TROUT COD

MACCULLOCHELLA MACQUARIENSIS

ACTION PLAN

Trout Cod *(Maccullochella macquariensis).* **Photo: E. Beaton, ACT Government**

PREAMBLE

Trout Cod *(Maccullochella macquariensis*) was listed as an endangered species on 6 January 1997 (initially Instrument No. 1 of 1997 and currently Instrument No. 265 of 2016). Under section 101 of the *Nature Conservation Act 2014*, the Conservator of Flora and Fauna is responsible for preparing, where required, a draft action plan for a relevant listed species. The first action plan for this species was prepared in 1999 (ACT Government 1999). The species was included in Action Plan 29 Aquatic Species and Riparian Zone Conservation Strategy (ACT Government 2007). This revised edition supersedes earlier editions.

Measures proposed in this action plan complement those proposed in the Aquatic and Riparian Conservation Strategy and component threatened species action plans such as the Macquarie Perch (*Macquaria australasica*), Silver Perch (*Bidyanus bidyanus*), Two-spined Blackfish (*Gadopsis bispinosus*) and Murray River Crayfish (*Euastacus armatus*).

CONSERVATION STATUS

Maccullochella macquariensis is listed as a threatened species in the following sources:

International: IUCN

Endangered C2a ver 2.3 (needs updating).

National

Endangered – *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth).
Critically Endangered – Australian Society for Fish Biology (Lintermans 2015).

Australian Capital Territory

Endangered – Section 91 of the *Nature Conservation Act 2014*.

Special Protection Status Species – Section 109 of the *Nature Conservation Act 2014*.

New South Wales

Endangered – *Fisheries Management Act 1994*.

Victoria

Threatened – *Flora and Fauna Guarantee Act 1988* (with an advisory status of Critically Endangered: Victorian Department of Sustainability and Environment 2013).

South Australia

Extinct – Action Plan for South Australian Freshwater Fishes (Hammer et al*.* 2009).

SPECIES DESCRIPTION AND ECOLOGY

Description

Maccullochella macquariensis is a member of the Family Percichthyidae, which contains the Australian freshwater basses and cods. *M. macquariensis*, along with three closely related freshwater 'cod' species in the genus *Maccullochella* (Eastern Freshwater Cod *M. ikei*, Mary River Cod *M. mariensis* and Murray Cod *M. peelii*), are all listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999*. *M. macquariensis* is a large, deep-bodied fish that has been recorded to 850 millimetres (mm) in total length and 16 kilograms (kg), but is now usually less than 5 kg (Lintermans 2007). It has a large mouth reaching to below the back of the eye, the head profile is straight and the upper jaw overhangs the lower. The tail is rounded and the pelvic fins are located below the pectorals. The species is not sexually dimorphic. The species was formally recognised as a separate species from Murray Cod in 1972 (Berra and Weatherley 1972) and is still often confused with this species. Hybrids between the two species are also known. The overhanging upper jaw and a speckled body pattern which is blue-grey, rather than yellow-green, distinguishes *M. macquariensis* from the otherwise similarly-shaped Murray Cod. Most individuals have a dark stripe through the eye, although this feature is also present in young Murray Cod (Lintermans 2007) (Figure 1).

Figure 1 *Maccullochella macquariensis*. Illustration: curtesy of NSW Government.

Distribution and abundance

M. macquariensis is endemic to the southern Murray–Darling river system. This species has suffered major declines in range and abundance with only a single 'natural' remnant population remaining (the Murray River between Yarrawonga and Barmah) (Koehn et al*.* 2013). Other populations have been re-established either through historic translocation (1920s) or through the national recovery program beginning in the late 1980s in Victoria, the Australian Capital Territory and New South Wales (Douglas et al*.* 1994, Koehn et al*.* 2013). Historically, the species was also recorded in the lower Murray River in South Australia.

M. macquariensis is broadly found in rivers and larger streams and rarely in smaller creeks. It has previously been stated that *M. macquariensis* was a species of cooler, upland reaches of the Murray–Darling Basin, but the sole remnant population occurs in the mid-Murray below Yarrawonga, which is not a river that is considered cool or upland. Similarly, surveys in the 1940s and 1950s recorded the species as widespread in the Murray River between Echuca and Yarrawonga, but less plentiful in the Murrumbidgee (Cadwallader 1977).

In the Canberra region *M. macquariensis* formerly occurred along the length of the Murrumbidgee River in the ACT and in adjoining reaches in NSW (downstream to Lake Burrinjuck and beyond, upstream to above Cooma) where it was recorded up until the 1970s (Berra 1974, Greenham 1981, Lintermans 2000, 2002, Gilligan 2005, Koehn et al. 2013, Trueman 2012). Greenham (1981) surveyed several experienced ACT anglers who reported *M. macquariensis* were not considered to be present in the Queanbeyan, Molonglo, Cotter, Naas/Gudgenby or Paddys rivers, but were present in the Murrumbidgee River and more abundant in the reach from the Molonglo confluence to Tharwa. Its abundance in these reaches was never considered common and became rarer after the 1950s (Greenham 1981).

The most recent naturally occurring population recorded in the ACT (and in fact the entire catchment) was near the Gigerline Gorge upstream of Tharwa, where a population persisted until the mid to late 1970s (Berra 1974, Lintermans et al*.* 1988), but there are Australian Museum records of individuals from Angle Crossing and Casuarina Sands in 1970. In the ACT, *M. macquariensis* is currently restricted to the Murrumbidgee and Cotter rivers, where it has been reintroduced as part of a national recovery program (Koehn et al*.* 2013). In the Murrumbidgee River in the ACT, scattered individuals are occasionally captured in government fish monitoring and by recreational anglers throughout the Murrumbidgee, particularly near Kambah Pool and Gigerline Gorge downstream of Angle Crossing, both of which are reintroduction sites in the ACT. Similarly, in the Cotter River, individuals are regularly recorded in Bendora Reservoir (a restocking site) and occasional individuals are sampled downstream of Bendora Dam, presumably of fish displaced out of the reservoir

(Lintermans 1995, ACT Government and University of Canberra unpublished data).

Conservation stocking

A total of 99,500 hatchery-bred fingerlings were released in the ACT from 1996 to 2005 (ACT Government 2007). Prior to this, hatchery-bred fingerling were also stocked into Bendora Reservoir (1989–1990, 8740 fish) in an attempt to establish a refuge population not subject to angling pressure. Stocking ceased at Angle Crossing in 2005 to facilitate easier recognition of potential natural recruitment and the stocking site was moved downstream to Kambah Pool where 44,000 fish were released between 2005 and 2007. Since 2008 no release of hatchery-bred *M. macquariensis* has occurred in the ACT.

In the broader Canberra region, *M. macquariensis* has been restocked by NSW Fisheries into locations on the Murrumbidgee River including:

- near Cooma (2 sites, 7 releases,1988–2005)
- near Adaminaby (1 site, 4 releases, 1992–95)
- near Michelago (1 site, 2 releases, 2005–08)
- below the ACT (2 sites, 5 releases, 2005–08).

Stocking has also been conducted in Talbingo Reservoir on the Tumut River (four releases, 1990–2015) (Koehn et al*.* 2013), in the Lower Murrumbidgee and in other rivers in the Murray–Darling Basin (e.g. Ovens River and Macquarie River) under the National Recovery Plan (Trout Cod Recovery Team 2008).

The national recovery plan for *M. macquariensis* was the first national recovery plan for a freshwater fish in Australia, with recovery efforts now spanning almost 30 years (Koehn et al*.* 2013).

Habitat and ecology

M. macquariensis is essentially a riverine species, although some lacustrine-stocked populations exist (Bendora and Talbingo reservoirs and historically in Lake Sambell). In lowland rivers the species has a preference for in-stream structural woody habitat (Growns et al*.* 2004, Nicol et al*.* 2004, 2007, Ebner and Thiem 2009, Koehn and Nicol 2014). They also have a preference for deeper habitats (greater than 2.4 metres) and slower water surface velocities, but *M. macquariensis* use slightly faster water velocities than Murray Cod, Golden Perch or Carp (Koehn and Nicol 2014). In the lower Murrumbidgee River adults occupy small areas of less than 500 metres centred on a 'home snag' and demonstrate site fidelity with limited movement. However, individuals can also occasionally undertake exploratory movements of 20–70 kilometres involving a return to their home site (Ebner and Thiem 2009). In a study in the mid-Murray region, 75% of tagged adults moved less than 25 metres over the four-year study period (Koehn and Nicol 2014). Fish are most active during low light (dusk to dawn) (Thiem et al*.* 2008).

M. macquariensis is a large-bodied carnivore that, as an adult, is a 'sit-and-wait' predator (Lintermans 2007). The diet includes fish, yabbies, aquatic insect larvae, shrimps, freshwater prawns and terrestrial organisms. A study based in the Murrumbidgee River found that *M. macquariensis'* diet comprised smaller items than that of Murray Cod, and was more similar to the diet of Golden Perch than Murray Cod (Baumgartner 2007).

M. macquariensis is thought to have a maximum lifespan of 20–25 years although very few individuals older than 12 years have been confirmed (Todd et al*.* 2004). Sexual maturity is reached at 3–5 years of age, with males thought to mature earlier and at a smaller size than females (Douglas et al*.* 1994). Mature females have been recorded at 330 mm Total Length (TL) and males at 315 mm TL, with spawning occurring in spring at a water temperature of around 15°C (Ingram and Rimmer 1993, Koehn and Harrington 2006). *M. macquariensis* spawn demersal and adhesive eggs (2.5–3.6 mm in diameter) onto a hard surface (based on hatchery observations) and, like other *Maccullochella* species (Murray Cod, Eastern

Freshwater Cod), it is assumed that there is parental care of the eggs. Between 1138 and 11,338 eggs have been stripped from females of 330–645 mm TL. Hatching commences approximately five days after fertilisation and continues for up to 10 days at 15.5–23°C. *M. macquariensis* spawning occurs at a similar time to that of Murray Cod but *M. macquariensis* larvae have only been collected in the drift in November, suggesting a shorter spawning period than Murray Cod (Douglas et al. 1994, Koehn and Harrington 2006).

CURRENT MANAGEMENT ACTIONS AND RESEARCH

The ACT has been an active partner in implementing the National Recovery Plan for *M. macquariensis* (Trout Cod Recovery Team 2008), with activities included in this plan outlined below.

Stocking

Stocking for conservation purposes was conducted in the ACT between 1989 and 2007 (see section on Conservation Stocking, above).

Fishing closures

Regulations prohibiting the take of *M. macquariensis* by anglers have been in place since the species was listed as threatened in 1997 (ACT Government 1999). Spatial fishing closures that protect the species from recreational take have also been implemented. To protect a range of threatened fish species, including the stocked population of *M. macquariensis* in Bendora Reservoir, fishing has been banned since August 1986 in the Cotter Catchment upstream of Bendora Dam in Namadgi National Park. This closure to fishing in Bendora Reservoir was a key factor in its selection as a refuge stocking site in 1989 (Lintermans 1995). In 2000, the reach of the Murrumbidgee River between Angle Crossing and the Gudgenby River confluence was also closed to recreational fishing to provide a safe haven for stocked *M. macquariensis* to establish.

The prohibition on take of Murray Cod during their breeding season, September to November (inclusive), under the *Fisheries Act 2000* is assumed to also provide some protection for *M. macquariensis*.

Habitat rehabilitation

Many sections of the Murrumbidgee River through the ACT are affected by accumulations of sand ('sand slugs') which cause reduced water depth and structural habitat diversity. Since 1998, strategies to rehabilitate fish habitat (create scour pools) and improve fish passage through the sand slug downstream of Tharwa have been under way with a series of rock groynes built in 2001 and, subsequently, two engineered log jams in 2013 (Lintermans 2004b, ACT Government 2013). Such works are intended to link fish habitat in good condition downstream of Point Hut Crossing with similarly good habitat in the Gigerline Gorge. The works at Tharwa have resulted in scour pools with increased depth and monitoring has shown that threatened fish species, including *M. macquariensis*, are now using the area.

Monitoring

Monitoring of all ACT populations of *M. macquariensis* has occurred since the early 1990s by the ACT Government (e.g. Lintermans 1995, ACT Government unpublished data) with supplementary information on the Bendora Reservoir population collected by the University of Canberra (Broadhurst et al. 2016, Lintermans et al. 2013). There is evidence of sporadic natural recruitment in Bendora on at least three occasions since the early 2000s (Lintermans unpublished data) but no reliable evidence of wild recruitment in riverine populations in the upper Murrumbidgee River (see discussion of hybridisation in Local Threats). A database for all ACT fish records has been established by the ACT Government.

Other research conducted in the 2000s includes the movement ecology of *M. macquariensis* in the Murrumbidgee River (Ebner and Thiem 2009, Ebner et al. 2007b) and Cotter River (Ebner et al. 2005, 2009) and the impacts of native predators on hatchery-reared adults released to the wild (Ebner et al. 2007a, 2009). A recent PhD study at the University of Canberra directed primarily at Murray Cod spawning ecology has also collected important information on *M. macquariensis* hybridisation with Murray Cod (Couch et al. 2016)

Cross-border management

The Upper Murrumbidgee Demonstration Reach (UMDR) commenced in 2009 as an initiative under the Murray–Darling Basin Native Fish Strategy and involves a partnership of government, university and community groups (ACT Government 2010). The UMDR is approximately 100 kilometres in length, stretching from the rural township of Bredbo in south-east NSW downstream to Casuarina Sands in the ACT. The vision of the UMDR is ‘a healthier, more resilient and sustainable river reach and corridor that is appreciated and enjoyed by all communities of the national capital region’.

The UMDR initiative has so far completed a number of documents including an implementation plan, community engagement plan, Carp management plan, monitoring literature review and monitoring strategy, an assessment of fishways in the ACT, study on the effectiveness of the Casuarina Sands fishway, revegetation and weed control, assessment of the sampling methodology for Murray Crayfish and the Tharwa Fish Habitat Project (see below), and successfully worked across the ACT–NSW border to implement its aims. Improvement of upper Murrumbidgee River habitat will benefit the native fish community, including *M. macquariensis*.

THREATS

Freshwater fish and their habitats are threatened globally, with many concurrent and overlapping threats operating across many countries and locations (Malmqvist and Rundle 2002, Dudgeon et al. 2006, Lintermans 2013a). The major threats affecting native fish are habitat destruction or modification, river regulation, barriers to fish passage, overfishing, alien fish species, and climate change. These threats are considered to have potential impacts on populations of *M. macquariensis* nationally and locally. In addition there is a specific local threat to *M. macquariensis* in the Canberra region with the risk to reintroduction efforts through hybridisation between Trout Cod and Murray Cod.

Habitat modification

Alteration or destruction of fish habitat is widely regarded as one of the most important causes of native fish decline in Australia (MDBC 2004, Lintermans 2013a) and overseas (Dudgeon et al. 2006).

Locally, *M. macquariensis* habitats have been impacted by sedimentation of streams (e.g. the Tharwa sand slug), cold water pollution (downstream of Bendora Dam) and riparian degradation (clearing for pine forests in the Cotter River Catchment, fire, Blackberry and Willow invasion along most rivers, and clearing of the Murrumbidgee riparian zone). Further information is provided in Appendix 1.

River regulation

In the Canberra region, Tantangara Dam reduces flows downstream by 99%, with water from the upper Murrumbidgee River diverted to Lake Eucumbene in the Snowy River Catchment (Anon. 1997). At the Mt Macdonald gauging station (near the confluence of the Cotter River), flow in the Murrumbidgee River has recovered to approximately 73% of natural flow (ACT Government 2004). Flow diversion infrastructure such as the Murrumbidgee River to Googong Reservoir (M2G) pipeline and pumping station at Angle Crossing and the Cotter Pumping Station at Casuarina Sands also affect riverine flows by diverting flow out of the Murrumbidgee River for domestic water supply.

Reduced flows downstream of dams also contribute to reduced fish passage when natural barriers (rock bars, small cascades) that would normally drown-out under natural flows cease to do so. Lake Burley Griffin and Googong Reservoir on the Molonglo–Queanbeyan River system reduce seasonal flows in the lower Molonglo River and adjacent Murrumbidgee, reducing the dilution of effluent discharge from the Lower Molonglo Water Quality Control Centre (LMWQCC). The average daily discharge of treated effluent from the LMWQCC is 90 megalitres/day or 33 gigaliters/year, with this effluent comprising approximately 30–40% of flow in the Murrumbidgee River at Mt Macdonald on average, but up to 90% of flow in dry years (e.g. 1998 and 2003) (Consulting Environmental Engineers 2005). Reservoirs, such as Lake Burley Griffin and Googong, provide large areas of non-flowing habitat and favour the establishment and proliferation of alien fish species such as Carp, Goldfish, Redfin Perch and Gambusia. Further information is provided in Appendix 1.

Barriers to fish passage

In the Canberra region there are a series of barriers that potentially block fish movements on a number of rivers including the Murrumbidgee (Tantangara, Point Hut Crossing, Casuarina Sands weir), Cotter River (3 dams and several road crossings) and Paddys River (weirs at the lower Cotter). Some of these barriers have had fishways installed (Vanitys Crossing, Casuarina Sands weir, Cotter Reserve weir, Pipeline Road Crossing) but maintenance and/or modifications are periodically required to optimise their usefulness. The isolation of fish habitats and fragmentation of fish populations caused by such barriers makes populations more vulnerable to random extinction events. The effluent discharge from LMWQCC is also thought to provide a chemical barrier that reduces movement of some fish species from the Murrumbidgee River into the Molonglo River (Lintermans 2004a).

Barriers can act synergistically with other threats by preventing recolonisation of streams after local declines or extinctions. For example, the collapse of tailings dumps at Captains Flat in 1939 and 1942 effectively sterilised the river downstream, and the presence of Scrivener Dam has prevented any recolonisation by native fish species from the Murrumbidgee River. For further information see Appendix 1.

Overfishing

Overfishing is cited as one of the contributing factors in the decline of *M. macquariensis* (Berra 1974) and has been shown to be important in the decline of other native fish species such as Murray Cod (*M. peelii*) (Rowland 1989). *M. macquariensis* was subject to heavy angling pressure directed primarily at Murray Cod (Berra 1974, Trueman 2012). Because of the confusion over taxonomic status and the limited ability of anglers to distinguish between the two cod species, anglers almost certainly took many *M. macquariensis*. In the Canberra region it was reported to provide good sport (Berra 1974), with anglers commenting on the reliability of being able to catch 'cod' in the 1950s prior to the widespread availability of refrigeration in rural areas (Greenham 1981). Greenham (1981) reported that ACT anglers perceived major declines in native recreational fisheries in the mid to late 1960s, particularly in the Murrumbidgee River, as a result of its popularity as a fishing location. Although the species can no longer be legally retained in the ACT or NSW, *M. macquariensis* can be difficult to release alive after accidental hooking when bait fishing, and some fish are still being caught and retained through ignorance or mistaken species identity (Lintermans unpublished data).

Sedimentation

Sediment addition to the Murrumbidgee River has likely resulted in significant decline of habitat quantity and quality for *M. macquariensis.* Sediment in streams may derive from point sources (e.g. roads, stock access points, construction activities), broad-scale land use or as a result of extreme events such as fires, floods and rabbit plagues. High levels of suspended solids in streams may be lethal to fish and their eggs but the major damage is to aquatic habitat. Sediment fills pools (important refuges for larger native species), decreases substrate variation and reduces usable habitat areas. Clogging of the substratum removes spaces between rocks used as rearing, refuge and habitat areas by juvenile fish, small species and stream invertebrates which are the primary food of juvenile *M. macquariensis* (Lintermans 2013a). Addition of sediments to rivers is particularly detrimental to fish such as *M. macquariensis* that lay adhesive eggs on the substrate, as sediment may smother the eggs and prevent their attachment. Increased sedimentation is also known to be damaging to benthic macroinvertebrate communities, which form a significant part of the diet of *M. macquariensis* (Baumgartner 2007).

Poor land management practices in the mid to late 1800s in the upper catchment resulted in extensive erosion and sediment addition to the river (Starr 1995, Olley 1997). Wasson (page 38 in Starr et al*.* 1997) estimated that sediment yield in the Southern Tablelands increased from 10 tonnes/km^2 prior to European settlement to around 1000 tonnes/km^2 by 1900 before declining again to their present value of 20 tonnes/km^2. Tantangara Dam has reduced the frequency of winter flooding and increased the occurrence of low flows (<1000 megalitres/day) in winter (Pendlebury 1997). This has probably led to the continued accumulation of sediments in the river as there are now fewer and smaller high-flow events that previously would have scoured the finer sediments out of the riverbed (Pendlebury 1997).

More recent sources of sediment addition have been from urban development immediately adjacent to the Murrumbidgee River in Tuggeranong in the 1980s and the Canberra fires of 2003 (Starr 2003, Wasson et al*.* 2003).

Reduction in water quality

The major reductions in water quality most likely to have affected the species in the Canberra region are sediment addition (see above), pollutant discharges to streams and changes to thermal regimes, either from the operation of impoundments or the clearing of riparian vegetation which shades streams. Point source (e.g. such as discharges from industries and sewerage works) or diffuse (e.g. agricultural chemicals) input of pollutants can also have significant impacts. Some pollutants disrupt aquatic ecosystems by mimicking naturally occurring hormones (endocrine disruptors), and so affecting sexual development and function and reproductive behaviour (Mills and Chichester 2005, Söffker and Tyler 2012). Locally, pharmaceutical products and oestrogenic activity has been documented in the discharge from LMWQCC (Roberts et al*.* 2015, 2016), although the impacts on local aquatic species are as yet unknown. Endocrine disruptors have been found up to 4 km downstream of the LMWQCC and may extend further (Roberts et al*.* 2015). Disjunct fish distributions above and below the LMWQCC have been known for many years, but the basis for this remains unknown (Lintermans 2004a).

Water releases from lower levels of thermally stratified impoundments are usually characterised by low dissolved oxygen levels and lowered water temperature, which can depress downstream temperatures in warmer months, increase downstream temperatures in winter, delay seasonal maximum temperatures by months and reduce diurnal temperature variability (Rutherford et al*.* 2009, Lugg and Copeland 2014). In Australia, cold water pollution has been reported as impacting river temperatures for hundreds of kilometres downstream of large dams (Lugg and Copeland 2014). In the Cotter River, altered thermal regimes were predicted for 20 km downstream of Bendora Dam (86 megalitres/day)

(Rutherford et al*.* 2009).

M. macquariensis are possibly impacted by cold water releases from Corin Dam and also Bendora Reservoir. Lowered water temperatures can delay egg hatching and insect emergence, and retard fish growth rates and swimming speeds (increasing predation risk) (Starrs et al*.* 2011, Hall 2005). Reduced growth rates mean that small fish will remain for a longer time-period in the size-class susceptible to predation, thus exacerbating the impacts of alien predators. Lowered water temperature also can disrupt reproductive behaviour, with many Australian fish cued by water temperature.

Other reductions in water quality likely to have had major effects in the ACT and region are the addition of sediment (see above) and the catastrophic pollution of the Molonglo River following the collapse of tailings dumps at the Captains Flat mine in 1939 and 1942. These collapses released large quantities of heavy metals including zinc, copper and lead, which virtually removed the entire fish population in the Molonglo River (Joint Government Technical Committee on Mine Waste Pollution of the Molonglo River 1974).

Introduction of alien species

Locally, *M. macquariensis* has had its distribution invaded by a range of alien fish species including trout, Carp (*Cyprinus carpio*), Goldfish (*Carassius auratus*), Redfin Perch (*Perca fluviatilis*), Eastern Gambusia (*Gambusia holbrooki*) and Oriental Weatherloach (*Misgurnus anguillicaudatus*).

The main interactions between alien species and *M. macquarienis* are likely to be via competition, predation, disease and parasite introduction. Introduced fish species such as Carp, Goldfish, Redfin Perch, Oriental Weatherloach and trout are likely have dietary overlap with *M. macquariensis* and trout likely preyed upon them historically.

A major impact of alien species on native fish is the introduction or spread of diseases and parasites to native fish species. A serious disease threat to a number of Australian freshwater fish species is Epizootic Haematopoietic Necrosis Virus (EHNV). Recent testing of a number of native species reported that *M. macquariensis* was not susceptible to EHNV under the test conditions (Whittington et al*.* 2011). Other viruses that have recently been introduced to Australia by alien fish include Dwarf Gourami Iridovirus (DGIV) that has been shown to cause mortality to farmed Murray Cod (Go and Whittington 2006) and can infect other native fish of the family Percichthyidae such as Golden Perch, Macquarie Perch and possibly Southern Pygmy Perch (*Nannoperca australis*) (Rimmer et al*.* 2016). *M. macquariensis* has not been tested for susceptibility to DGIV.

C. carpio or *P. fluviatilis* are considered to be the source of the Australian populations of the parasitic copepod *Lernaea cyprinacea* (Langdon 1989) and Carp, Goldfish or Eastern Gambusia are probably implicated as the source of the introduced tapeworm *Bothriocephalus acheilognathi* which has recently been recorded in native fish (Dove et al*.* 1997). This tapeworm causes widespread mortality in juvenile fish overseas. Both *Lernaea* and *Bothriocephalus* have been recorded from native fish species in the Canberra region, with *Lernaea* occasionally recorded on *M. macquariensis* in the Murrumbidgee River (ACT Government unpublished data).

Further information regarding alien species is in Appendix 1.

Changing climate

In addition to the above threats, the species is likely to be susceptible to the predicted impacts of climate change (Koehn et al*.* 2013). Overall climate change is predicted to make the ACT region drier and warmer (NSW OEH and ACT Government 2014, Timbal et al*.* 2015).

Fish (as ectotherms) have no physiological ability to regulate their body temperature and are therefore highly vulnerable to the impacts of climate change, particularly given their dispersal is generally constrained by linear habitats in freshwaters (Buisson et al*.* 2008, Morrongiello et al*.* 2011). Species with demersal adhesive eggs are likely to be negatively impacted by the increased occurrence of extreme summer rainfall events, coupled with likely increases in bushfire occurrence. Burnt catchments and increased rainfall intensity will result in increased sediment loads in streams (Carey et al*.* 2003, Lyon and O'Connor 2008), which may persist for decades until the bedload moves downstream (Rutherfurd et al*.* 2000). *M. macquariensis* is known to favour deep habitats, further from the bank and faster flowing habitats than Golden Perch and Murray Cod (Koehn and Nicol 2014), with such habitats at risk of infilling from increased sedimentation and reduction in flows. As *M. macquariensis* is thought to spawn in response to day length and water temperature there is a risk that spawning cues can become decoupled with earlier seasonal warming, resulting in reduced recruitment success. For further information see Appendix 1.

Hybridisation and genetic diversity

M. macquariensis and Murray Cod were distinguished as separate species relatively recently (Berra and Weatherley 1972), but the presence of hybrids between the two species is well known from Cataract Reservoir (where both species are translocated) and occasional hybrids have been reported from natural 'wild' populations (Douglas et al*.* 1995). In Cataract Reservoir, *M. macquariensis* exhibits high levels (32–50% of the population) of hybridisation with Murray Cod (Wajon 1983).

Hybridisation with Murray Cod was perceived as a significant risk to the *M. macquariensis* recovery program in the first national recovery plan (Douglas et al*.* 1994), so a criterion for the selection of stocking sites was the absence of Murray Cod (Douglas et al*.* 1994). This criterion has subsequently been relaxed, and *M. macquariensis* are now extensively stocked where Murray Cod are known to be present (Koehn et al*.* 2013). Murray Cod are thought to have been historically absent or very rare in the upper Murrumbidgee Catchment upstream of Gigerline Gorge (Lintermans 2002), which was an important consideration in the selection of *M. macquariensis* stocking sites in this sub-catchment. However, in response to recreational angler requests, Murray Cod stocking by NSW Fisheries commenced in the Numeralla Catchment in 2008–09, with 16,000 fingerlings stocked across three rivers (Big Badja, Kybeyan, Numeralla) between 2009 and 2015 (NSW Fisheries unpublished data).

Fieldwork in recent years has captured a number of 'odd' looking juvenile cod (less than 150 mm length) and anecdotally these were referred to as hybrids, but no morphological or genetic confirmation of their hybrid status was undertaken. As part of research into the reproductive characteristics of Murray Cod in the ACT, genetic investigations of larval cod sampled from the Murrumbidgee River in the ACT in 2011–2013 recorded a number of first and second generation hybrids between *M. macquariensis* and Murray Cod (Couch et al*.* 2016). This is the first time hybrid Trout Cod–Murray Cod larvae have been detected in Australia, and the first record from a natural wild population (as opposed to an artificial reservoir environment) that hybrid offspring are fertile (Couch et al*.* 2016). Stocked *M. macquariensis* have been recorded as breeding in the upper Murrumbidgee River (Beitzel et al*.* 2011), although it is not known whether the juvenile caught was pure *M. macquariensis* or a hybrid with Murray Cod.

There were no pure *M. macquariensis* larva found in the 251 larvae that were genetically examined, meaning all reproductively active *M. macquariensis* were hybridising with Murray Cod (Couch et al*.* 2016). The proportion of these hybrid larvae that survive and go on to reproduce is unknown. At least some must survive as demonstrated by second generation hybrids. At best, hybridisation represents wasted reproductive effort by reintroduced *M. macquariensis*, at worst, it indicates the genetic integrity of the two cod species in the Upper Murrumbidgee River is at risk.

The population of *M. macquariensis* in Bendora Reservoir was established from a very small number of individuals (8740) stocked in 1989 and 1990. These juveniles were sourced from the initial breeding experiments on the species and the number of adults available for breeding was limited (S. Thurston pers. comm.). These factors increase the likelihood that the population in Bendora would have limited genetic variability and, when added to the limited breeding events recorded since introduction, the risk that the population would be genetically impoverished is high and may impact on its sustainability.

MAJOR CONSERVATION OBJECTIVE

The overall conservation objective of this action plan is to re-establish and maintain in the long term, viable, wild populations of *Maccullochella macquariensis* as a component of the indigenous aquatic biological resources of the ACT and as a contribution to regional and national conservation of the species. This includes the need to maintain natural evolutionary processes and resilience.

Specific objectives of the action plan:

- Protect sites in the ACT where the species occurs.
- Manage habitat to conserve existing populations and re-establish new populations.
- Enhance the long-term viability of populations through management of aquatic habitats, alien fish species, connectivity, stream flows and sedimentation in habitats contiguous to known *M. macquariensis* populations to increase habitat area and connect populations.
- Establish additional populations through stocking or translocation.
- Improve understanding of the species' ecology, habitat and threats.
- Improve community awareness and support for *M. macquariensis* and freshwater fish conservation.

CONSERVATION ISSUES AND INTENDED MANAGEMENT ACTIONS

Protection

M. macquariensis largely occurs on Territory Land within Namadgi National Park and in nature reserves and special purpose reserves in the Murrumbidgee River Corridor. The fish is not known to occur on rural leasehold Territory Land, or Commonwealth owned and managed land (National Land).

Conservation effort for *M. macquariensis* in the ACT is focused on protecting reintroduced populations in Bendora Reservoir and the Murrumbidgee River, and allowing these populations to establish and expand in distribution. Although there are some individual *M. macquariensis* that get displaced out of Bendora Reservoir, there is almost certainly no downstream connectivity between the Cotter River and Murrumbidgee populations and the barrier formed by Cotter Dam prevents any upstream connectivity. However, protection of the Cotter River habitats for other threatened fish species including Macquarie Perch, Two-spined Blackfish (*Gadopsis bispinosus*), and potentially Murray River Crayfish (*Euastacus armatus*) also provides opportunities to protect habitat for the expansion of the Bendora *M. macquariensis* population.

The primary reproducing population of *M. macquariensis* in the ACT is in the Bendora Reservoir, where water is managed by Icon Water but the catchment is managed by ACT Parks and Conservation Service. Juvenile 'Trout Cod' have been found in the Murrumbidgee River around Angle Crossing and Tharwa but it is suspected that juveniles may be hybrids with Murray Cod. In planning terms, the primary purpose of the Cotter River Catchment is water supply, with conservation a secondary objective. Consequently, protection of this *M. macquariensis* population is tempered by water supply considerations, but protection of threatened fish in the Cotter River Catchment remains a key issue for both Territory and Commonwealth governments (ACTEW Corporation 2009). The national conservation status of the species provides some protection from 'significant' impacts. The ACT Government will liaise with Icon Water to ensure continued protection and management of *M. macquariensis* in the Cotter Catchment.

Recreational harvest of Trout Cod in the ACT is prohibited by the Nature Conservation Act, and fishing is completely prohibited in Bendora Reservoir and the Murrumbidgee River between Angle Crossing and the Gudgenby River confluence. Protection from fishing for Trout Cod will remain a key focus of this action plan.

Survey, monitoring and research

There has been considerable research, survey and monitoring directed at Trout Cod over the last 25 years, resulting in the fifth-largest number of on-ground recovery actions directed at a single species nationally (Lintermans 2013b). There is a relatively good understanding of the species distribution, ecology and relative abundance within the Murray–Darling Basin and the ACT, with ongoing regular monitoring of the species within the Cotter Catchment (both Bendora Reservoir and downstream riverine sites) undertaken by ACT Government since 1992 with additional surveys by the University of Canberra since 2010.

A representative set of sites where *M. macquariensis* is known or suspected to occur will need to be monitored to investigate the success of reintroductions, determine long-term population trends and to evaluate the effects of management. Key sites for population monitoring are those that have an established long-term monitoring program (Bendora Reservoir, Murrumbidgee River). Monitoring programs for *M. macquariensis* should use multiple sampling methods to sample a range of age classes (larvae, juveniles, sub-adults and adults) as done for other ACT threatened fish species (e.g. Beitzel et al. 2015, 2016, Lintermans 2013c, 2016, Broadhurst et al. 2016). The current biennial monitoring program for the Murrumbidgee River fish community (which commenced in 1994) should continue to provide information on the status of *M. macquariensis* in this river within the ACT and at upstream sites where the species has also been stocked.

Knowledge of the characteristics of spawning movement patterns (timing, extent, environmental cues or correlates) for *M. macquariensis* is derived from studies in lowland rivers (e.g. Koehn and Harrington 2006, King et al. 2016), with little or no information available from upland rivers. Monitoring of larval cod populations in the ACT would provide valuable information on whether wild spawning of reintroduced *M. macquariensis* is occurring locally and would inform environmental flow management and potentially identify key spatial areas for spawning management.

A range of recent research has been targeted at *M. macquariensis* populations and their ecology. Further research and adaptive management is required to better understand the habitat requirements for the species. Research priorities include:

- further investigations into whether reintroduced populations in the Murrumbidgee River are reproducing (requires regular monitoring at key sites)
- population estimates and genetic diversity for the Bendora Reservoir population
- monitoring of frequency, level and genetic diversity of wild recruitment in the Bendora Reservoir population
- movement and dispersal of adult and juvenile fish in riverine habitats

- breeding biology including timing, location and migration
- the importance of natural in-stream barriers (e.g. Red Rocks Gorge, Gigerline Gorge) to population connectivity in the Murrumbidgee River (see Dyer et al. 2014)
- impacts and drivers of hybridisation with Murray Cod, and the contribution of hybrids to juvenile, sub-adult and adult age classes
- effect of recreational stocking of Murray Cod on the levels of hybridisation in riverine populations on Trout Cod and Murray Cod
- the efficacy of environmental flow releases in maintaining recruitment of riverine and reservoir populations.

Management

Based on current knowledge of the habitat requirements and ecology of *M. macquariensis,* management actions should aim to maintain riverine habitats with appropriate seasonal flow regimes, intact riparian zones, pool depths, and minimal sediment inputs from roads and surrounding land use.

Protection and revegetation of riparian zones will enhance organic matter contributions, provide shade, which buffers water temperatures, provides cover, prevents erosion and filters sediment from run-off. Minimising sediment addition will protect pools from becoming shallower, which is essential in providing a critical habitat for the species.

From an ecological community perspective a low sediment, with intact pools and riparian zones, will also benefit other threatened aquatic species such as Macquarie Perch, Two-spined Blackfish and, Murray River Crayfish.

There has been no stocking of *M. macquariensis* in the ACT since 2008 and the issue of hybridisation between Trout Cod and Murray Cod in the Murrumbidgee River potentially suggests that reproductive effort by adult *M. macquariensis* may be influenced by a scarcity of conspecific mates (Couch et al. 2016).

Additional riverine stocking of *M. macquariensis* may be required to address a shortage of adult fish, with a long-term stocking approach more likely to be effective (Lyon et al. 2012, Lintermans et al. 2015). Liaison with NSW Fisheries in relation to stocking of Murray Cod upstream of the ACT is also required. The predicted low genetic diversity of the *M. macquariensis* population In Bendora Reservoir (resulting from few founding individuals) would also benefit from introduction via stocking of additional more genetically diverse individuals.

Management of fish passage to facilitate habitat connectivity and promote expansion of small re-established populations is important. For example, the building of fishways at Vanitys Crossing and Pipeline Road Crossing on the Cotter River were intended to ultimately link Cotter River reaches and Macquarie Perch sub-populations previously isolated by road crossings, but such fishways will also provide fish passage for *M. macquariensis* if the population expands downstream of Bendora Reservoir. If this population expansion occurs, further fishways (e.g. at Burkes Creek Road Crossing) may be required for similar aims. Alternatively, active translocation of *M. macquariensis* could be pursued if deemed necessary.

Engagement

As with any endangered species, the importance of information transfer to the community and people responsible for managing their habitat is critical. Actions include:

- Provide advice on management of the species and maintain contact with land managers responsible for areas in which populations presently occur.
- Update and maintain the guide to fishing in the ACT to limit angling target of the species
- Ensure that angling signage is up-to-date and placed in relevant areas.

- Report on the monitoring of the species in the Government's Conservation Research Unit's biennial report, which is distributed to a broader audience.
- Liaise with other jurisdictions and departments to increase the profile of native fish conservation.

Further information about conservation and management is in Appendix 4.

IMPLEMENTATION

Implementation of this action plan and the ACT Aquatic and Riparian Conservation Strategy will require:

- Collaboration across many areas of the ACT Government to take into consideration the conservation of threatened species.
- Allocation of adequate resources to undertake the actions specified in the strategy and action plan.
- Liaison with other jurisdictions (particularly NSW) and other landholders (such as National Capital Authority) with responsibility for the conservation of threatened species.
- Collaboration with Icon Water, universities, CSIRO and other research institutions to facilitate and undertake required research.
- Collaboration with non-government organisations to undertake on-ground actions.
- Engagement with the community, where relevant, to assist with monitoring and other on-ground actions and to help raise community awareness of conservation issues.

With regard to implementation milestones for this action plan, in five years the Conservator will report to the Minister about the action plan and this report will be made publicly available. In ten years the Scientific Committee must review the action plan.

OBJECTIVES, ACTIONS AND INDICATORS

Table 1 Objectives, actions and indicators.

Objective	Action	Indicator
1. Protect sites in the ACT where the species occurs.	1a. Maintain the protected status of the species within Namadgi National Park and the four nature reserves in the Murrumbidgee River Corridor.	1a. Namadgi and Murrumbidgee River Corridor populations continue to be protected in national park or nature reserve.
	1b. Ensure all populations are protected from impacts of recreation, infrastructure works, water extraction and other potentially damaging activities, using an appropriate legislative mechanism.	1b. All other populations are protected by appropriate measures (Conservator's Directions, Conservation Lease or similar) from unintended impacts.
2. Conserve the species and its habitat through appropriate management.	2a. Monitor abundance and external parasite loads/disease of key populations, together with the effects of management actions.	2a. Trends in abundance and fish health are known for key populations, management actions recorded.
	2b. Manage to conserve the species and its habitat, including appropriate flow patterns and temperature, preventing in-stream sedimentation, alien fish management, and fish passage practices (recognising current imperfect knowledge).	2b. Habitat is managed appropriately (indicated by low rates of sedimentation, maintenance of appropriate riparian cover, provision of suitable flows, availability of suitable pool habitat, maintenance of fish passage).
	2c. Where appropriate, stock *M. macquariensis* to increase population numbers, genetic diversity and chance of establishment of wild reproducing populations.	2c. Wild recruitment detected in reintroduced populations.
	2d. Continue to not stock Murray Cod in ACT riverine environments where *M. macquariensis* are known to occur and liaise with NSW Fisheries about stocking of Murray Cod upstream of the ACT.	2d. Murray Cod not stocked in riverine environments. Incidence of hybrid adult cod (Murray/Trout cod) is investigated.
	2e. Manage recreational fishing pressure to conserve the species.	2e. Appropriate fishing closures, prevention of take and keep, fish stocking and gear restrictions are in place to prevent fish harvest.

Objective	Action	Indicator
3. Increase habitat area and promote population connectivity.	3. Manage aquatic habitats adjacent to known *M. macquariensis* locations to increase habitat area.	3. Aquatic habitats adjacent to known *M. macquariensis* habitat is managed to improve suitability for the species (indicated by an appropriate sedimentation and flow regime, absence of priority alien fish species, maintenance of appropriate riparian cover, and fish passage).
4. Improve understanding of the species' ecology, habitat and threats.	4. Undertake or facilitate research on habitat requirements, techniques to manage habitat, and aspects of ecology directly relevant to conservation of the species. Collaborate with other agencies/ individuals involved in *M. macquariensis* conservation and management.	4. Research results reported and where appropriate applied to the conservation management of the species. Engagement and/or collaboration with other agencies/individuals involved in *M. macquariensis* conservation and management (i.e. recovery teams, state agencies, universities).
5. Improve community awareness and support for Trout Cod and freshwater fish conservation.	5. Produce materials or programs to engage and raise awareness of *M. macquariensis* and other freshwater fish threats and management actions.	5. Community awareness materials/programs produced and enhanced community awareness evident.

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APPENDIX 1: THREATS—FURTHER INFORMATION

Habitat modification

In the ACT, riparian zones have been cleared and what remains is modified by weed invasion (e.g. Blackberries, African Lovegrass, Willows). Siltation has filled pools and smothered spawning sites, reducing light penetration and the diversity and abundance of invertebrates. Dams on the Cotter River and upper Murrumbidgee River have reduced flows, lessening the frequency of overbank flow events and so reducing connectivity between spawning, nursery and feeding habitats. Dams have altered sediment and nutrient regimes and may release cold, hypoxic water, impacting the habitats of downstream native fishes. Dams have also flooded previously riverine habitats, rendering them unsuitable for critical ecological functions such as reproduction (e.g. blackfish could not breed in Cotter dam as a result of sediment smothering spawning sites).

River regulation

Alterations to natural flow patterns of streams, including flow magnitude, frequency, duration, timing, variability and rate of change, are a major threat to lotic species (Naiman et al. 2008, Poff et al. 1997). The construction of large dams and the diversion of water for domestic, hydroelectric or agricultural water supply has dramatically affected flow regimes downstream (Naiman et al. 2008) with approximately 450 large dams (wall height greater than 10 metres) now present in Australia (Kingsford 2000). In southern Australia, capture and storage of waters in reservoirs during the wet season for subsequent release during dry seasons tends to reverse the seasonal flow pattern in rivers (Maheshwari et al. 1995) and reduce short-term variability overall (Poff et al. 2007). Reduced seasonal volumes of water in rivers are not only the result of dams, but can also be the result of direct abstraction by pumping (Malmqvist and Rundle 2002, Baumgartner et al. 2009). Large dams remove the occurrence and magnitude of small–medium flood peaks as well as reducing the size, rate of rise and fall and duration of flood events (Poff et al. 1997). Low flows downstream of dams can magnify the impacts of barriers to fish passage, as previously insignificant barriers fail to 'drown out' under regulated low flows. Low flows, particularly during drought, also can cause serious water quality problems (high temperatures, low dissolved oxygen that can result in substantial fish mortality. Altered flow regimes also favour generalist alien species with broad tolerances and a capacity for rapid growth and reproduction (e.g. Carp and Eastern Gambusia) (Gehrke et al. 1995).

Barriers to fish passage

Fish habitats are unique in that they are often linear, narrow, and therefore extremely susceptible to fragmentation. Barriers can be structural (dams, weirs, road crossings) or chemical (e.g. discharge of effluents, pollutants, contaminants) and can be partial (i.e. only operate under some conditions such as low flows) or total (e.g. large dams and weirs, piped road crossings). Barriers prevent the movement of fish, either local movements such as for feeding or refuge or larger scale migrations for breeding.

Alien species

Brown Trout (*Salmo trutta*) and Rainbow Trout (*Oncorhynchus mykiss*) were introduced to the Canberra region in the late 1800s and have been established in south-eastern NSW for a century or more. Trout are known to prey upon several native fish species including Macquarie Perch juveniles (Butcher 1967, S. Kaminskas pers. comm.) and may prey upon native fish larvae (e.g. Ebner et al. 2007a). Initial research has developed a genetic method for detecting Macquarie Perch presence in salmonid stomachs (MacDonald et al. 2014), but no such test has been developed for Trout Cod.

Changing Climate

The uplands of the ACT (above ~500 metres elevation) are generally characterised by seasonal rainfall patterns with maximum precipitation in winter and spring with maximum stream flow in spring. In part of the uplands, winter precipitation may comprise significant quantities of snowfall followed by spring snowmelt.

By 2090 the number of days above 35°C in Canberra more than doubles under the RCP4.5 (Representative Concentration Pathways) used by the Intergovernmental Panel on Climate Change (IPCC) and median warming, and the number of days over 40°C more than triples (Timbal et al. 2015), with associated impacts on summer–autumn water temperature. Similarly, by 2090 the average number of frosts is expected to fall (Hennessy et al. 2003, Timbal et al. 2015).

The daily intensity of rainfall, time spent in meteorological drought and the frequency of extreme drought are also predicted to increase by 2090 in the Murray Basin (which includes Canberra) (Timbal et al. 2015). By 2090 rainfall in winter in the Murray Basin is projected to change by -20 to +5 % under RCP4.5 and -40 to +5 % under RCP8.5. A harsher fire weather climate in the future is predicted for the Murray Basin (Timbal et al. 2015) and Marcar et al. (2006) predict that a 5% reduction in evapotranspiration in the upper Murray Catchment following bushfire would result in a 20% reduction in run-off, without factoring in any effect of reduced rainfall. In the Snowy Mountains, snow depth in spring declined by ~40% between 1962 and 2002 (Nicholls 2005) with such declines predicted to continue (Hennessy et al. 2003, Fiddes et al. 2015, Timbal et al. 2015), resulting in changed flow regimes from altered snowmelt patterns.