Background concepts to the restoration of diverse native fish communities at Barmah-Millewa Forest.

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Background

Barmah-Millewa Forest (B-MF) is a vast (66, 615ha), highly complex floodplain wetland ecosystem of the mid-Murray River (Figure 1), has international significance under the Ramsar Convention (Ward 2005) and is one of six icon sites for the Murray-Darling Basin Authority's Living Murray initiative. River red gums characterise the forest, which is also recognised for its highly complex network of aquatic habitats including rivers, permanent and temporary creeks, permanent lagoons, swamps and wetlands and the floodplain proper; all of which are totally inundated during large floods from the Murray River. The ecology of B-MF is dependent on flows from the Murray River, and ecological links with the main river channel are important in considerations for understanding the processes affecting the status of fish communities at B-MF.

Historically, twenty eight species of fish have been recorded at B-MF (18 native: 10 exotic) (Lyon et al. 2002). This number has declined over past decades, with nineteen species recorded between 2007- 2009 (McKinnon 1997; Jones and Stuart 2004; Raymond et al. 2011; Sharpe and Wilson 2012). Since 2009, species diversity has declined further, with the most recent assessments of the species diversity present at B-MF reporting eleven native and four non-native fish species (Raymond et al. 2011; Sharpe and Wilson 2012; Sharpe et al. 2014) (Table 1.1).

These include the native large bodied Murray cod, trout cod, golden perch and silver perch and small bodied species such as carp gudgeons, Australian smelt, un-specked hardyhead Murray-Darling rainbowfish amongst others, and exotic species including common carp (carp), goldfish, Oriental weatherloach and Eastern gambusia. Notably, one species has recently become locally extinct - the endangered southern pygmy perch, which has not been recorded at B-MF since 2009 (Sharpe and Wilson 2012). Furthermore, several native species including Bony herring, flatheaded gudgeon and trout cod have been recorded as only a few individuals in recent surveys (Raymond et al. 2011; Sharpe and Wilson 2012).

The continued decline in overall native species diversity and the increasing rarity of many native species, particularly on the floodplain, are causes for concern and requires management intervention. This document provides a brief summary of the current knowledge of the spatial and temporal distribution of native fish and recent research into native and exotic fish ecology at B-MF, with the aim of identifying and prioritising a program of targeted research to inform management and restoration of native fish communities across the B-MF region. This document provides;

- review of the spatial and temporal distribution of native and exotic fish at B-MF
- review of the factors affecting spawning and recruitment of fish at B-MF
- review of the factors affecting the status of fish communities at B-MF, with focus on the factors affecting the colonisation of floodplain and permanent creek, wetland and lake habitats – principally the lateral movement of various fish life history stages to and from the Murray River and the B-MF floodplain.
- Identification of major on-ground management opportunities to restore the status and abundance of B-MF native fish communities

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1. Recent research findings on spatial and temporal patterns

Spatio-temporal patterns, relative abundance and population structure of native and exotic fishes have been examined across four major ecotypes at B-MF; Rivers, Creeks, Lakes and Wetlands, since 2007 (Tonkin and Baumgartner 2007; Rourke and Tonkin 2009; Raymond et al. 2011; Sharpe and Wilson 2012).

- There are persistent differences in the structure of fish communities across the four ecotypes types examined at B-MF.

  Creeks and Lakes share similar native species composition, with small bodied species characterising those assemblages. Assemblages in River and Wetlands are distinct to each other and to Creeks and Lakes. Of note, large bodied native species have been absent from Wetland and Lake habitats and have been generally absent from Creek sites, albeit that a few individuals of golden perch and Murray cod have been captured from Creek sites at Barmah Forest (but not Millewa Forest) (Jones 2008; Jones and Stuart 2010).

  Creek and Lake habitats are dominated by common carp, Eastern gambusia and generalist native carp gudgeons. Several studies have highlighted that Creek habitats host a range of attributes conductive to supporting large bodied native fish assemblages – and the absence of those species is a key point for discussion here. Favourable attributes in Creek habitats include high densities of large woody debris (Figure 1.1) and hydrodynamic diversity (including fast flowing water) during irrigation and environmental flow periods (King et al. 2007; Jones and Stuart 2008; Sharpe and Wilson 2012).

- **Key points for consideration:**
  - Restoring fish *colonisation pathways* and *perennial flow* to Creek habitats would support the restoration of large bodied fish populations in creeks habitats at B-MF.
  - Studies have highlighted that flow regulation structures (e.g. Gulf Creek regulator) are barriers to the colonisation of Creek habitats by large bodied fish from the Murray River, particularly during low-flow conditions in the Murray River (< 8 000 ML/d @ Yarrawonga).
  - Examine colonisation pathways for large bodied fish to enter B-MF creek habitats
  - Evaluate and prioritise barriers to fish colonisation, and exit, from B-MF Creek habitats

  The *River* ecotype is characterised by large bodied native species including Murray cod, trout cod, golden perch and silver perch and small bodied species including un-specked hardyhead, Murray-Darling rainbowfish, and Australian smelt (Rourke and Tonkin 2008; Raymond et al. 2011).

- **Key points for consideration:**
  - The river habitat is the source for restoring large bodied fish communities in Creek habitats of B-MF (Jones and Stuart 2008).
  - However, little work to examine the inter-annual (decadal) flow regime in the Murray River has been undertaken to identify the hydrological

factors influencing and supporting the status of the riverine fish community (e.g. low winter flow).

- The *Creek* ecotype is characterised by Murray-Darling rainbowfish, carp gudgeons and Eastern Gambusia (NB: large bodied native fish are generally absent from Creek habitats in surveys undertaken; Rourke and Tonkin 2009; Raymond et al. 2011; Sharpe and Wilson 2012).
- The *Lake* ecotype is characterised by goldfish, common carp and Australian smelt and un-specked hardyhead (Stuart and Jones 2006; King et al. 2007; Raymond et al. 2011).
  - Lake habitats support strong annual carp recruitment (Stuart and Jones 2006; King et al. 2007).
  - Carp recruits from Barmah Lake contribute to the regional Murray River population (Stuart and Jones 2006).
  - There have been no large bodied native species recorded in Lake habitats in studies undertaken since 2008 (Raymond et al. 2014).
  - Anecdotal accounts historically describe significant catches of large bodied native fish from Lake habitats, with Moira and Barmah Lakes supporting commercial fisheries based on native fish including Murray cod and golden perch (King 2005; Trueman 2011).

- The *Wetland* ecotype is characterised by carp gudgeons and Eastern gambusia (Rourke and Tonkin 2009; Raymond 2011; Sharpe and Wilson 2012). Wetlands across B-MF are typified by low species diversity (Raymond et al. 2011; Sharpe and Wilson 2012). Historically, wetlands exhibited considerably higher species diversity.

2. Spawning and recruitment;

a. In the main channel of the Murray River (King et al 2004, 2009, 2007; 2010)
   i. Murray cod, trout cod, golden perch, silver perch and several small bodied native species spawn in the Murray River at B-MF. For Murray cod and trout cod, spawning occurs from October-January. For golden perch and silver perch, spawning has only been observed to have occurred in conjunction with flow pulses and rising water temperatures. Small bodied native species spawn from September – May.
   ii. Local recruitment of Murray cod and trout cod occurs in the Murray River at B-MF with strongest recruitment observed following floods. For golden perch and silver perch there is no evidence of local recruitment from recently documented local spawning events. Recent research using otolith microchemistry to determine natal origin indicates that golden perch and silver perch recruitment to B-MF populations has largely resulted from colonisation migrations from as far downstream as the lower Murray River and from the Darling River (Zampatti et al. 2015).

b. In wetlands, Australian smelt, carp gudgeons, un-specked hardyhead, flatheaded gudgeon and Southern pygmy perch and four exotic species including Eastern gambusia, Oriental weatherloach, common carp and goldfish have all been observed to recruit locally (within wetlands)(King et al. 2007;

Tonkin et al. 2008), Albeit that Southern pygmy perch are now thought locally extinct and flatheaded gudgeon and un-specked hardyhead are now rare in Wetlands (Sharpe and Wilson 2012; Sharpe 2014; Raymond et al. 2014). Australian smelt and carp gudgeons spawn and recruit in isolated wetlands (Rourke and Tonkin 2009; Sharpe and Wilson 2012).

c. In Lakes, Australian smelt, carp gudgeon, un-specked hardyhead, Southern pygmy perch and four exotic species including Eastern gambusia, Oriental weatherloach, common carp and goldfish exhibit local recruitment (King et al. 2007; Stuart and Jones 2006; Tonkin et al. 2008). Lakes are a recruitment hotspot for common carp (Stuart and Jones 2006).

d. In Creeks, Murray cod, Australian smelt, carp gudgeons, un-specked hardyhead, flatheaded gudgeon, Murray-Darling rainbowfish and Southern pygmy perch have been recorded as larvae, suggesting that those species either spawn in creeks or drift in as larvae from the Murray River (King et al. 2007). Again, southern pygmy perch are now thought locally extinct, and several of these species have become increasingly rare in creeks (e.g. Murray-Darling rainbowfish, un-specked hardyhead and flatheaded gudgeon).

    i. The impact of undershot regulators on fish larvae drifting through regulators is recognised as having a very significant detrimental impact on larval mortality elsewhere in the MDB (Baumgartner 2006). This is also likely to occur at B-MF (Jones 2008), for larval colonisation of Creeks, Lakes and Wetlands and may impact heavily on the establishment of native fish populations in regulated Creeks at B-MF.

3. Lateral fish movement

a. Several studies have examined the movement of juvenile and adult native fish on and off the B-MF floodplain (Jones 2008; Jones and Stuart 2010). These have noted that large bodied native fish including Murray cod and golden perch move into regulated and unregulated floodplain creeks at high flows.

Tracking studies of large bodied native fish undertaken by Jones (2008) and Jones and Stuart (2008) identified that during periods of hydrological connection between the river and creek habitats (at high Murray River flows ~>8 000 ML/d), large bodied native fish move from the main river channel into B-MF creeks. Tracked fish occupy Creek habitats until when river flows begin to recede, upon which they move back to the Murray River (in unregulated creeks) but are stranded in regulated Creeks, unable to pass flow regulation structures back to the Murray River (i.e. Gulf Creek regulator, Mary Ada regulator on Toupna Creek), but persistently attempt to move back to the River, undertaking searching movements up to impassable regulators (Jones and Stuart 2008). Impassable barriers at creek/river effluent points, such as Gulf Creek, can strand very high numbers of large and small bodied fish on the floodplain when high river flows recede (Jones and Stuart 2008).

    i. Large bodied native fish move into floodplain Creeks during periods of high flow, indicating that Creek habitats, when flowing, are suitable for large bodied native fish including Murray cod, trout cod, golden perch and silver perch.

4. Management opportunities and research priorities

The B-MF fish community is relatively diverse, reflecting the diversity of river and floodplain habitat types. Native fish species diversity is highest in the River ecotype, whilst floodplain wetlands, lakes and creeks exhibit considerably lower species diversity. Enhancing native fish species diversity, and increasing the abundance and distribution of native fish at B-MF are high management priorities.

Contemporary approaches to the management and restoration of native and exotic fish populations are based on understanding of species' life history processes and habitat requirements, facilitating those with appropriate management intervention, and applying that understanding to identify and mitigate negative influences. For each species within a community, there are three overarching tenants, or prerequisites of a 'sustainable population'; - flow, habitat and connectivity (Mallen-Cooper et al. 2014). Each fish species within a community will likely exhibit different flow, habitat or connectivity requirements, however, the use of conceptual models of a species life history can identify the key factors associated with either phase of the flow-habitat connectivity continuum to target appropriate management intervention, and effective population restoration or enhancement efforts. An example of a conceptual model is provided for Murray cod in Table 4.1.

In the Murray River system, Murray cod populations are the strongest in perennially flowing anabranch habitats that exhibit high hydrodynamic diversity (slow and fast flowing areas), high snag densities, and that are connected to the main stem of the Murray River. Well known examples are the 11 km Mullaroo Creek in north-west Victoria and the ~10 km Chowilla Creek in South Australia. The structure of Murray cod populations at those sites are among the strongest known in the entire southern M-DB.

Understanding of the flow-habitat-connectivity requirements that support strong Murray cod populations can be extended to B-MF, to enhance and restore populations throughout the system. The B-MF Murray cod population is essentially limited to the main stem of the Murray River; is less 'robust' in demography than for example Mullaroo Creek, but where potentially hundreds of kilometres of optimal Murray cod habitat can be restored – principally – by restoring flow and connectivity to the habitat (snag) rich Creeks of the B-MF floodplain, for example Gulf Creek (> 80 km),Toupna Creek (> 80 km), Gulpa Creek (> 100 km), Tongalong Creek (> 80 km) and many others.

These Creeks offer tremendous potential as optimal Murray cod habitat, and for restoration of permanent, self-sustaining Murray cod populations and likewise for trout cod, silver perch and golden perch. The present understanding is that the larger Creek habitats of B-MF contain high densities of large, highly complex woody debris, are hydrodyamically diverse *when flowing – i.e. seasonally and are at times connected to the main-stem of the Murray River, albeit that connections are regulated.

The latter two points are key to restoring strong populations of large bodied native fish at B-MF: should perennial flow be restored, as well as connectivity and thus potential for colonisation enhanced, then restoring strong populations of large bodied fish throughout B-MF is considered highly achievable.

Table 4.1. A conceptual model of Murray cod life history ecology, flow and habitat requirements in the southern, regulated Murray-Darling Basin.

HABITAT

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- Murray cod prefer perennial flowing river reaches with hydraulic complexity/diversity and snags.
- Murray cod can spawn and recruit during low stable flows, rising flows and floods.
- In regulated rivers, Murray cod require year-round flow, especially in winter when some rivers are shut down.
- Recruitment potential may be increased when additional habitat resources such as food and shelter are created as benches and riparian zones are inundated by rising flows.
- Murray cod eggs and larvae require a steady flow increase and very little daily variations in water level (0.1 m) to maximise spawning success.

RECRUITMENT

- There is high mortality of young fish but those that survive their first summer and winter and grow to 90-140 mm long tend to have a good chance of recruiting into the sub-adult population (250-600 mm long).
- Murray cod mature late (3-5 years) and at a reasonably large size (>600 mm long) but females have relatively low egg numbers (fecundity).
- Murray cod are long-lived (>40 years) and can grow to a large size (e.g. 1.4 m).

SPAWNING

- In the temperate reaches of northern Victoria, southern NSW and SA Murray cod spawn in October/November and sometimes December each year.
- Murray cod display complex pre-spawning courtship behaviour and females may spawn with more than one male.
- Males guard nests for up to 2 weeks while the eggs hatch.

COLONISATION

- Movements may be up to 120 km but are usually only a few kilometres (e.g. commonly up to 30 km).
- Small movement may still be ecologically important, such as between the main river channel and seasonally available anabranches and flood runners.

CONNECTIVITY

- Murray cod move from their home snag to spawning areas in August/September on rising water temperature in late winter and early spring.
- Many adult fish move back to their home snag post spawning.
- Juvenile fish disperse from natal areas to establish new home sites and drive population expansion.

Summary of project logic

To restore Murray cod populations, the best-practice current scientific knowledge is that Murray cod require four simple life-history components: (i) flowing water which is hydrodynamically diverse, (ii) perennial flow without winter shut down, (iii) stable spring flows to complete spawning, (iv) physical habitat (snags). These components are all present, potentially over 100's of kilometres at B-MF anabranches: **with the major exception of perennial flows** (Figure 4.1)

Where these components of the riverine environment are restored, then a subsequent redistribution and significant population expansion of Murray cod and other native fish can be expected. Successful recent case-studies have demonstrated the value of this approach, for North Central CMA at Gunbower Creek (Sharpe and Stuart 2015), for MDBA in the lower Darling River (Sharpe et al. 2015), in Yanco/Billabong Creek for Murray LLS (Sharpe and Stuart 2013, 2015). Importantly - the simplicity of the approach, and for the project logic here at B-MF, is key to its potential success.

We highlight that this logic is based on an excellent and intimate knowledge of fish ecology, which is the basis of the conceptual models, and the specifically designed, targeted hydrographs that are required to support the restoration of large bodied fish populations. This unique practical approach to restoring fish communities has been pioneered by the project team and is based on our desire to scientifically recover fish communities; rather than simply document their decline.

The details of the project methods are outlined below but our logic is centred on the practical vision of restoring flowing anabranches as the 'engine rooms' of Murray cod and other native fish recovery. This hands-on approach to fish ecology has been developed over the last 10-years, by a small number of leading fish ecologists, and is becoming the leading fish recovery philosophy for river managers, stakeholder groups and the scientific community (http://www.nccma.vic.gov.au/Biodiversity/Conservation_and_Habitat/Native_Fish_Recovery_Plan/index.aspx) (http://murray.lls.nsw.gov.au/our-region/programs-and-projects/billabong-yanco-creek-system-project) (http://www.mdba.gov.au/media/mr/lower-darling-river-flow-advice-menindee-lakes-release-increase)

Methods

‘Restoring large bodied fish populations throughout B-MF, as a case study for fish recovery’

The scientific approach would follow established lines of investigation, after Figure 4.2. Briefly;

- Identify ‘treatment’ Creeks;
  - Treatment 1: two creeks where management intervention can implement perennial flow (e.g. Toupna Creek, Gulpa Creek)
  - Treatment 2: two creeks that can be managed as historically seasonal (e.g. Cutting Creek, Tongalong Creek, Black Engine Creek).
- Establish potential longitudinal increase in habitat area (km’s)
- Work with River Murray operators to ensure perennial flow can be maintained to 2 Creeks and operate 2 as seasonally flowing
- Design hydrographs appropriate to life history models
- Conduct baseline surveys prior to intervention to establish status, distribution and abundance of large bodied fish populations
- Implement perennial flow intervention - Treatment 1 and 2 (Year 2)
- Conduct follow-up surveys to determine colonisation of large bodied fish from the Murray River (Year 2)
- Monitor fish movement in response to Treatment 1 (maintain perennial flow) and Treatment 2 (impose seasonal drawdown). Monitoring requires tracking of acoustically tagged fish captured in creeks throughout intervention (Year 2). Do fish take residency coinciding with Treatment 1; do fish return to Murray River coinciding with Treatment 2?
- Implement both Treatments for 2 ‘flow years’, continue with active surveys to determine redistribution and or improvement in fish population status and distribution (Year 2, Year 3)
- Evaluate residency of populations in relation to fish tracking information, evaluate effect of treatment (Year 2, Year 3)
- Implement fish spawning study within both treatments, establish if perennial treatment becomes self-sustaining (Year 3)
- Expand fish tracking study to examine dispersal (longitudinal and lateral) (Year 3)
- Examine population structure within Treatment 1 and 2 (Year 3), completion of study.

Figure 4.1. (Top): Toupna Creek at Barmah –Millewa Forest, with zero flow in winter but good snag habitat. The low winter flow, or seasonal flow typifies the flow regime for Creek habitats at Barmah-Millewa Forest. Restoration of perennial flow and connectivity in B-MF Creeks would result in restoration of hundreds of kilometres of optimal large bodied native fish habitat. Large bodied fish are presently rare on the B-MF floodplain. Bottom: Gunbower Creek, perennial flows have been restored at Gunbower Creek and likewise, strong Murray cod and other large bodied fish populations are returning.

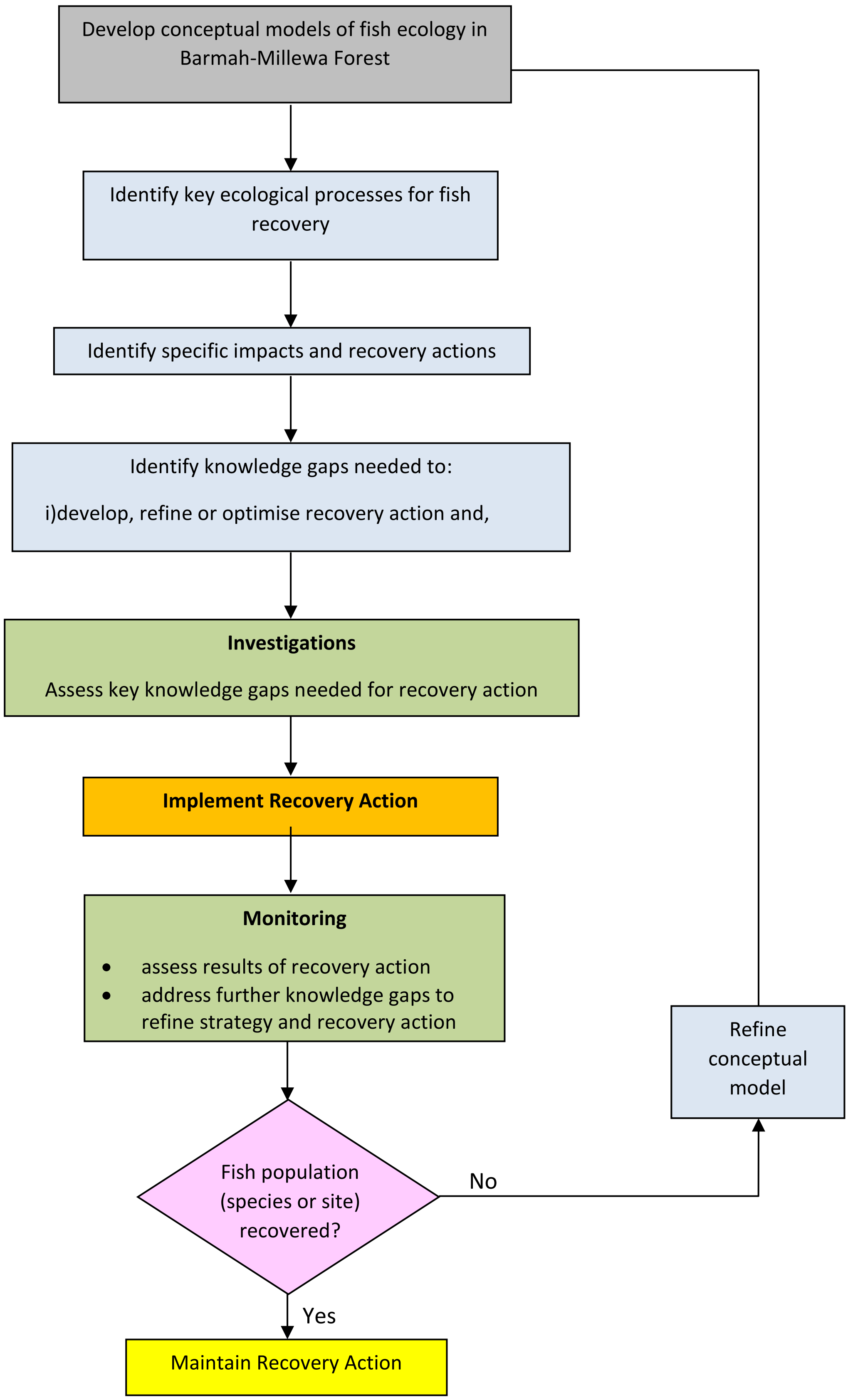

Fig. 4.2. Flow chart for recovery actions.

Following on from the use of conceptual models and the experimental framework outlined above for restoration of large bodied fish populations throughout Creek habitats, a project to restore fish populations in the large floodplain lakes Moira and Barmah may also be explored. The large floodplain lakes at B-MF were historically important habitats for fish including Murray cod, golden perch and silver perch (King 2005; Trueman 2011). Following the approach outlined above (Figure 4.1), we consider that restoration of the Lake habitats as functional nursery grounds for several species can be achieved. Briefly, a loose conceptual and experimental model is provided below:

- Golden perch and to lesser extent silver perch are known to spawn in the Murray River at B-MF but there has been little evidence for local recruitment (Raymond et al. 2014; Koster 2015).
- Golden perch and to lesser extent silver perch recruit strongly in floodplain lakes elsewhere in the MDB and these habitats are thought to be the powerhouses for recruitment of those species, when larvae drift from the main river channel into recently inundated lake habitats (Sharpe 2011; Mallen-Cooper et al. 2014).
- Following the over-winter period, when young fish are ~150-300 days old, re-connection flows facility dispersal from the Lake habitat to riverine habitats. Dispersal throughout the river system occurs (over 1,000's km).
- Carp also recruit strongly in floodplain lakes but exhibit a contrasting recruitment strategy – adults migrate to and spawn in lakes (Stuart and Jones 2006). This behaviour can be exploited to reduce carp recruitment strength, but is not discussed further here.
- Barmah and Moira Lake's may be managed to accommodate strong golden perch and silver perch recruitment – locally.
- The lakes would be dried, and then filled in conjunction with a spring flood pulse in the Murray River, when golden perch and silver perch are predicted to have spawned and their eggs and larvae are present in the main river channel (Year 1).
- The lakes would be filled when eggs/larvae are present in the river, thus providing the larvae with optimal nursery conditions in the floodplain lakes (Year 1 larval monitoring – also examines mortality at regulators).
- Associated real-time monitoring in the river for eggs and larvae of these species would increase precision and confidence in the optimal timing for filling of the lakes (Year 1).
- The lakes are filled and then closed over summer/autumn/winter (Year 1).
- The following spring (Year 2), the lakes are reconnected to the main river channel during a spring flood pulse, when it is predicted that young recruits of golden and silver perch would migrate from the lakes back to the main river channel and disperse. These would disperse to contribute to the regional population, including to B-MF Creek habitats.

A third project has been identified that is required to restore the diversity of native fish in Wetlands at B-MF. This project aims to recover locally rare, and locally extinct small bodied fish species in floodplain wetlands and creeks. The rational and approach for this concept at B-MF is provided by Sharpe and Wilson (2014).

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