerned with Lake Mokoan and Casey's Weir only (Figure 1).

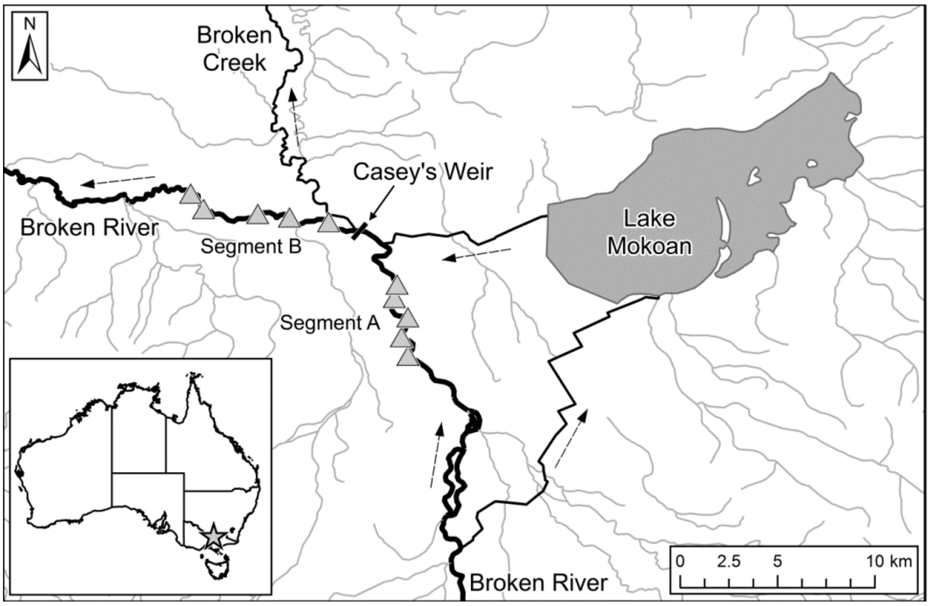

Figure 1. Map of the two river segments studied herein, above (Segment A) and below (Segment B) Lake Mokoan outputs, each of which was ~15 km long. Water impacted by Lake Mokoan enters the Broken River at Casey's Weir. Each of the ten reaches (triangles) was defined by 200 m of river. Dashed arrows indicate direction of flows, including diversions.

Lake Mokoan was constructed in 1971 as an off-stream storage, with a maximum capacity of 365,000 ML, a surface area of 7,890 ha and a maximum depth of 7 m when full. Lake Mokoan was filled by diversions from Holland's Creek and the Broken River each year and traditionally supplied approximately 22,000 ML to downstream diverters and irrigators annually. Its construction resulted in the flooding of a sequence of natural wetlands, including Winton, Green, Ashmeads, Taminick, Lindsays, Humphries, Saddlers and Black Swamps (URS 2003). Preparatory work for the decommissioning of Lake Mokoan commenced during 2008, with outputs to the Broken River ceasing during January 2009.

The other control structure of immediate relevance to this study is Casey's Weir, which is located 15 km downstream of Benalla and was constructed in 1885 to divert flows into the Broken Creek system (Figure 1). Water is diverted at Casey's Weir to support the irrigation requirements on Broken Creek. Water from Casey's weir also supplies water to small, local towns. Casey's Weir would have traditionally represented an impassable barrier to fish movement along the Broken River, however, a vertical slot fishway was constructed during 2005, which may promote the movement of fishes around the weir (ARI 2006) (Figure 2).

Figure 2. Vertical slot fishway on Casey's Weir. Photo: Rick Stoffels.

The three primary reasons for the decommissioning of Lake Mokoan were: 1) evaporative water loss; 2) the costs associated with operating the lake, including the equitable sharing of these costs; and 3) poor water quality, both within the lake itself and incipient effects on the Broken River downstream of Lake Mokoan (URS 2003).

Research has indicated that Lake Mokoan was extremely inefficient as a water storage, losing as much as 50,000 ML per annum (URS 2003), which is approximately 21% of mean annual discharge below Casey's Weir. Moreover, the total annual cost of operating and maintaining Lake Mokoan in 2001/02 was $676,000, with an additional $54,000 spent by Department of Sustainability and Environment on fish stocking, legislative compliance management and research (URS 2003).

Of particular relevance to the present study, is the fact that Lake Mokoan has been characterised by very poor water quality since the early 1980s. In particular, the lake has been characterised by high nutrient—hence algae—concentrations, and very high turbidity, caused by a combination of the following: a generally shallow profile, underlying fine clays, orientation of the lake's long axis with the prevailing southwesterly winds, and the proliferation of common carp, *Cyprinus carpio*, which are known to resuspend fine sediments in such water bodies (King et al. 1997, Robertson et al. 1997). It follows that the water quality within the Broken River downstream of Lake Mokoan was also significantly decreased by the operation of Lake Mokoan (URS 2003).

Figure 3. Panorama view of Lake Mokoan, October 2009, after drainage. Photo: Wayne Tennant.

The present study concerns the dynamics of fishes andwater quality in two segments of the Broken River, each of which can be divided into five reaches (*sensu* Fausch et al. (2002);

Figure 1). Each replicate reach consisted of 200 m of river. The two segments were each approximately 15 km in length and corresponded to two regulation treatments: Segment A (A = ‘above’ discharge point), upstream of Casey’s Weir where Mokoan discharge enters the Broken River, and Segment B (B = ‘below’ discharge point), downstream of Casey’s Weir. Previous analyses have shown that the in-stream structure of habitat does not differ significantly between Segments A and B, nor does temperature (Stoffels and Weatherman 2013).

Stoffels and Weatherman (2013) showed that operation of Lake Mokoan had the following impacts on the Broken River:

1. Diversion of water from the Broken River into Lake Mokoan has resulted in Segment A incurring a higher probability of prolonged zero-flow events from 1990-2010;
2. Highly turbid discharge from Lake Mokoan has resulted in sustained elevated turbidity within Segment B of the Broken River. Turbidity below Lake Mokoan input was particularly high, averaging 173 NTUs over several years, compared to only 33 NTUs above Lake Mokoan inputs;
3. Discharge from Lake Mokoan has resulted in sustained elevated total nitrogen (TN) and total phosphorus (TP) levels within Segment B of the Broken River;
4. The fish community in Segment A was significantly and strongly different to that of Segment B. The fish community in Segment A was characterized by high abundances of small-bodied fishes, few Murray cod and more alien species such as carp and mosquitofish. In contrast, Segment B was characterised by Murray cod and fewer small-bodied and alien fishes;

The general objectives of this monitoring project were to determine the impact of the decommissioning on:

1. Turbidity and nutrient levels within the Broken River;
2. The structure of the Broken River fish community;

Our knowledge of the fishes inhabiting the Broken River, as well as certain analyses, led us to hypothesise that the driver of fish community differences between Segments A and B was the zero-flow events within Segment A (Stoffels and Weatherman 2013). Specifically, we hypothesised that more regular and protracted zero-flow events within Segment A caused strong reductions in the abundance of Murray cod in Segment A, which had 'knock-on' effects on the rest of the fish community, whereby small-bodied fishes and alien species were released from piscivory and thrived in Segment A (Stoffels and Weatherman 2013). By extension, we hypothesised that elevated nutrient and turbidity levels in Segment B were not driving the spatial patterns in the fish community (Stoffels and Weatherman 2013).

Here we report on the dynamics of water quality and fishes during a 6-year period following the decommissioning of Lake Mokoan. We hypothesised that Lake Mokoan decommissioning had the following effects:

1. The difference in turbidity, TN and TP levels between Segments A and B would converge to zero. In other words, turbidity, TN and TP of Segment B would all decline to match levels in Segment A;
2. Murray cod abundance in Segment A would gradually recover, following the restoration of flows to that segment, which would in turn reduce the abundance of small-bodied and alien fishes. Accordingly, we hypothesised that the fish community structure of Segment A would converge to that of Segment B, not vice versa.

2 Materials and Methods

2.1 Data collection

2.1.1 Turbidity and nutrients

The inferences we make concerning turbidity and total nutrients are based on data collected as part of two studies: during the period 2006-2008, turbidity and nutrient data within each river segment, were collected as part of a long-term drought monitoring study ("drought monitoring;" B. Gawne, unpublished data), which incorporated multiple sites in both Segment A and B. Thereafter, total nutrients and turbidity data were collected as part of the present study, whose focus was primarily on the dynamics of the fish community.

Turbidity and nutrients 2006-2008.

Turbidity (NTU; estimated using Quanta Hydrolab™), total nitrogen (TN) and total phosphorous (TP) were measured from the middle of the main channel at three reaches in Segment A and six reaches in Segment B. Turbidity, TN and TP were measured monthly. Water samples were taken in PET bottles, stored on ice immediately, and frozen later that day. TN (µg N l^{-1}) and TP (µg P l^{-1}) were measured by flow injection analysis, using standard methods (American Public Health Association, 1995), in an analytical laboratory operating to national guidelines of quality control and quality assurance.

Turbidity and nutrients 2008-2014.

Turbidity was measured as stated above, but at each of the ten reaches four times per year—once each season—from Spring 2008 through to Winter 2010. Thereafter, sampling frequency was decreased to annual censuses and so turbidity was measured at each of the ten reaches once each summer from 2011 through to 2014.

During the period 2009 – 2011 TN and TP were determined from just a single site within each segment once each summer. Thereafter (2012-2014) TN and TP were determined from each of our ten reaches once each summer.

2.1.2 Fish sampling

The fish communities of Segments A and B were censuses at each of the ten reaches once each year during late summer – early autumn (Feb-Mar). We used backpack electrofishing for large-bodied species, and fine-mesh fyke netting for small-bodied species, because previous experience had indicated the need for more than one method to collect both size-fractions of the community (Stoffels unpublished data, Humphries et al. 2002, 2008). Eight double-winged fyke nets (<1 mm stretched mesh, each wing 2.5 m x 1.2 m; hoop Ø = 0.55 m) were set randomly in each reach between 1000 and 1600, usually for 2 h on each trip. All fish captured in fykes were identified and enumerated, and total lengths were measured from a random sub-sample of 10 fish of each species, from each net. Each reach was exhaustively fished for large-bodied species using single-pass backpack electrofishing (Smith Root LR24 with 250 mm diameter anode ring). This involved fishing as much of the 200 m stretch as possible (usually 95-100%), and identifying, weighing and measuring the length of all large-bodied species captured. Abundances of fish collected in fyke nets and by electrofishing were standardised as catch-per-unit time.

2.2 Data analysis

2.2.1 Turbidity and nutrients

We have two objectives with respect to the response variables TN, TP and turbidity: (1) We want to know whether the values of these variables in each segment converge following the decommissioning of Lake Mokoan; (2) We want to know what state they are converging to. Considering, for example, turbidity with respect to the second analysis objective, we would like to see turbidity in Segment B converge to that of Segment A, not *vice versa*. To make the direction of any convergence easy to visualise we simply plot time series of segment means. To determine whether and when convergence has occurred we construct 95% confidence intervals (CIs) for the differences between segments, for each of the three response variables (Manly 2007).

More explicitly, let $v_{A,i}$ and $v_{B,j}$ be the values of one of the response variables (*v* is either TN, TP or turbidity) in Segment A and B respectively, estimated from one of the replicate reaches *i* = 1,…,*n* or *j* = 1,…,*m* within each segment. To obtain a bootstrapped CI for the difference in mean response variable values, we calculated $d_k = v_{A,i} - v_{B,j}$ for all $i \neq j$, thus giving $l = i \cdot j$ differences for each response variable within each year. Generally, *i* = *j* = 5 replicate reaches per segment hence *l* = 25 such differences for each year. The d_k–values are then sorted to give a vector $\mathbf{d}$ of length *l*. The upper and lower 95% limits about the mean are the elements of **d** 2.5% up from the end of **d** and 2.5% from the first element of d (to the nearest integer) (following Manly 2007).

In any given year, we concluded no significant difference in variable means between segments when the CI contained zero. Note, however, that we only had replicate reaches for nutrients—hence CIs—for the years 2006-2008 and 2012-2014. In contrast, replicate reaches were utilized for turbidity estimates across all years. All bootstrapping was programmed in MATLAB.

2.2.2 Fish community dynamics

Fish catch per unit effort (CPUE) data were used to determine spatial and temporal patterns in abundance, diversity, alien-fish abundance and community structure. We have two objectives with the fish community analysis: (1) We wish to show that the fish community structures of Segments A and B are converging following decommissioning of Lake Mokoan. (2) In addition to convergence per se, we also wish to determine the direction of change within each segment; we have hypothesized in the Introduction that the fish community of Segment A will converge to that of Segment B, not *vice versa*. For all multivariate analyses of convergence and direction of convergence we used Bray-Curtis similarities calculated between mean *ln*(CPUE + 1) values for individual reaches (hence 10 reaches or means per year).

Convergence of community structure in two river segments over time essentially requires a significant 'Segment × Time' interaction in a two-factor PERMANOVA. Accordingly, we test for this interaction effect using PERMANOVA. This interaction term will not, however, tell us when convergence is occurring, nor whether the communities of each segment have fully converged by summer 2014. To better understand the timing and level of convergence we simply determine the R-statistic associated with Analyses of Similarity (ANOSIM; Clarke 1993, Clarke and Warwick 2001) conducted within years, between the structures of each segment. In any given year, an R-statistic of 1 indicates that all reaches within segments are more similar to each other than any reaches of the other segment. In contrast, if R = 0, then inter-reach similarities between and within segments will be the same on average. We examine the trend in R-statistics over years graphically (Clarke 1993, Clarke and Warwick 2001). We also determine the direction of community change within each segment graphically, using PCO and associated species vectors.

3 Results

3.1 Turbidity and nutrients

Turbidity was significantly higher in Segment B than in Segment A of the Broken River during the three years prior to decommissioning (Figure 4). There was a sharp and strong convergence in mean turbidities of both segments immediately after decommissioning, during summer 2009, with turbidity in Segment B declining to approximate that of Segment A (Figure 4). Indeed, although turbidity was significantly—yet marginally—higher in Segment B during the summers of 2010 and 2012, there was no significant difference in mean turbidity values between segments for the sampling events 2009, 2011, 2013 and 2014.

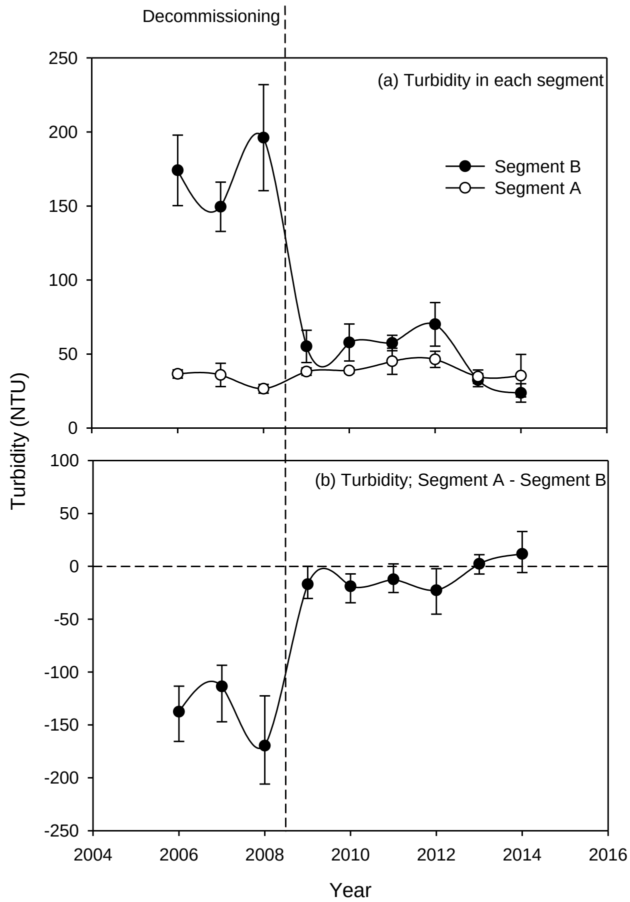

Figure 4. Trends in turbidity within Segments A and B of the Broken River. (a) Mean (+/- St. Dev.) Turbidity in Segment A (white) and B (black) during three years prior to decommissioning and six years post decommissioning. (b): Time series of the mean difference (+/- 95% CI; non-parametric) between Segment A and B turbidity, such that means below the zero-line indicate mean turbidity in Segment B is higher than that in Segment A; if the zero-line is not contained within the CI, the difference between Segment A and B turbidities is significantly different.

Both TP and TN exhibited significantly higher concentrations in Segment B for all years except the most recent two sampling years, 2013 and 2014 (Figure 5). The difference was particularly great, however, during the three years prior to decommissioning, for both TP and TN (Figure 5). The inter-segment difference ($d_k = v_{A,i} - v_{B,j}$; Figure 5b and d) for both nutrients exhibited a similar dynamic over the 9 years of monitoring, and this dynamic involved a noticeable shift towards zero during 2009, immediately after decommissioning. Thereafter there appeared to be a noisy upward trend towards zero, with no significant difference between segments observable during 2013, for the first time in eight years (Figure 5b and d). Nutrient concentrations were actually significantly—yet marginally—higher in Segment A during the final year of monitoring, 2014 (Figure 5).

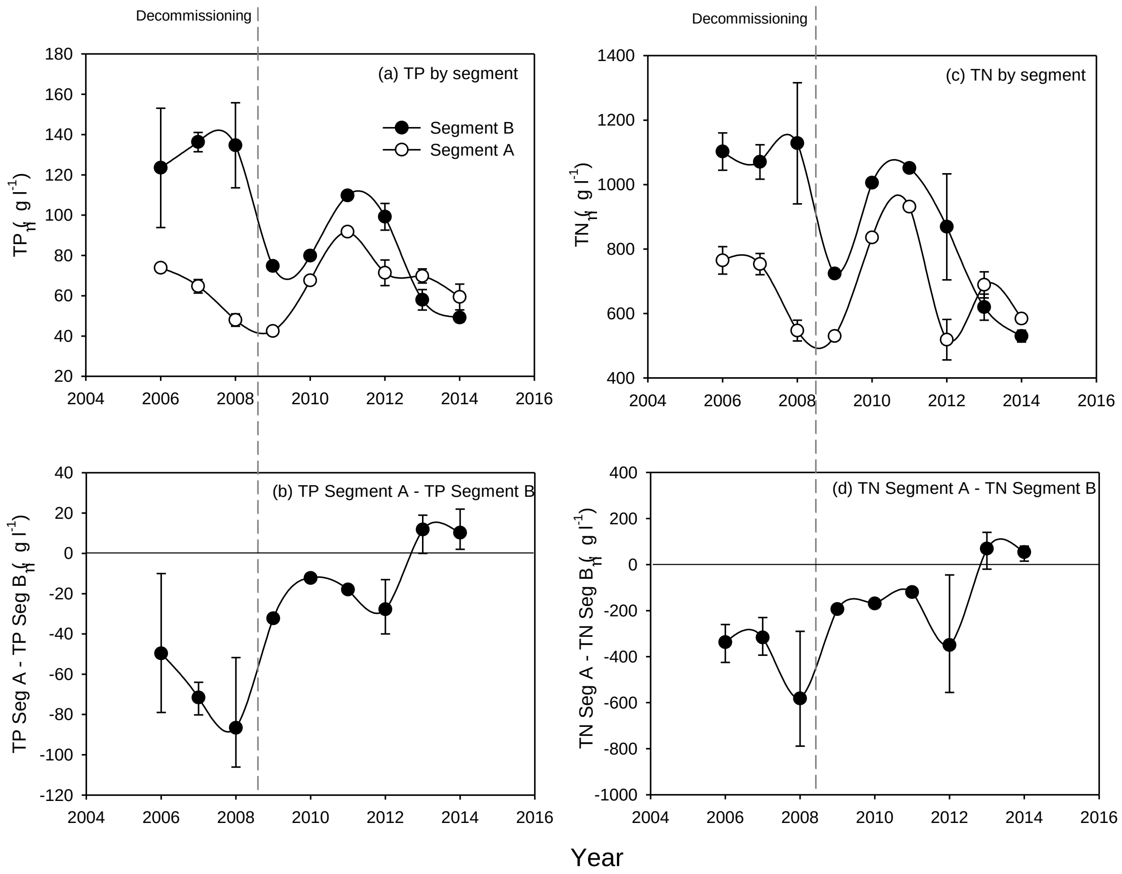

Figure 5. Trends in total nitrogen (TN) and total phosphorous (TP) within Segments A and B of the Broken River. Mean (+/- St. Dev.) TP (a) and TN (c) in Segment A (white) and B (black) during three years prior to decommissioning and six years post decommissioning. No replicate reaches were sampled for years 2009-2011. (b) and (d): Time series of the mean difference (+/- 95% CI; non-parametric) between Segment A and B concentrations of TP (b) and TN (d), such that means below the zero-line indicate mean concentrations in Segment B are greater than those in Segment A; if the zero-line is not contained within the CI, the difference between Segment A and B concentrations is significantly different.

3.2 Fish community dynamics

There was a significant Segment × Time interaction in fish community structure (Pseudo-F = 2.85; $P < 0.001$), indicating the fish community of the Broken River was changing over years, but that the nature of that change was segment-specific. The fish communities of each segment converged in structure very quickly between 2009 and 2010, but then the level of convergence levelled-out, with an obvious asymptote in convergence from 2010 through to 2014 (Figure 6). The similarity between the fish communities of each segment was greatest in 2014, our most recent sampling event (Figure 6). Despite this convergence we recorded significant differences ($P < 0.05$) between segments within all years of sampling, including our final sampling event, summer 2014.

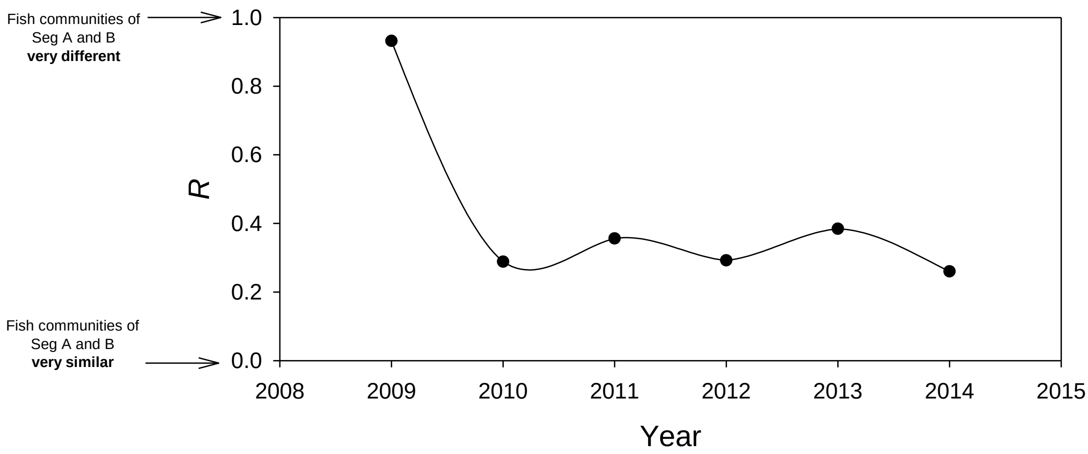

Figure 6. Pairwise R-statistics calculated between the fish community structures of Segments A and B of the Broken River each summer from 2009 through to 2014. In any given year, an R-statistic of 1 indicates that all reaches within segments are more similar to each other than any reaches of the other segment. In contrast, if R = 0, then inter-reach similarities between and within segments will be the same on average. All R-statistics are associated with a significant ($P < 0.05$) difference in fish community structure.

With respect to direction of convergence, it is clear from Figure 7 that Segment A is converging to that of Segment B. Although subtle inter-annual changes in fish community structure were observed in Segment B, there were stronger changes in Segment A, where the abundances of small-bodied fishes declined, and the abundance of Murray cod slowly began to increase, particularly from 2012 to 2014.

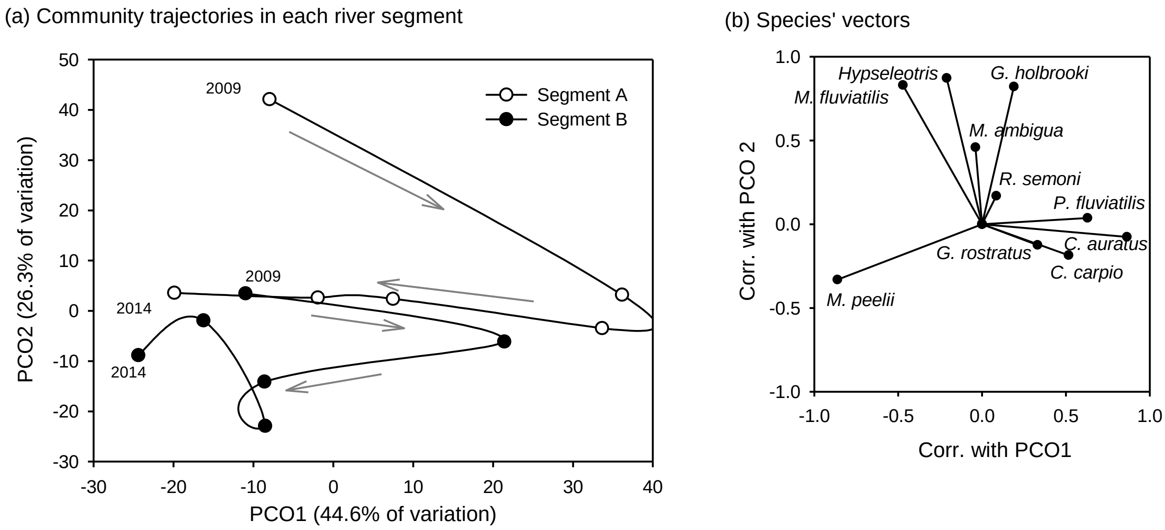

Figure 7. (a) Principal Coorindate Ordination (PCO) of fish community trajectories within Segments A and B of the Broken River. Each point represents mean fish community structure within a segment, within a year, each year from immediately after decommissioning of Lake Mokoan (2009) to five years following decommissioning (2014). (b) Vector plot corresponding to the PCO, showing direction and magnitude species abundances have with each PCO axis in (a). Vectors essentially 'point' to the region of ordination space characterized by that species.

4 Discussion

4.1 Turbidity and nutrients

The dynamics of turbidity and nutrients since the decommissioning of Lake Mokoan were concordant with our hypothesis: The high levels in Segment B, below the historical Lake Mokoan discharge point, declined to match those observed in Segment A. Turbidity levels of Segment B declined very quickly after decommissioning. Within one year there was no significant difference between the turbidity levels of Segments A and B. By contrast, TN and TP were slower to respond, taking 5 years for the levels in Segment B to match those of Segment A. This is an interesting result as it shows that effects of nutrient enrichment can be retained with the broader food web for many years after the source of enrichment has been eliminated. For this to happen we hypothesise that much of the total nutrients exported from Lake Mokoan must have entered benthic and epibenthic pools (e.g. biofilm-based food chains), where they were retained for longer than would have been the case if nutrients simply remained in the water column.

The significant reduction in turbidity and nutrient levels of the Broken River represents a good socio-ecological outcome. Production of the floating fern *Azolla* is tightly linked to nutrient levels (Rees et al. 2007), and the reduction in nutrient input to the Broken River should reduce the abundance of *Azolla* downstream of Casey's Weir (Stoffels and Weatherman 2013). The very high turbidity levels of the Broken River downstream of Casey's Weir were caused by Lake Mokoan operation, and so removing these turbid inputs should not only make the Broken River more appealing from a social point of view (swimming, aesthetics, etc.) but may also facilitate the recolonisation of Segment B by submerged macrophytes like *Vallisneria australis*, which were significantly more abundant in Segment A, where the water was less turbid.

4.2 The fish community

Concordant with our hypothesis, the fish community of Segment A gradually converged with that of Segment B over the six years since decommissioning. This is concordant with Lake Mokoan shaping the fish community of the Broken River through the reduction of flows between the Lake Mokoan diversion weir upstream of Benalla and the discharge point at Casey's Weir. This diversion of flows resulted in a higher probability of zero-flow events in Segment A (Stoffels and Weatherman 2013). These rare zero-flow events had strongly reduced the abundance of Murray cod in Segment A, and we speculate that this reduction of a top carnivore (Stoffels 2013), had knock-on effects on the rest of the fish community that may represent prey to Murray cod; carp and small-bodied species were all more abundant in Segment A prior to the decommissioning of Lake Mokoan.

However, a major caveat must be stated here: the convergence of fish communities between segments may not be due—wholly or partially—to the decommissioning of Lake Mokoan. This year we discovered Victorian Fisheries (DEPI) has been stocking Murray cod within the Broken River for the past three years (2012-2014). It is possible, therefore, that the recolonisation of Segment A by Murray cod is not due to resumption of flows following the decommissioning of Lake Mokoan, but due to stocking. This was a great surprise as correspondence between Victorian Fisheries and us at the beginning of this project led us to believe that Murray cod were not to be stocked in the Broken River, nor had they been stocked during the decade prior to this study. Indeed, the Broken River contains a self-recruiting population of Murray cod (Humphries et al. 2002, Humphries 2005, Humphries et al. 2008). We submitted a proposal to Victorian Fisheries to determine whether recent cod stocking has had a significant effect on the trends uncovered by the present analysis. They indicated they did not want to fund the proposal.

Irrespective of the cause, juvenile Murray cod appear to be recruiting within Segment A quite well. A Murray cod growth model, whose parameters were estimated from cod recaptures (Stoffels, unpublished data), indicated that cod were recruiting into the 2+ and 3+ cohorts well, and will likely reach sexual maturity within the next couple of years (by 2017). Now that flows cannot be diverted around Segment A, we hypothesise that a spawning population should become re-established upstream of Casey's weir. By extension, we hypothesise that this Murray cod population will restructure the fish community of Segment A to a state that is more desirable from a socio-economic point of view; lower abundances of alien fishes and more Murray cod.

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