A program of initiatives to mitigate the impacts of drought and climate change on native fish communities in the Murray-Darling Basin

Matt Barwick Jim Barrett and Mark Lintermans

Murray-Darling Basin Commission

Canberra, Australia

ABSTRACT

The overarching aim of the Murray-Darling Basin Commission's (MDBC's) Native Fish Strategy is to return native fish populations in the Murray-Darling Basin (MDB) to 60% of pre-European levels by 2050. The Strategy provides a response to the key threats to native fish populations in the MDB, including flow regulation, habitat degradation, lowered water quality, manmade barriers to fish movement, introduction of alien fish species, fisheries exploitation, spread of diseases and translocation and stocking of fish.

Drought and climate change can impact detrimentally on native fish populations through exacerbating a number of the abovementioned threats. Mitigating the impacts of drought and climate change on native fish in the MDB is therefore critical to achieving the aim of the Native Fish Strategy.

This paper describes a number of research projects and activities initiated by the MDBC to better understand, and more effectively mitigate the impacts of drought and climate change on native fish. Information gathered will help mitigate the impacts of current low rainfall conditions experienced in the MDB, and to safeguard against the impacts of subsequent low rainfall events on native fish, to help ensure that the Basin sustains viable fish populations and communities throughout its rivers.

KEYWORDS [drought, Murray-Darling Basin, native fish, climate change, threats]

INTRODUCTION

The Native Fish Strategy was released in 2004, with the intention of bringing communities and governments of the Murray-Darling Basin (MDB) together to enhance native fish populations throughout the Basin over the next 50 years. It is recognized now, that native fish populations in the Basin are at approximately 10% of their condition prior to European settlement (MDBC, 2004), and the Strategy has the overarching aim of rehabilitating native fish populations back to 60% by 2050. This is an optimistic aim, particularly so, given that the Strategy came into being during one of the worst droughts experienced in southeastern Australia since European settlement (Murphy and Timbal, 2007). Mean average rainfall over virtually the entire south east region during 1997 to 2006 was below-average to the lowest rainfall on record (1900-2006) (Murphy and Timbal, 2007), with an observed failure of the 'autumn break' rains – a situation never before recorded in the Murray-Darling Basin (National Water Commission, 2006). Many rivers within the MDB have experienced record low inflows (Figure 1), with mounting evidence indicating that low runoff and rainfall is linked to global warming (MDBC, 2008). Coupled with low rainfall, has been a gradual increase in temperature. Mean temperature for Australia has increased by approximately 1°C since 1900 (Hennessy et al., 2008) and the rate of warming has increased in recent decades (Murphy and Timbal, 2007). The frequency of exceptionally hot years in the MDB has also increased rapidly over recent decades (Hennessy et al., 2008), and this trend is expected to continue. By 2010-2040, the area and frequency of exceptionally hot years are projected to increase to affect about 65% of the MDB, and occur every 1.6 years on average (Hennessy et al., 2008). Low flows, rising temperatures and consequent increasing evaporation rates are already resulting in declining populations and localized extinctions of some native fish species in regions of the MDB (Lintermans and Cottingham, 2007).

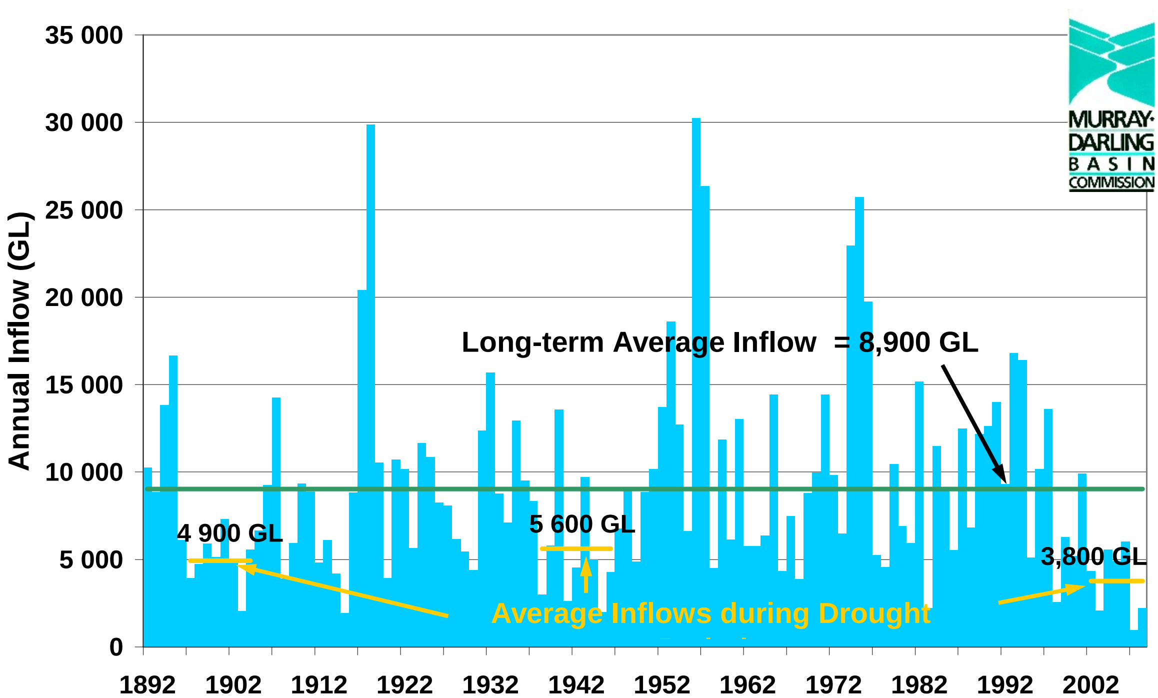

Figure 1. Murray system annual inflows (excluding Darling inflows and Snowy releases) (Source, MDBC 2008)

The Native Fish Strategy has 6 driving actions through which 8 key threats to native fish are addressed (see Table 1). Drought magnifies the impact of each of these threats for native fish. Flows are increasingly regulated to provide for human needs; habitat continues to degrade through declining health of riparian vegetation (MDBC, 2003); habitat complexity is lost as pools recede (Lake, 2008), and through increased sedimentation and loss of wetlands; and water quality declines with increased salinity, acidity, temperature and nutrient and contamination concentration. Barriers such as weirs also become less transparent to fish as they drown out less frequently; fishways become less effective as they become inoperable in low flows; and hydrological cues for movement and spawning may be lost due to flow regulation (Bunn and Arthington, 2002). Altered conditions may also provide opportunities for proliferation of some alien species (Bunn and Arthington, 2002); diseases may become more prevalent due to increased crowding of fish in what poor quality water remains, and increased stress (Lake, 2008); fishing pressure may remain constant at a time when all these other stressors increase on native fish populations, and stocking and translocation continues, or possibly increases, in well-meaning attempts to reverse the impacts of drought on fish stocks (Lintermans and Cottingham, 2007).

Table 1: Key threats to native fish management in the Basin (Source, MDBC 2004)

Threat	Threatening process
Flow regulation	Loss of water to other uses, critical low flows, loss of flow variation, loss of flow seasonality, loss of flow to medium floods, permanent flooding and high water, increased periods of no flow
Habitat degradation	Damage to riparian zones, removal of in-stream habitats, sedimentation
Lowered water quality	Increased nutrients, turbidity, sedimentation, salinity, artificial changes in water temperature, pesticides, and other contaminants
Barriers	Impediments to fish passage resulting from the construction and operation of dams, weirs, levees, culverts, etc., and non-physical barriers such as increased velocities, reduced habitats, water quality and thermal pollution (changes in water temperature)
Alien species	Competition with and/or predation by carp, gambusia, oriental weatherloach, Redfin perch and trout
Exploitation	Recreational fishing pressure on depleted stocks, illegal fishing
Diseases	Outbreak and spread of EHNV (Epizootic Haematopoietic Necrosis Virus) and other viruses, diseases and parasites
Translocation and stocking	The loss of genetic integrity and fitness caused by inappropriate translocation and stocking of native species

Long-term climate trends suggest that the frequency of drought events is likely to increase in the future (Humphries and Baldwin, 2003) with some suggesting that we have experienced a downward step-wise shift in rainfall in the last decade (Fawcett, 2004). Bond et al. (2008) note that presently, most management responses to drought in Australia are reactive, calling for a shift in emphasis in the management of drought, from short-term crisis management, to long-term proactive strategies to minimize the impacts of drought for native fish, including restoration of riverbank zones, maintenance of refuge habits, and provision of flows and fish passage. The MDBC is responding, investing through the Native Fish Strategy and other programs in a range of long-term pragmatic initiatives to aid rehabilitation of native fish. Several of these initiatives are described below, and considered in the context of opportunities and challenges presented by low streamflow associated with drought and/or climate change.

BACKGROUND

Fish out of water – managing fish during drought

As community and government grappled with drought and its impacts in 2007, the need was identified to ensure that critical needs of native fish were considered when providing for human consumption and use. In June 2007 the Commission convened a panel with expertise in biology, ecology and hydrology to provide advice to the MDBC and other federal and state agencies on management of native fish during drought (Lintermans and Cottingham, 2007). The report identifies a number of high priority actions, several of which have been adopted through initiation of research projects described below, and the need for continued long-term monitoring. A number of actions to be avoided are also highlighted.

Demonstration Reaches

Demonstration reaches are sizable (20-100km) portions of a river or riverine system that are degradable but likely to respond positively to a suite of rehabilitation actions applied simultaneously and for a prolonged period. It is recognized that multiple interventions, applied simultaneously, will enhance the likelihood and trajectory of rehabilitation (Figure 2). Such reaches should be visible to and supported by the local community, be rigorously planned under an adaptive management framework, and be properly monitored (Barrett and Ansell 2005). At least 10 demonstration reaches are being established in the Basin through the MDBC (Figure 3).

Habitat Management Areas

Habitat Management Areas are designed to protect remnant areas of high quality fish habitat. Protected areas of high quality habitat are particularly important during drought conditions, as they improve resilience and resistance capacity of native fish following drought (Lake, 2008). The MDBC is looking to develop a network of Habitat Management Areas throughout the MDB, and has commissioned two reports to progress a way forward. The first entitled "*River Parks: Building a system of 'habitat management areas' across the Murray-Darling Basin*" (Phillips and Butcher, 2005) collated existing knowledge on establishment of freshwater protected areas on an international scale, identified potential management options for use in the Murray-Darling Basin, and outlined a strategy for the implementation of a system of HMAs across the Basin. The second report, entitled "*Audit of freshwater protected areas of the Murray-Darling Basin and development of a 'River Parks' toolkit*' (Phillips, 2008) provides an overview of what areas are currently 'protected' in the Basin, and identifies approximately 1,000 existing 'protected areas' across the MDB that could (following further investigation) be suitable for inclusion into a Basin-wide network.

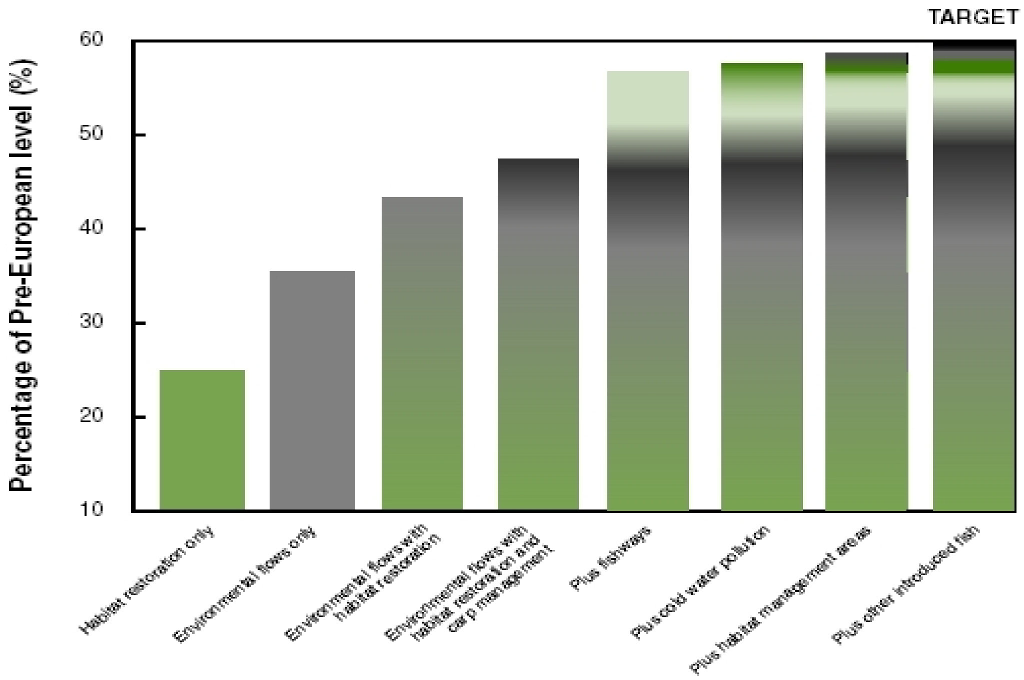

FIGURE 2: cumulative benefits of multiple intervention techniques on native fish recovery (Source, MDBC 2004).

Resnagging

The importance of snags (sometimes called large woody debris or structural woody habitat) to native fish has been become increasingly evident in the last decade. Studies such as those by Nicol et al. (2004) between Yarrawonga and Tocumwal on the Murray River have shown a significant response by species such as Murray cod and the critically endangered Trout cod to the judicious placement of snags back into the river. Research has also demonstrated that reintroduction of timber structures can buffer against drought-induced declines in species such as River blackfish and the vulnerable Southern pygmy perch in sand-slug affected streams (Bond and Lake, 2005). Re-snagging activities are now a relatively common element of river rehabilitation, particularly in the development of demonstration reaches.

Mitigating impacts of cold water pollution

Cold water released from the bottom of large storages can be up to 16 degrees lower than the normal temperatures tolerated by native fish species, resulting in absence of fish and poor recruitment for many kilometres downstream (Boys et al. 2007). This issue will likely increase in prevalence as storages are modified or new ones built, to increase security of water for critical human needs. Fortunately, several engineering solutions have been identified to ameliorate these impacts (Sherman, 2000), and some jurisdictions (e.g. NSW – Keepit and Burrendong Dams) are including these options in major future works programs.

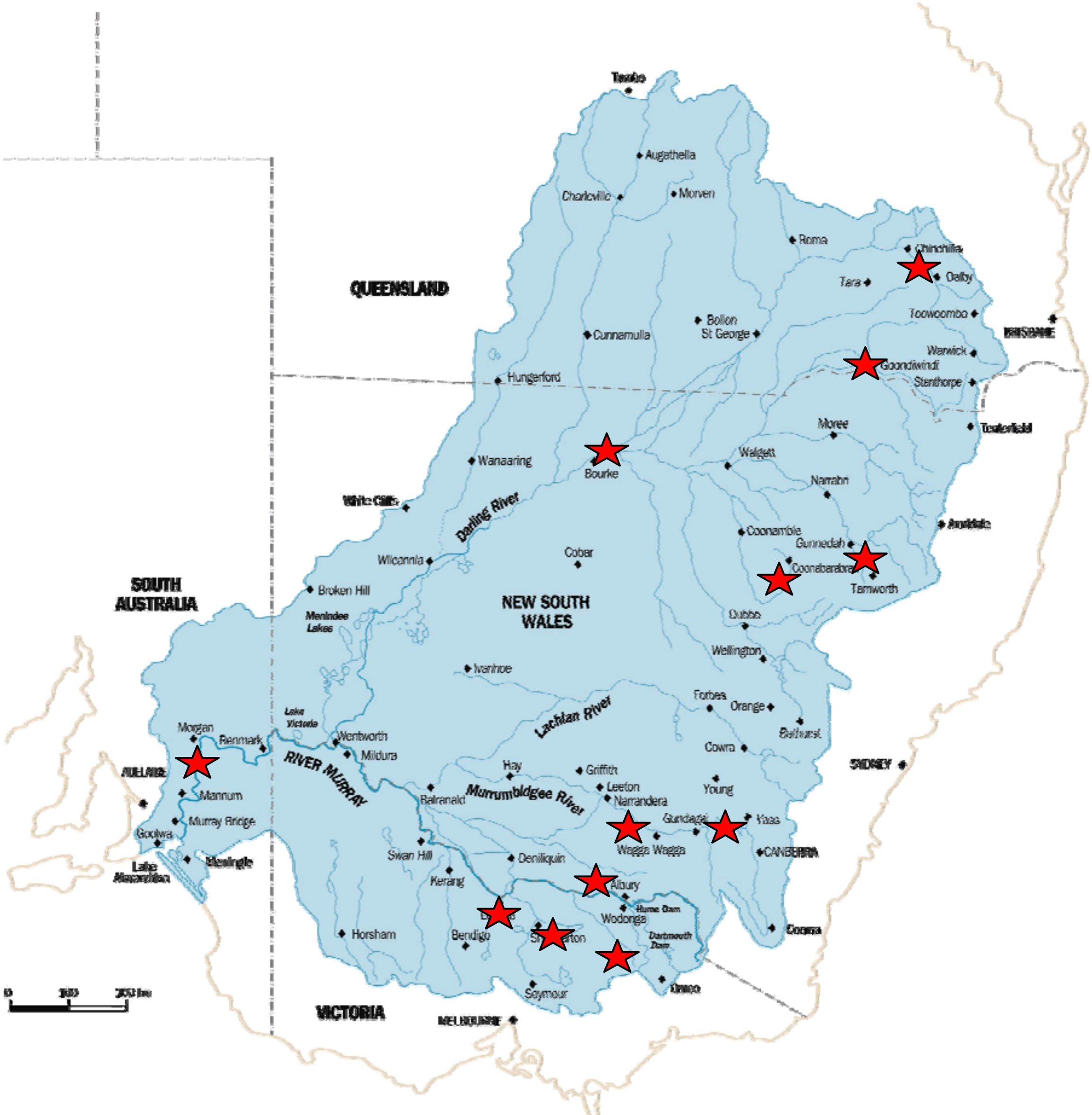

FIGURE 3: Map of demonstration reaches in the MDB

Restoring Fish Passage

The "Sea to Hume Dam" program is one of the largest whole-of-catchment scale rehabilitation activities in the world, seeking to restore fish passage along a 2,255 kilometre stretch of the Murray River, through installation of fishways. The program commenced in 2001 and new fishways have been constructed at Locks 1, 7, 8, 9, 10 and 15, with several prototype fishways also being built at the Barrages (Barrett and Mallen Cooper, 2006). The design criteria for these fishways are unique, in that they are intended to pass the whole fish community (up to 13 species have been recorded using fishways constructed to date), and over the maximum size-range possible (approximately 40mm – 1000mm). Most fishways internationally are designed to provide passage to only larger, recreationally and economically important species. As well as fishways on the main river stem, fishway options are also being explored at a number of Murray River anabranches, including Chowilla, Gunbower forest, Moira Lake, Edwards River and Hattah Lakes. Several of these anabranches are very significant for spawning and recruitment of native fish, and habitat for small-bodied species.

Reducing mortality associated with downstream movement

The need to examine impacts of different weir designs (undershot or overshot) on survival of native fish was identified as recommendation of a workshop funded by the MDBC on downstream movement of fish in the Murray-Darling Basin in 2003 (Lintermans and Phillips, 2003). Recent research undertaken by NSW Department of Primary Industries has highlighted significant mortality among larval native fish travelling downstream through undershot weirs (Baumgartner et al., 2006). Significant mortality rates for key iconic species have been recorded (95% for Golden perch, and 52% for Murray cod). Such mortality rates become even more significant when considering potential for declining spawning/recruitment success in future associated with non-seasonal flow conditions (Bunn and Arthington, 2002). These preliminary results have prompted jurisdictions to consider designs for more fish friendly weirs and regulators and retrospective adjustments to existing structures.

Reducing entrainment of fish into irrigation offtake channels

The need to examine impacts of removing eggs, larval, juvenile and adult native fish from the river population through irrigation and water diversions was identified as a recommendation of a workshop funded by the MDBC on downstream movement of fish in the Murray-Darling Basin in 2003 (Lintermans and Phillips, 2003). Up to 50% of total river flow can be extracted from some river systems for irrigation purposes during periods of high demand (Baumgartner et al., 2007). A project funded by the Commission and undertaken by New South Wales Department of Primary Industries has demonstrated the potential for millions of native fish to be drawn into, and become entrained in, irrigation channels (Baumgartner et al., 2007). These fish are either injured or killed during the pumping or extraction process, or subject to predation, poaching, stress or desiccation as water is drawn down. Those that may survive are unable to contribute to the gene pool of nearby riverine populations. Increased reliance on pumped water for irrigation purposes due to low rainfall, coupled with potential declines in spawning/recruitment success associated with non-seasonal flow conditions (Bunn and Arthington, 2002) is likely to increase the severity of this problem for native fish in the future. To address this threat, the NFS has commissioned research into the trial and implementation of possible mitigation measures.

Increasing survival of stocked threatened fish

Stocking is an important component of the recovery strategies for several threatened native fish species in the MDB. The importance of such activities is likely to increase under drought conditions, with potential for declines in natural spawning/recruitment success associated with non-seasonal flow conditions (Bunn and Arthington, 2002), and potential for loss of populations due to stresses associated with low streamflow. All four species of Australian freshwater cod are nationally threatened and stocking programs have been initiated for them all (Lintermans et al. paper in Lintermans and Phillips 2005). The stocking program for Trout cod (*Maccullochella macquariensis*) has been in operation for 20 years, with more than 1 million fish released across three jurisdictions in the MDB. However, lower observed survival of stocked fish in comparison to wild fish (Ebner et al., 2006) is suspected to be the result of differences in behaviour, including predator avoidance, lower foraging success, and altered social behaviours (Brown & Day 2002).

A study funded by the MDBC and undertaken by QLD Department of Primary Industries is trialing techniques to reduce domestication or behavioural changes among hatchery-reared fish, and measure improvement in survival in the wild. Juvenile Silver perch, Freshwater catfish and Murray cod are being exposed to predators in a controlled environment (Figure 4) for varying time periods, and their behaviour is then compared to a control group which is not exposed to predator training. Preliminary results have suggested that training has a positive effect on some species (Figure 5), with recognition and avoidance by trained fish increasing as training time increases (Hutchison, 2008). It is hoped that the outputs of this project will assist in maximizing the effectiveness of recovery programs for threatened species on cessation of drought conditions.

FIGURE 4: Predator exposure tank. Note mesh screen permeable to fingerlings, but not predators. PVC screen is used to control predator exposure (source, Michael Hutchinson).

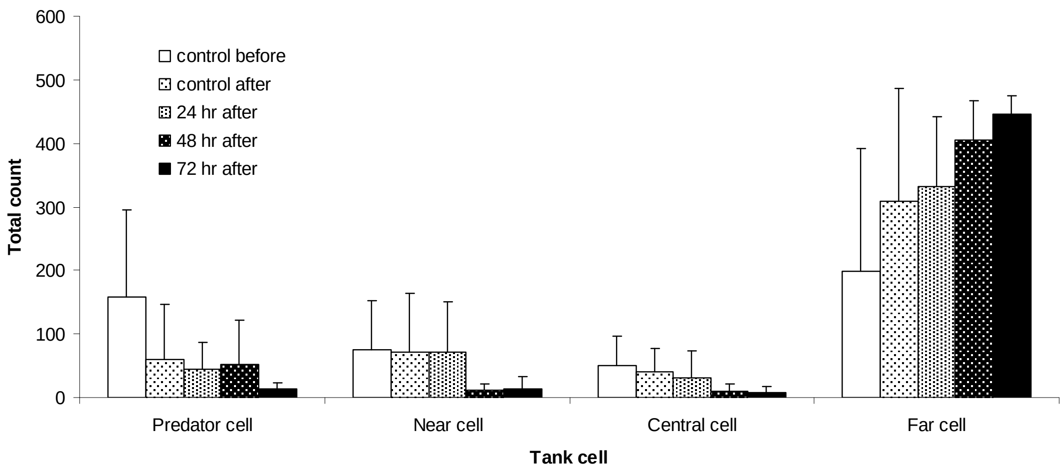

Figure 5: Use of tank cells by groups of eight silver perch before (control only) and after (all treatment groups) introduction of a predator (Murray cod) to the predator cell. Number of replicates is eight. Bars show mean values. Error bars show one standard deviation (Source: Hutchison, 2008)

Developing appropriate management of genetic resources

Drought events have been demonstrated to result in population bottlenecks, with flow-on implications for the evolution of impacted species (Humphries and Baldwin, 2003). Adverse genetic implications may also unintentionally result from emergency rescue operations and captive maintenance programs to prevent loss of populations due to declining water quality and drying of refuge habitat. The need is now more prominent than ever to define Evolutionary Significant Units (ESUs) and Management Units (MUs) (Moritz et al., 1995), to ensure that such activities do not compromise the genetic heritage of native fish populations in the MDB.

Following a MDBC workshop on emergency responses, a project has recently been initiated to define the level of genetic management required to maintain distinct evolutionary significance of native fishes within the Basin. The key outcome of this project will be development of a consistent approach for the genetic management of native fish across the Basin.

Drought refugia management

Australian aquatic flora and fauna exhibit both resistance and resilience traits in adaptation to high prevalence of drought (Bond et al., 2008). Resilience traits enable recolonisation from refugia after drought conditions improve. What constitutes drought refugia for native fish is not currently well understood in the MDB, much less the location of key refuge areas (Lintermans and Cottingham 2007). What *is* known however, is that protection/restoration of refugia is as important, if not more, than restoration of what is termed “residential” habitat (Bond and Lake, 2005).

A new project funded by the MDBC, and undertaken by a consortium of researchers led by the South Australian Research and Development Institute, will develop criteria for the identification of refuge areas in the Basin through broad consultation with experts in various fields. The project team will also work with NRM groups in two pilot valleys containing important refuge habitats (one in the northern MDB, one in the South) to develop management plans to ensure protection of these refugia. These management plans will provide a template for subsequent development of management plans to protect other refugia identified.

Understanding ecosystem resilience

Another new project which will link closely with the drought refugia management project described above, will improve understanding of the resilience and resistance capacity of functional groups of native fish in the MDB to varying degrees of pressure, and potential thresholds levels in refugia. It is intended that outputs of this project will equip decision-makers with knowledge to enable them to manage refugia above critical thresholds.

Native fish hotspots

It is understood that spawning and recruitment of native species, as well as diversity and abundance is not uniform across riverine habitats, and that certain locations contribute disproportionately to the above attributes of native fish communities (King et al. 2007). It is extremely important that these ‘hotspots’ are known and managed accordingly. Particularly so, given potential for declines in spawning/recruitment success associated with non-seasonal flow conditions (Bunn and Arthington, 2002), developments planned to modify riverine and wetland habitats to safeguard water for critical human needs, and to provide watering to other ecosystem components.

A project recently scoped initiated under the NFS will be examining existing information, augmented with field sampling, to identify spawning, recruitment, abundance and diversity hotspots for several key species, and recommend management actions to ensure their protection. The study will be preceded by a pilot study, which will identify information available and needed, and develop an appropriate methodology to achieve project objectives.

Triage

The initiatives described above are intended to provide strategic and long-term assistance to native fish communities to enable them to deal with perturbations, including low-flow events associated with drought and climate change. Whilst this program of initiatives will assist, in the absence of significant rainfall, there is still a pressing need to provide capacity to respond tactically to emergency situations.

The Commission has coordinated the development of an emergency protocol, to enable the partner governments to respond consistently and effectively to emergency situations which may threaten native fish populations. The protocol (soon to be released) identifies triggers and responses to identify and respond to emergency situations.

Emergency Fund

A contingency fund has also been established through the NFS to facilitate rescues/interventions of Basin fish populations under imminent threat as a result of extreme events (drought, bushfire, alien species invasion etc). The MDBC is providing 'seed' funding for the initial response, with jurisdictions co-investing for the medium to longer term activities that follow the initial response. Two such intervention activities have been funded so far, one for maintenance and recovery of the Southern purple-spotted gudgeon population to prevent extinction due to habitat decline, and another to conserve a population of River blackfish in South Australia.

Other MDBC Programs

It is important to highlight that activities undertaken through the NFS are part of a broader, Commission-wide program of activities to understand and address drought and climate change impacts. The Commission has initiated a Climate Change Program, to identify management and research priorities to respond to climate change. The Climate Change Program manages the South Eastern Australian Climate Initiative (SEACI): a three year, $7 million research program investigating the causes and impacts of climate change and variability across south eastern Australia (for more information go to www.mdbc.gov.au/subs/seaci).

The Sustainable Rivers Audit is a critical program designed to evaluate the condition of river systems (including fish populations) at a Basin-scale over time. The SRA will be useful in the long-term to provide an understanding of the impacts of drought or climate change, and in evaluating the effectiveness of management responses (for more information go to www.mdbc.gov.au/SRA).

The Living Murray initiative (TLM) invests strategically in activities which benefit the fish, bird and vegetation communities at six icon sites along the Murray River including the River Murray Channel. TLM aims to recover an average of 500 gigalitres of water per year during 2004-2009. The recovered water will be delivered maximise the ecological benefits to plants, animals and the broader River Murray system. TLM plays also pivotal role in construction of fishways as part of the Sea to Hume project. Monitoring is underway to provide information on the benefits gained from water delivery and other management interventions, such as resnagging and other works. This information enables the adaptive management so that the environmental benefits can be optimised and progress made toward the ecological objectives for the Icon sites. For more information go to http://thelivingmurray.mdbc.gov.au/

The Basin Salinity Management Strategy continues to provide guidance on controlling salinity in the Basin to protect natural resources including fish, and will play an even more important role in the future if low inflows persist (for more information go to www.mdbc.gov.au/salinity).

The Northern Murray-Darling Basin Program (NBP) continues to enhance our understanding of the Darling River and its tributaries. A number of initiatives have been funded through the NPB which provide benefit to fish, including the purchase of water to provide environmental flows to key areas such as Narran Lakes, and identifying barriers to fish passage and exploring opportunities for remediation (for more information go to www.mdbc.gov.au).

Discussion

Challenges and Opportunities

Current record low rainfall and inflow levels are certainly presenting challenges from Natural Resource Management and research perspectives, but also a number of opportunities.

Fishways with design criteria based on historical flow data run the risk of being inoperable over longer durations due to lack of sufficient flows. There is a need to apply innovative thinking to future designs, to maximise fish passage opportunities, whilst minimising water 'loss' through such structures. Conversely, low flows and frequency of flood events provide increased access to structures such as weirs and irrigation offtakes, providing opportunities to construct fishways and cold water pollution mitigation solutions, install fish exclusion screens, and modify weir designs, at relatively low cost.

It may be difficult to maintain motivation for some activities carried out through community driven initiatives such as Demonstration Reaches, whose overall objective (to achieve a positive, long-term increase in the health of the system, including native fish populations) may be constrained by a prolonged drought.

Record low inflows are eliciting highly visible signs of stress within riparian vegetation communities, with implications for success rates of rehabilitation activities. Fish access to rehabilitated habitats (vegetation and snags), which can provide essential refuge to small-bodied fish in drought conditions, may also be limited by low water levels (Lake, 2008). Conversely, low water levels provide greater opportunities, at lower cost for placement, anchoring and retention of snags.

Opportunities for rapid progress in other areas are also being identified, as low water levels offer opportunities for control of alien species due to failed breeding events, increased visibility and/or concentration of aggregations, and reduced opportunities for range extension, or incursion by species not yet in the Basin such as Tilapia. Declining water availability, necessitating the need to manipulate water levels in wetlands, has also exposed key behavioural differences between alien species and natives which will likely assist in their control. As a wetland artificially drains, native fish follow the flow of falling waters back to the river channel, whereas Carp mover further into the wetland, where they eventually become stranded, or are able to be harvested more efficiently (*pers comm. Ben Smith*).

Lessons

A number of important lessons can be derived from current conditions. The need to assist recovery through adaptive management was recognized by the Drought Expert Panel (Lintermans and Cottingham, 2007). There is value in setting long-term strategic research priorities, in addition to providing adequate flexibility to enable tactical response to newly emerging issues. Flexibility in research and its management is required, as lack of water or uncharacteristic conditions may necessitate modification of timelines. The drought and potential for future increase in climate change and variability has also reinforced the need to work and invest collaboratively to achieve outcomes of common interest.

At this time, a number of significant activities are being contemplated in efforts to safeguard human requirements (e.g. new dams and weirs) with potential for negative impacts on aquatic ecosystems. The challenge is to learn from history to inform future trade-off decisions. This is particularly important under low inflow conditions.

Community involvement and support will continue to be essential. In a period that is testing our ability to provide for critical human needs more than ever before, the importance of preserving conditions necessary for survival of native fish is unlikely to be supported by the public on conservation values alone. We are challenged with the need to demonstrate the importance of safeguarding the ecosystem services provided to our communities by freshwater aquatic ecosystems in the MDB.

A final lesson, and message which needs to be conveyed to the broader community, is that even under optimal conditions, recovery will take time. Recovery will vary between functional groups (Lintermans and Cottingham 2007), in accordance with the various survival/recolonisation strategies employed (Humphries and Baldwin, 2003), and it will take some time for balance to be restored at an ecosystem scale. Lake (2006) suggests that recovery time is proportional to drought duration, and it is likely that synergistic impacts of anthropogenic influences such as barriers to passage, and diversion of water (and, inadvertently, fish) for irrigation will likely further extend the time required for native fish populations to recover. Being a long-term 50 year initiative, the Native Fish Strategy will be critical, both to guide and coordinate restorative activities over that time, and to communicate progress.

References

Barrett, J and Ansell, D (2005). Demonstration reaches for native fish: moving from theory to practice. In I. D. Rutherford, I. Wiszniewski, M.J. Askey-Doran & R. Glazik (Eds.) *Proceedings of the 4th Australasian Stream Management Conference: linking rivers to landscapes*. (pp. 59-67). Department of Primary Industries, Water and Environment, Hobart, Tasmania.

Barrett, J and Mallen Cooper, M (2006). The Murray River's 'Sea to Hume Dam' fish passage program: progress to date and lessons learned. *Ecological Management and Restoration, 7*, 173-183.

Baumgartner, L.J. Reynoldson, N. and Gilligan, D.M. (2006) Mortality of larval Murray cod (Maccullochalla peelii peelii) and golden perch (Macquaria ambigua) associated with passage through two types of low-head weirs. *Marine and freshwater research*, 57: 187-191.

Baumgartner, L. Reynoldson, N. Cameron, L. and Stanger, J. (2007) The effects of selected irrigation practices on fish of the Murray-Darling Basin. NSW Department of Primary Industries Narrandera Fisheries Centre, NSW

Bond, N.R., Lake, P.S. (2005). Ecological restoration and large-scale ecological disturbance: the effects of drought on the response by fish to a habitat restoration experiment. *Restoration Ecology* Vol. 13, No. 1, pp. 39-48.

Bond, N.R., Lake, P.S. and Arthington, A. H. (2008). The impacts of drought on freshwater ecosystems: an Australian perspective. Hydrobiologica 600: 3-16.

Boys, C.A. Miles, N. & Rayner, T. (2007). Scoping options for assessing the impact of cold water pollution mitigation on the fish assemblage downstream of Keepit Dam, Namoi River. NSW Department of Primary Industries Port Stephens Fisheries Centre, NSW

Brown, C. and Day, R.L. 2002. The future for stock enhancements: lessons for hatchery practice from conservation biology. Fish and Fisheries 3: 79-94.

Bunn, S.E. and A.H. Arthington, 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.

Ebner B., Thiem J. and Lintermans M. (eds)(2006.) An ecological approach to re-establishing Australian freshwater cod populations: an application to Trout Cod in the Murrumbidgee catchment. Final Report to Fisheries Research & Development Corporation. Wildlife Research and Monitoring, Environment ACT.

Fawcett R. (2004) A long-term trend in Melbourne rainfall? *Bulletin of the Australian meteorological and oceanographic society* 17: 122-126.

Humphries, P. and Baldwin, D.S. (2003). Drought and aquatic ecosystems: an introduction. *Freshwater biology* 1141-1146.

Hutchison, M. (2008). *Improved methodology for introducing threatened hatchery reared fishes*. Unpublished data

King, A., Tonkin, Z. and Mahoney, J. (2007). Assessing the effectiveness of environmental flows on fish recruitment in Barmah-Millewa Forest. Arthur Rylah

Institute for Environmental Research. Report to the Murray-Darling Basin Commission.

Lake, P.S. (2008) Drought, the “Creeping Disaster”. Effects on Aquatic Ecosystems. Land and Water Australia, Canberra.

Lintermans, M. (2003). The use of local translocations and re-introductions in the conservation management of threatened freshwater fish In Managing Fish Translocation and Stocking in the Murray-Darling Basin workshop, Canberra.

Lintermans, M. and Cottingham, P. (eds) 2007. Fish out of water – lessons for managing native fish during drought. Final Report of the Drought Expert Panel. Murray-Darling Basin Commission, Canberra.

Lintermans, M. and Phillips, B (eds) 2003. *Downstream movement of fish in the Murray-Darling Basin – workshop held in Canberra, 3-4 June 2003: Statement, recommendations and supporting papers*. Murray-Darling Basin Commission, Canberra.

Lintermans, M. and Phillips, B. (eds) 2005. *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers*. Proceedings of a workshop held in Canberra ACT, 3-4 June 2004. Murray-Darling Basin Commission, Canberra.

MDBC, 2003. Preliminary investigations into observed River Red Gum decline along the River Murray below Euston. Murray-Darling Basin Commission, Canberra.

MDBC (2004) *Native Fish Strategy for the Murray-Darling Basin 2003-2013*. Murray-Darling Basin Commision.

MDBC (2008). River Murray system – Drought update No. 13 May 2008. Murray-Darling Basin Commission, Canberra.

Murphy, B.F. & B. Timbal, 2007. A review of current climate variability and climate change in southeastern Australia. International journal of Climatology. Doi:10.1002/joc.1627.

National Water Commission (2006). *Australia’s water supply status and seasonal outlook.* National Water Commission: Canberra, ACT; 17 October 2006.

Nicol, S.J Lieschke, J.A. Lyon, J.P. and Hughes, V. (2004) Restoring structural woody habitat *in* workshop: *the River Murray in Native Fish Habitat Rehabilitation and management in the Murray-Darling Basin, Albury*.

Phillips, B. (2008) Audit of freshwater protected areas of the Murray-Darling Basin and development of a Habitat Management Areas ‘toolkit’. Murray-Darling Basin Commission Report.

Phillips, B. and Butcher, R. (2005). River Parks: building a system of “Habitat Management Areas” across the Murray-Darling. An international and national review of freshwater ‘protected areas’ for conserving aquatic biodiversity and river health. Murray-Darling Basin Commission Report.

Sherman, B. (2000) *Scoping Options for Mitigating Cold Water Discharges from Dams*. CSIRO Land and Water, Canberra.