MACQUARIE PERCH

MACQUARIA AUSTRALASICA

ACTION PLAN

Macquarie Perch (*Macquaria australasica*). Photo: E. Beaton, ACT Government

PREAMBLE

Macquarie Perch *(Macquaria australasica*) 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 of the action plan supersedes earlier editions.

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

CONSERVATION STATUS

Macquaria australasica is recognised and listed as a threatened native species in the following sources:

International: IUCN

Data Deficient (2015–4).

National

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

Australian Capital Territory

Endangered – Section 91 of the *Nature Conservation Act 2014*.
Special Protection Status native 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 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

Macquaria australasica is a member of the Family Percichthyidae, which contains the Australian freshwater basses and cods. It is a moderately-sized, deep-bodied, laterally-compressed fish with large white eyes (Figure 1). It occurs in both the inland drainage of the Murray–Darling Basin (MDB) and the coastal drainages of the Shoalhaven and Hawkesbury–Nepean Catchments in New South Wales (Lintermans 2007, Faulks et al. 2010). It is now considered that the morphologically distinct and geographically disjunct forms in inland and coastal drainages are likely to be separate taxa (Faulks et al. 2010), with possibly two taxa present in the coastal drainages.

In the MDB the maximum length is ~550 millimetres (mm) total length (TL) and maximum weight is 3.5 kilograms (kg), but individuals larger than 400 mm TL or one kilogram are uncommon (Harris and Rowland 1996, Lintermans 2007, Lintermans and Ebner 2010). The body colour is generally black-grey or bluish grey on the dorsal and lateral surfaces and some individuals are distinctly mottled, particularly small juveniles. The ventral surface is whitish. The lateral line is obvious and there are conspicuous open pores on the snout and around the eyes. The tail is rounded, the eye is large and white and the mouth is large with the jaws equal in length. Adult specimens possess a distinct 'humped back' and the tail is rounded. The species is not sexually dimorphic.

Figure 1 *Macquarie australacia*. Illustration: curtesy of NSW Government.

Distribution and abundance

M. australasica is currently typically found in the cooler, upper reaches of the Murray–Darling river system in Victoria, New South Wales and the Australian Capital Territory. Historically the species was more broadly distributed with populations in lowland, slower flowing habitats such as the Murray River between Euston and Tocumwal, Edwards and Wakool rivers and Barmah Lakes near Deniliquin (Cadwallader 1977, 1981, Llewellyn and MacDonald 1980). There are also some natural coastal populations in New South Wales, notably the Nepean, Hawkesbury and lower Shoalhaven rivers. The species was introduced into some other coastal drainages from the MDB in the late 1800s and early 1900s.This action plan only relates to the Murray–Darling stock of *M. australasica* in the ACT region.

In the ACT, *M. australasica* is currently restricted to natural populations in three rivers— the Murrumbidgee, lower Paddys and Cotter rivers—with translocated individuals present in the Upper Cotter River (upstream of Corin Dam), the Molonglo River (upstream of Molonglo Gorge in Kowen Forest) and the mid Paddys River (near Murrays Corner) (Lintermans 2000b, 2013d). The species has been recorded along the entire length of the Murrumbidgee River in the ACT (Greenham 1981, Lintermans 2000b, ACT Government unpublished data). The fish found near the confluence with the Cotter River are likely vagrant fish from the established population in Cotter Reservoir. Individuals captured near Angle Crossing are thought to represent the downstream extent of the population that extends from below Yaouk to Angle Crossing.

Translocations

Since the 1980s there have been a number of translocations of *M. australasica* in the Canberra region. In 1985, 41 individuals were removed from Cotter Reservoir when it was drained for maintenance of the dam wall. These fish were released into Bendora Reservoir but this translocation attempt failed (Lintermans 2013d). Another emergency translocation was conducted in the Queanbeyan River in 1980 when it was realised the construction of Googong Dam had inundated the only available spawning sites for the species, and a natural barrier (Curleys Falls) blocked access to the river for reservoir-resident *M. australasica* (Lintermans 2013c). Sixty-six adult *M. australasica* were collected from the newly-formed reservoir and translocated past the waterfall and released approximately 4 kilometres (km) upstream into the Queanbeyan River. After a substantial delay, this translocation appeared to be successful with a reproducing population persisting for approximately a decade. However, genetic investigation of this period indicated significant genetic impoverishment (Farrington et al. 2014). The population was not detected in the last monitoring in 2014.

A planned translocation program was started in 2006 in an attempt to establish additional populations of *M. australasica* outside the lower Cotter Catchment. The program primarily uses juvenile fish (to minimise impacts on the Cotter Reservoir donor population), with approximately 730 fish translocated to the upper Cotter River (upstream of Corin Reservoir) and 430 translocated to the Molonglo River upstream of Molonglo Gorge (Lintermans 2013d).

Habitat and ecology

The current preferred habitat of *M. australasica* across its range is cool, shaded, upland streams and rivers with deep rocky pools and substantial cover. The species also survives well in impoundments with suitable feeder streams in which to breed. Historically the species was more broadly distributed with populations in lowland, slower flowing habitats (Cadwallader 1977, 1981). The species now seems to be largely confined to the upper reaches of catchments, which are more pristine, well-forested and less affected by agriculture and sedimentation (Cadwallader 1981, Lintermans 2007, Faulks et al. 2011).

M. australasica are reported to live for up to 26 years but such age is rare and most individuals would be expected to live less than ~12–15 years (M. Lintermans pers. comm.). Earlier studies recorded that males reach sexual maturity at two years of age and 210 mm total length, and females at three years and 300 mm total length (Harris and Rowland 1996). However, in Cotter Reservoir ripe males have been recorded at 140–150 mm (Lintermans and Ebner 2010). *M. australasica* undertake a spawning migration into flowing rivers (Lintermans et al. 2010, Tonkin et al. 2010) and gather in schools before spawning, which can last several weeks (Battaglene 1988, Tonkin et al. 2010).

Spawning occurs in late spring/summer when day length increases and water temperatures reach approximately 16–16.5°C. The spawning season generally spans October to December (Broadhurst et al. 2012, Douglas 2002, Tonkin et al. 2010). Fish are reported to deposit eggs at the foot of pools or head of riffles or fast-flowing sections of river (Tonkin et al. 2010, McGuffie unpublished data) where males fertilise them. The eggs are then washed downstream where they lodge in gravel or rocky areas until hatching (Cadwallader and Rogan 1977, Douglas 2002, Tonkin et al. 2010). Fecundity is approximately 31,000 eggs per kilogram of fish weight (Cadwallader and Rogan 1977). Larvae hatch in 10 to11 days at water temperatures of 15–17°C (Gooley 1986) with the larvae being about 7 mm long upon hatching (Battaglene 1988).

The diet of *M. australasica* consists predominantly of freshwater prawns and shrimps (*Macrobrachium* and *Paratya*), and small benthic aquatic insect larvae, particularly mayflies, caddisflies and midges. Yabbies, dragonfly larvae, zooplankton and molluscs are also eaten (Battaglene 1988, Butcher 1945, Cadwallader and Eden 1979, Hatton 2016, Lintermans 2006, McKeown 1934, Norris et al. 2012).

Radio-tracking studies in Cotter Reservoir found that adult and sub-adult fish are mostly crepuscular or nocturnal (i.e. active at dusk, dawn and night) with fish moving on average around 500 metres (m) per day (Ebner and Lintermans 2007, Ebner et al. 2011, Thiem et al. 2013), but moving double that in winter (Thiem et al. 2013). The increased winter movement is possibly related to either increased foraging effort to capture preferred food items such as freshwater prawns, which are less abundant in winter (Norris et al. 2012), or reduction in cormorant predation pressure because cormorants are largely absent during winter.

Like most Australian native freshwater fish, *M. australasica* is not known to jump and swimming performance is influenced significantly by fish size (large fish can swim faster and longer) and water temperature, with swimming performance declining below 16°C (Starrs et al*.* 2011). This is an important consideration when considering natural and anthropogenic in-stream barriers to fish movement and how to remediate them.

Recent research indicates that the majority of remaining populations of *M. australasica* in Australia have reduced genetic diversity, most likely as a result of lack of connectivity between populations and/or initially small numbers of founding fish (Pavlova et al*.* in revision). Reduced genetic diversity has been reported for the Cotter Reservoir and upper Murrumbidgee River populations in the Canberra region (Pavlova et al*.* submitted).

Further information about *M. australasica* ecology is in Appendix 1.

CURRENT MANAGEMENT ACTIONS AND RESEARCH

Environmental flow requirements for the Cotter River downstream of Bendora Dam have been in place since 2000. These flows include specific flows for *M. australasica* that target pool and riffle maintenance prior to breeding season.

Regulations prohibiting the take of *M. australasica* by anglers have been in place since the species was listed as threatened in 1997 (ACT Government 1999). Following the completion of construction of the Enlarged Cotter Dam, the total closure to fishing in the Cotter River was extended from the dam upstream to the junction with Condor Creek. To protect a range of threatened fish species including the translocated *M. australasica,* fishing is prohibited in the Cotter Catchment upstream of Bendora Dam in Namadgi National Park. These regulations are still current.

Ongoing annual monitoring of all ACT populations of *M. australasica* has occurred since the mid-2000s by either the ACT Government or the University of Canberra (Lintermans 2013b, Lintermans et al*.* 2013) and is ongoing. A database for fish records has been established by the ACT Government.

Under the ACT *Water Resources Act 2007*, a program of environmental flow releases in the Lower Cotter Catchment make particular provision for threatened fish species with riffle and pool maintenance flows released (ACT Government 2013a). These Environmental Flow Guidelines are reviewed and updated every five years.

The pine forests of the lower Cotter Catchment were severely burnt during fires in 2003, leading to erosion and then sedimentation of the Cotter River. Substantial revegetation with native plants and reduction of forestry roads was conducted to reduce sediment getting to the lower Cotter River. In addition to improved water quality, less sediment in the river also provides better fish habitat. The Lower Cotter Program is ongoing until at least 2019.

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, which includes the Murrumbidgee *M. australasica* population. 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'. This initiative is ongoing.

Many sections of the Murrumbidgee through the ACT are affected by accumulations of sand ('sand slugs') which cause reductions in water depth and structural habitat diversity. Since

1998 attempts 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 engineered log jams (ELJs) in 2013 (Lintermans 2004c, ACT Government 2013b). The works at Tharwa have resulted in scour pools with increased depth, and monitoring of the ELJs has found that threatened fish species are now using the area. Funding has been awarded by the ACT Government for more ELJs downstream of those constructed in 2013. Construction is planned to commence 2017–18.

The Cotter Reservoir contains a major population of *M. australasica*. The enlargement of the Cotter Dam (ECD), finished in 2013, required a suite of research and management actions. Current or ongoing projects include:

- a fish monitoring program, focused on the reservoir and upstream river sites
- cormorant management
- *M. australasica* translocation program
- investigation into *M. australasica* spawning and passage requirements.

Appendix 2 provides information on past management and research actions.

THREATS

Freshwater fish and their habitats are imperilled 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 impacted on populations of *M. australasica* nationally and locally. In addition, there are specific local threats to *M. australasica* in the Canberra region, including effects of wildfires, reduced genetic diversity, increased predation from native predators and reduction in spawning habitat availability.

Habitat modification

The Lower Cotter and Murrumbidgee Catchments have been impacted by clearing and weeds. Sedimentation of streams has filled pools, smothered spawning sites as well as reduced light penetration and diversity and abundance of invertebrates. Dams on the Cotter River have reduced flows, particularly high-flow events, although this is partially addressed by environmental flow regulations. Dams also release colder hypoxic water and have flooded previously riverine habitats. Locally, *M. australasica* habitats have been impacted by sedimentation of streams (e.g. the Murrumbidgee sand slug and forestry impacts in the Lower Cotter River) and reservoirs (e.g. excessive sedimentation of the old Cotter Reservoir) and cold water pollution (downstream of Googong, Corin and Bendora dams).

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). In the Canberra region Tantangara Dam reduces flows downstream by 99%, diverting water to Lake Eucumbene in the Snowy River Catchment (Anon. 1997). At the Mt Macdonald gauging station, flow in the Murrumbidgee River has recovered to approximately 73% of natural state (ACT Government 2004). In the Cotter River, the flow downstream of Bendora Dam is significantly reduced as water is captured and piped to Canberra for domestic water supply. As a result of these low flows, natural in-stream barriers that would have drowned out in winter and spring now present movement barriers that block upstream spawning migrations by *M. australasica*. Environmental flows are provided downstream of Bendora to improve habitat and assist *M. australasica* breeding.

Barriers to fish passage

Fish habitats are unique in that they are usually 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) 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. *M. australasica* has been particularly impacted by barriers in the ACT region with local populations impacted by dams (e.g. Cotter, Bendora, Scrivener and Googong), weirs (at Casuarina Sands and in the Queanbeyan town centre) and road crossings (e.g. Vanitys Crossing, Point Hut Crossing, Angle Crossing).

Overfishing

Overfishing is cited as one of the contributing factors in the decline of *M. australasica* (Cadwallader 1978, Harris and Rowland 1996). *M. australasica* was a popular angling species in the Canberra region and was reported to provide both good sport and good eating (Greenham 1981, Trueman 2012). Although the species can no longer be legally retained in the ACT or NSW, it can be difficult to release alive after accidental hooking. Some fish are still being caught and retained—either through ignorance or mistaken species identity or deliberately (Lintermans unpublished data).

Sedimentation

Sediment addition to the Murrumbidgee River has resulted in severe decline of habitat quantity and quality for *M. australasica*. Sediment in streams may derive from point sources (e.g. roads, stock access points, construction activities), from 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, 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 (Lintermans 2013a). Sedimentation in rivers is particularly detrimental to fish such as *M. australasica* as sediment may smother the eggs and prevent their lodgement. Increased sedimentation is also known to be damaging to benthic macroinvertebrate communities which form the majority of the dietary items of *M. australasica* (Lintermans 2006, Norris et al. 2012, Hatton 2016).

Reduction in water quality

The major reductions in water quality most likely to have affected *M. australasica* 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. Some pollutants disrupt aquatic ecosystems by mimicking naturally occurring hormones (endocrine disruptors), consequently affecting sexual development, 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 the Lower Molonglo Water Quality Control Centre (LMWQCC) (Roberts et al. 2015, 2016), although the impacts on local aquatic species are, as yet, unknown.

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 the Cotter River, altered thermal regimes were predicted for 20 kilometres downstream of Bendora Dam (at flows of 1 m^3s^{-1} or 86 ML/day) (Rutherford et al. 2009). Lowered water temperatures can delay egg hatching and insect emergence and retard fish growth rates and swimming speeds (increasing predation risk). Cotter River *M. australasica* swimming capacity is strongly correlated with water temperature (Starrs et al. 2011). Reduced growth rates mean small fish will remain for a longer time in the size-class susceptible to predation, thus exacerbating the impacts of alien predators. Lowered water temperature can also disrupt reproductive behaviour.

Other reductions in water quality likely to have had major effects on *M. australasica* 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 in an area that previously supported populations of *M. australasica* (Trueman 2012, Kaminskas 2015).

Introduction of alien species

Locally, *M. australasica* has had its distribution invaded by a range of alien fish species including Brown Trout (*Salmo trutta*), Rainbow Trout (*Oncorhynchus mykiss*), Carp (*Cyprinus carpio*), Goldfish (*Carassius auratus*), Redfin Perch (*Perca fluviatilis*), Eastern Gambusia (*Gambusia holbrooki*) and Oriental Weatherloach (*Misgurnus anguillicaudatus*). Alien fish can have impacts on native fish species due to:

- competition for food and habitat (spawning areas, territory)
- predation
- introduction and spread of diseases (e.g. Epizootic Haematopoietic Necrosis Virus EHNV) and parasites (e.g. *Bothriocephalus* and *Lernaea*)
- habitat degradation (e.g. uprooting of aquatic vegetation and increased water turbidity by Carp feeding).

The main impact on *M. australasica* is thought to be through all of these interactions with alien fish.

Changing climate

In addition to the above threats, the severe decline of a number of *M. australasica* populations during the millennium drought (1997–2010) (Lintermans et al. 2014) suggests the species is likely to be susceptible to the predicted impacts of climate change. 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 thus highly vulnerable to the impacts of climate change, particularly given their dispersal is generally constrained by linear habitats in fresh waters (Buisson et al. 2008, Morrongiello et al. 2011). *M. australasica* eggs lodge in riffles below upland pools and 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). This species spawns in response to day length and water temperature. The spawning cues can become decoupled, with predicted earlier seasonal warming resulting in reduced recruitment success.

Fires

Bushfire impacts of consequence to *M. australasica* include:

- sedimentation from denuded catchments following rain events

- a decrease in dissolved oxygen concentrations as organic material (leaves, ash) washed into streams following rain events begins to decompose
- chemical changes in water quality as ash is deposited in streams
- impacts from the loss of riparian (streamside) vegetation such as increased water temperature due to lack of shade.

As a result of the 2003 bushfires (further information in Appendix 3), fire management practices in the ACT have been amended with road access to remote areas upgraded, new fire trails constructed and an increased frequency of control burns. As a result of increased fire management activities, the impacts of broadscale bushfires are likely mitigated, however even fire mitigation activities can themselves pose a risk to aquatic environments if not planned and conducted carefully. Results of fish monitoring after an escaped hazard reduction burn conducted in the upper Cotter Catchment in 2015 recorded high levels of electrical conductivity in the river (ACT Government 2015). This reflected chemical changes as a result of ash and sediment deposition, which are not well understood for the ACT.

Genetic bottlenecks/impoverishment

Recent genetic studies have shown that almost all remaining populations of *M. australasica* in Australia have low genetic diversity and have undergone recent bottlenecks (Faulks et al. 2011, Pavlova et al. submitted). Estimates of effective population size in Cotter Reservoir also indicate that, in addition to low genetic diversity, only a relatively small number of adults in this population contribute to breeding annually (Farrington et al. 2014, Pavlova et al. in revision). Species or populations with small effective population size and low genetic diversity are at increased risk of extinction (Frankham 2005, Weeks et al. 2011). 'Genetic rescue' is where individuals, cross breeds or genetic material from a donor population are introduced to an impacted population to reduce genetic isolation, increase genetic variation and reduce inbreeding depression. Genetic rescue aims to improve the fitness and evolutionary potential of the recipient population (Weeks et al. 2011). Where populations of *M. australasica* have been mixed via translocation (e.g. Yarra River, Cataract River) there is no evidence of adverse genetic effects (Pavlova et al. submitted).

Reduction in spawning habitat availability

M. australasica require riffles in flowing water for spawning. Therefore reservoir populations require access to upstream riverine habitats to breed. Recent research has also indicated that generally *M. australasica* may only use a subset of available riffles for spawning (Tonkin et al. 2016, P. McGuffie unpublished data). Prior to the enlargement of the reservoir, spawning sites for the Cotter Reservoir population of *M. australasica* were largely concentrated in the kilometre or two of river immediately upstream of the initially impounded waters (Ebner et al. 2007, Lintermans 2012). These spawning sites have been inundated, so fish must seek alternative spawning sites further upstream, traversing a steep-gradient river reach with many natural in-stream barriers that prevent upstream fish migration under low or inappropriate flows (Lintermans 2012, Broadhurst et al. 2013). In-stream barriers are probably contributing to the factors limiting recruitment since 2013 (Broadhurst et al. 2015). The number, location, accessibility or physical characteristics of spawning sites for the riverine population of *M. australasica* in the Cotter River are unknown.

Cormorant predation

Recent research on Macquarie Perch in the Cotter Reservoir has suggested that bird predators such as cormorants may have a potentially significant effect on the small population of *M. australasica* in the reservoir (Lintermans et al. 2011, Ryan et al. 2013). Radio telemetry investigations indicate that a small population of cormorants may prey on a significant proportion of adult fish as they congregate at the top of the reservoir prior to spawning. Investigations of cormorant diet revealed that Macquarie Perch were present in 22% and 14% of Great Cormorant and Little Black Cormorant stomachs respectively, with one Great Cormorant having six *M. australasica* present in its stomach (Lintermans et al. 2011).

Further information on threats is in Appendix 3.

MAJOR CONSERVATION OBJECTIVE

The overall conservation objective of this action plan is to maintain in the long term, viable, wild populations of *M. australasica* 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 establish or re-establish new populations.
- Enhance the long-term viability of populations through management of aquatic habitats, alien fish species, connectivity, spawning site access, stream flows and sedimentation in existing habitats as well as those adjacent to known *M. australasica* populations to increase habitat area and connect populations.
- Enhance genetic diversity of Cotter Catchment populations of *M. australasica* to improve long-term viability.
- Improve understanding of the species' ecology, habitat and threats.
- Improve community awareness and support for *M. australasica* and freshwater fish conservation.

CONSERVATION ISSUES AND INTENDED MANAGEMENT ACTIONS

Protection

M. australasica largely occurs on Territory Land including Namadgi National Park and the Lower Cotter Catchment (water supply protection area). *M. australasica* is not known to occur on rural leasehold Territory Land, or Commonwealth owned and managed land (National Land).

Conservation effort for *M. australasica* in the ACT is focused on protecting viable populations in the Cotter River and Cotter Reservoir below Bendora Dam. In planning terms, the primary purpose of the Cotter River Catchment is water supply, with conservation a secondary objective. Consequently, protection of this *M. australasica* 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. australasica* in the Cotter Catchment.

General habitat and water quality improvement works and protection in the Murrumbidgee River and catchment will assist in conserving the Murrumbidgee population in the region.

Recreational harvest of *M. australasica* in the ACT is prohibited by the Nature Conservation Act with fishing completely prohibited on the Cotter Reservoir and inflowing Cotter River up to the junction with Condor Creek. Recreational fishing is also prohibited in the waters of the

Cotter River Catchment upstream of the Bendora Dam wall. Protection from fishing for *M. australasica* will remain a key focus of this action plan.

Survey, monitoring and research

There is a relatively good understanding of the species distribution, ecology and relative abundance in the ACT, with ongoing annual or biennial monitoring of the species within the Cotter Catchment (both Cotter Reservoir and riverine sites) undertaken by ACT Government since 2001 and by the University of Canberra. A representative set of sites with *M. australasica* will need to be monitored to determine long-term population trends and to evaluate the effects of management. The establishment and condition of translocated *M. australasica* at the three current translocation sites (upper Cotter River, Molonglo River above Blue Tiles, Paddys River) (Lintermans 2013d) requires further monitoring. The current biennial monitoring program for the Murrumbidgee River fish community (which started in 1994) should continue to provide information on the status of *M. australasica* in this river within the ACT and at upstream sites where Macquarie Perch are extant.

Regular monitoring of the Cotter Catchment (upstream of Cotter dam) to detect invasion by alien fish species (Carp and Redfin Perch) should also continue, as should monitoring of cormorant abundance on Cotter Reservoir. Investigation of the potential to limit the upstream spread of Redfin Perch in Paddys River should also occur (location of natural barriers, potential sites for constructed barriers), as it may be possible to successfully reintroduce *M. australasica* to this catchment in the future.

While the broad spawning movement ecology of *M. australasica* is understood, recent studies to characterise the location and nature of potential spawning movement barriers (Broadhurst et al. 2016) are hampered by a lack of understanding of the location and characteristics of *M. australasica* spawning sites and the lack of knowledge of the spawning movement patterns (timing, extent, duration) in the Cotter River. Knowledge of the characteristics and spatial distribution of spawning sites will facilitate increased protection and management of these critical habitats. As well as assisting in the identification of spawning sites, study of the spawning movement patterns will help determine where remediation efforts should be focused for fish passage barriers.

Further research and adaptive management is required to better understand the habitat requirements for the species. Research priorities include:

- population estimates for Cotter Reservoir and Cotter River populations
- spawning site characteristics and distribution along the Cotter River
- spawning migration patterns including timing, extent of migration and duration of migration
- remediation techniques for natural in-stream barriers (flows, barrier modification, barrier removal, fishways)
- impact of temperature on spawning behaviour and success
- impacts of bushfire management
- magnitude and significance of annual *M. australasica* population fluctuations and relationship to seasonal or annual conditions (flow, temperature)
- investigation of the benefits of increasing genetic diversity (genetic rescue) of both riverine and reservoir populations in the lower Cotter Catchment
- the efficacy of environmental flow releases in maintaining recruitment of riverine and reservoir populations
- further investigations of trout predation on larval or juvenile *M. australasica*
- investigation of techniques and the feasibility of rehabilitating and mitigating

sedimentation of Paddys River with a view to population expansion.

Key sites for population monitoring are those that have an established long-term monitoring program (Cotter Reservoir, Cotter River, Murrumbidgee River). Monitoring programs for *M. australasica* should use multiple sampling methods potentially including gill nets, electrofishing and fyke nets. Fyke nets, which capture the greatest number of individuals, are the only method that reliably detects young-of-year fish (Lintermans 2013c, 2016).

Past and present monitoring work in the Cotter River Catchment has demonstrated the broad distributional range of the species, but further survey and monitoring effort is required for the Queanbeyan River to ascertain whether this population is extant (Lintermans 2013c).

Management

Based on current knowledge of the habitat requirements and ecology of *M. australasica,* management actions should aim to maintain riverine habitats with appropriate seasonal flow regimes, intact riparian zones, sufficient pool depths, minimal sediment inputs from roads and surrounding land use, an absence of Redfin Perch and Carp, and connectivity between spawning and non-spawning habitats.

Management of riparian zones will enhance organic matter contributions, which are the basic food supply for many stream invertebrates that form the majority of the diet of *M. australasica*. Intact riparian zones also 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 and will protect the function of riffles as spawning habitat for *M. australsica*.

Preventing the establishment of Redfin Perch and other alien species, such as Carp, will protect *M. australasica* from predation and resource competition as well as largely eliminating the threat posed by EHN virus.

Management of prescribed burns, particularly in the Cotter Catchment, needs to be carefully considered to avoid impacts on threatened aquatic species. The adequate assessment of risk and resourcing is critical in minimising likelihood of unintended outcomes of prescription burns. The application of buffers for autumn burns and other measures are important to minimise the impact of prescription burns. The aquatic ecology guidelines concerning the Bushfire Operations Plan (under the Emergencies Act) are event-specific and included in the ecological guidelines that accompany the Bushfire Operations Plan.

Continued access to suitable spawning habitats is an essential requirement for a population to be self-sustaining. Once the characteristics of spawning migrations and sites are understood (see research priorities), management actions will likely be necessary to ensure continued spawning success.

Management of fish passage to prevent fragmentation of existing populations and habitats is a priority. There may also be opportunities to expand or reconnect sub-populations. For example, the building of fishways at Vanitys Crossing and Pipeline Road Crossing were intended to ultimately link Cotter River reaches and expand *M. australasica* populations previously fragmented by road crossings. It is also likely that remediation of natural barriers in the river reach between the enlarged Cotter Reservoir and Vanitys Crossing, whose effect is exacerbated by low, regulated flows downstream of Bendora Dam, may be required during the life of this action plan.

Engagement

As with any threatened 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.
- Keep the guide to fishing in the ACT up-to-date 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 Conservation Research Unit's biennial report, which is distributed to a broad 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 action, 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. Apply formal measures (national park, nature reserve, water supply protected area) to protect the large population in the lower Cotter River.	1a. The lower Cotter population is protected in national park, water supply protected area or an area set aside specifically for conservation of the species.
	1b. Maintain the protected status of the species within Namadgi National Park and the four nature reserves in the Murrumbidgee River Corridor.	1b. Namadgi and Murrumbidgee River Corridor populations continue to be protected in national park or nature reserve areas.
	1c. Ensure all populations are protected from impacts of recreation, infrastructure works, water extraction and other potentially damaging activities, using an appropriate legislative mechanism.	1c. 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 of key populations and the effects of management actions.	2a. Trends in abundance are recorded for key populations and management actions. Populations are stable or increasing (taking into account probable seasonal/annual effects on abundance fluctuations).
	2b. Manage volumes, quality and timing of water releases from Bendora reservoir to maintain an appropriate flow regime to conserve the species.	2b. Appropriate timing, volumes and water quality of water releases minimise sediment accumulation and thermal impacts to maintain appropriate riffle and pool habitat.
	2c. Maintain the integrity of the riparian vegetation and reduce erosion and sedimentation through appropriate land management (i.e. run-off, fire and weeds).	2c. Riparian zones are protected from impacts of erosion, sedimentation and prescribed burns. Invasive plants (e.g. Willows, Blackberries) are controlled and areas replanted with appropriate native species.
	2d. Alien fish species are prevented from establishing and existing alien populations are managed where feasible to reduce impacts or population expansion.	2d. No new alien fish species established in Cotter River. Existing alien fish populations are not expanding in abundance or distribution where *M. australasica* is present.
	2e. Impediments to fish passage are managed to minimise impacts on the populations, through	2e. Fish population sustainability is not impacted by barriers to fish movement.

Objective	Action	Indicator
	remediation, flow management or trap and transport.	
	2f. Manage recreational fishing pressure to conserve the species.	2f. Appropriate recreational fishing restrictions are in place and enforced to prevent deliberate or inadvertent harvest.
3. Increase habitat area and connect populations.	3. Manage aquatic habitats adjacent to *M. australasica* habitat to increase habitat area or habitat connectivity.	3. Aquatic habitats adjacent to, or linking, *M. australasica* habitat are managed to improve suitability for the species (indicated by an appropriate sedimentation and flow regime, absence of priority alien fish species, and fish passage).
4. Establish additional populations through translocation and improve genetic diversity of the Cotter River population.	4a. Translocate *M. australasica* to suitable habitats outside the lower Cotter River and Murrumbidgee River.	4a. One additional population established outside the lower Cotter River Catchment.
	4b. Improve genetic diversity of Cotter Reservoir and lower Cotter River populations through introducing appropriate new genetic stock.	4b. Genetic diversity of *M. australasica* in Cotter Reservoir and lower Cotter River improved compared to 2015 levels.
5. Improve understanding of the species' ecology, habitat and threats.	5. 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. australasica* conservation and management.	5. 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. australasica* conservation and management (recovery teams, state agencies, universities).
6. Improve community awareness and support for *M. australasica* and freshwater fish conservation.	6. Produce materials or programs to engage and raise awareness of *M. australasica* and other freshwater fish threats and management actions.	6. Community awareness materials/programs produced and distributed.

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APPENDIX 1: ADDITIONAL INFORMATION ON *MACQUARIA AUSTRALASICA* ECOLOGY

Distribution and abundance

An early morphometric and genetic study suggested there were three distinct stocks of *Macquaria australasica*, with the Murray–Darling populations being distinct from a Shoalhaven stock and Hawkesbury stock (Dufty 1986). More recent molecular investigations have supported separate specific status for these three stocks (Faulks et al. 2010).

In the Cotter River prior to the 2000s, the species was restricted to the lower section of the river from its junction with the Murrumbidgee up to Vanitys Crossing (including Cotter Reservoir) (Lintermans 2000b). Anecdotal reports indicate that the species did occur further upstream on the Cotter but had disappeared from this area and was unable to pass the high concrete causeway built at Vanitys Crossing in the late 1970s (Lintermans 1991).

The only natural record from the past four decades from the Molonglo River has been from the lower end of the river below the Lower Molonglo Water Quality Control Centre (LMWQCC), where two individuals were captured in 1981. The discharge of treated effluent from the LMWQCC since 1978 is likely to provide a chemical barrier that discourages dispersal of some native fish species from the Murrumbidgee to the Molonglo River (Lintermans 2004a). Scrivener Dam now prevents upstream movement of fish species from the lower Molonglo and effectively restricts access to the majority of the Molonglo River. The species was historically present in the Molonglo River (Trueman 2012) but was likely eliminated along with almost all other fish species by heavy metal pollution from the Captains Flat mines.

M. australasica was reported to be historically present in Paddys River based on angler interviews summarised in Greenham (1981) and confirmed by Lake (P.S. Lake pers. comm. to M. Lintermans). A survey of five sites in 2000 of the lower and mid reaches only recorded the species within 500 metres of the confluence with the Cotter River with these individuals likely to represent upstream dispersal from the Cotter River (Lintermans 2000a).

In the broader Canberra region, *M. australasica* has also been recorded since the 2000s as viable populations from three other locations:

- A population of unknown size in the Murrumbidgee River between Michelago and Yaouk (Lintermans 2002).
- A substantial population in the Abercrombie River below Crookwell (Gilligan et al. 2010).
- A small population in Adjungbilly Creek upstream of Gundagai.

Populations that have declined substantially since the late 1990s–early 2000s and may no longer be present or viable. There may be:

- A possible remnant population in Burrinjuck Dam.
- A remnant population in the lower Goodradigbee River near Wee Jasper.
- A small population in the Lachlan River near Wyangla Dam.
- A small translocated population possibly still present in the Queanbeyan River immediately upstream of Googong Reservoir (Lintermans 2013c).
- A relict translocated population in the Mongarlowe River near Braidwood (Lintermans 2008).

Translocations

To guide the numbers and age-classes of fish to use in this translocation program, a population model has been constructed to provide an estimate of the likelihood of success of various strategies (Todd and Lintermans 2015). In response to the development of this model, since 2015 a small number of adult fish (less than 25) have been translocated to the Upper Cotter site to increase the chance of successful population establishment.

Habitat and ecology

Mature unfertilised eggs are 1–2 mm in diameter and cream coloured. After fertilisation the eggs swell to approximately 4 mm diameter and are amber coloured (Battaglene 1988).

Small groups of larval *M. australasica* (<10 mm length) have been observed to swim in the mid to upper water column along steep rock-faces in deep sections of pools (>1.5 m) and in low or no-flow areas. However juveniles (10–50 mm length) quickly become more benthic in their habitats, becoming closely associated with boulders, cobbles or large woody debris, usually towards the head or foot of pools where some surface flow is present (Broadhurst et al. 2012).

In the Queanbeyan River, larger items such as freshwater prawns and shrimps were eaten by adults, with immature and young-of-year fish consuming mainly larvae of mayflies, midges and caddisflies (Lintermans 2006).

During daylight hours, individuals in Cotter Reservoir shelter in cover provided by fringing reed beds or other cover—individual fish have well-defined home ranges that can change every few months (Ebner and Lintermans 2007). Adult fish in Cotter Reservoir tended to be found in habitats with depths of 2–5 m except in summer when deeper water habitat (mean 7.2 m) was used. This change in depth of habitat use was hypothesised to be influenced by predator avoidance (from cormorants) in summer, or the seasonal interplay between behavioural thermoregulation and limitations of dissolved oxygen available in a reservoir that stratifies over summer and autumn (Thiem et al. 2013).

The effective population size (the number of adults that contribute to breeding in a particular year) of *M. australasica* in Cotter Reservoir before its enlargement was estimated to be 14–65 from samples collected in 2001–07 (Farrington et al. 2014).

APPENDIX 2: PAST MANAGEMENT AND RESEARCH ACTIONS

During the 1997–2010 millennium drought, flows in the Cotter River downstream of Bendora Dam were greatly reduced. Modified environmental flows were provided, with ecosystem monitoring including *M. australasica* recruitment. It was feared that lower flows would result in sediment accumulation in riffles, which is critical spawning habitat for *M. australasica*. Consequently the environmental flow releases from Bendora were modified to both maintain riffle quality before the spring spawning season and during the summer larval growth period. Similarly, following the severe 2003 bushfires in the Canberra region, there was significant erosion and sedimentation of streams, particularly in the Cotter River (Carey et al. 2003). Again, concern over conditions for spawning resulted in environmental water releases to maintain riffles in suitable condition to protect spawning in *M. australasica*.

Vanitys Crossing formed a barrier to upstream movement of *M. australasica*. In 2001 a fishway designed specifically for *M. australasica* was constructed at Vanitys Crossing—it has allowed a significant expansion in the species range in the lower Cotter River (Broadhurst et al. 2012, 2013). The species has become established above Vanitys Crossing up to Pipeline Crossing (7.7 river km) and recorded as far as Burkes Creek Crossing (approximately 3.9 km further upstream). Another fishway specifically designed for *M. australasica* was constructed at Pipeline Crossing in 2011 by ACTEW Water. The Vanitys Crossing fishway has been rebuilt following significant damage in floods in 2010 and 2011. The existing fishway at Casuarina Sands on the Murrumbidgee River has also been recently modified to enhance fish passage.

A review of Canberra's water supply options resulted in the construction of an enlarged Cotter Reservoir between 2008 and 2013. As the Cotter Reservoir contained the only self-sustaining population of *M. australasica* in the ACT, a suite of research and management actions were undertaken, which represented a significant investment in knowledge generation and mitigation activities for the species. Projects included:

- the identification of risks and benefits to fish populations of various enlargement options (Lintermans 2005, 2012)
- an investigation of the movement patterns and habitat use of *M. australasica* in the existing reservoir and the potential effects of cormorant predation (Ryan et al. 2013)
- the sterilisation between the old and new dam walls to prevent transfer of EHN virus
- the investigation into actual levels of predation on *M. australasica* by cormorants (Lintermans et al. 2011)
- the construction of 7 km of rock reef shelter habitat for *M. australasica* in the new reservoir's ECD inundation zone (Lintermans et al. 2010)
- the use of underwater video to investigate artificial habitat use by juvenile *M. australasica* (Lintermans et al. 2010)
- the installation of a fishway at Pipeline Road Crossing to provide access additional riverine habitat for *M. australasica*
- a preliminary project to investigate the timing of the upstream spawning migration of *M. australasica* from Cotter Reservoir (Lintermans et al. 2010)
- the establishment of an ongoing comprehensive monitoring program for threatened and alien fish in the reservoir and the river upstream (Lintermans et al. 2013; Broadhurst et al. 2015)
- the initial development of a genetic test to determine the presence of *M. australasica* in trout stomachs (Macdonald et al. 2014)
- the preparation of emergency translocation plans for *M. australasica* in the event of critically low water quality in the newly filling ECD (ACTEW Corporation 2013)
- the investigation of potential need and design of translocation programs for a range of threatened fish, the development of a population model to guide translocation efforts and the establishment of a translocation program for *M. australasica* to the upper Cotter River and Molonglo River in Kowen Forest (Lintermans 2013d; Todd and Lintermans 2015)
- the investigation of fish food resources and diet of *M. australasica* in the existing Cotter Reservoir (Norris et al. 2012)
- investigations of the swimming capacities of *M. australasica* and other fish species to inform fishway design and management (Starrs et al. 2011, 2017)
- the mapping and characterisation of potential movement barriers that might limit *M. australasica* accessing spawning habitats (Hugh 2010, Broadhurst et al. 2016)
- the preparation of a cormorant management plan for the ECD should cormorant abundance increase to critical levels in the filling reservoir (ACTEW Corporation 2013).
- the preparation of a series of fish management plans for Cotter Reservoir encompassing planning to operational phases (e.g. ACTEW Corporation 2013).

Other research conducted in the 2000s included the movement response of a range of fish species (including *M. australasica*) to environmental flow releases (Ebner et al. 2008), the development of snorkelling as a technique to monitor Macquarie Perch spawning time and larval distribution (Broadhurst et al. 2012), the diel behaviour of small individuals of *M. australasica* and Two-spined Blackfish in the Cotter River (Ebner et al. 2009) and the success of Vanitys Crossing fishway in allowing a significant expansion in the range of *M. australasica* above Vanitys Crossing (Broadhurst et al. 2013).

APPENDIX 3: FURTHER INFORMATION ABOUT THREATS

River regulation

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 ML/d or 33 GL/yr, 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).

Barriers to fish passage

The construction of Cotter Dam in 1915 isolated the Cotter River population of *M. australasica* from the Murrumbidgee River stock. The subsequent construction of Vanitys Crossing in the late 1970s further fragmented the Cotter River population with *M. australasica* becoming restricted to the Cotter Reservoir and the 5.5 kilometre stretch of river between the reservoir and Vanitys Crossing. The construction of Googong Dam impounded the Queanbeyan River up to the base of a waterfall (Curleys Falls), inundating all suitable spawning areas for *M. australasica* below the falls. Fish had to be translocated past the barrier posed by the waterfall to allow successful spawning to occur (Lintermans 2013c). The effluent discharge from LMWQCC is 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 construction of Scrivener Dam to form Lake Burley Griffin in 1963 effectively isolated the Molonglo and Queanbeyan rivers from the Murrumbidgee River and has prevented any recolonisation by *M. australasica*.

Sedimentation

The impacts of sedimentation on fish in the ACT are particularly obvious in the Murrumbidgee River. The sediment derived from land management practices and the 2003 fires in the Cotter River Catchment (Starr 2003, Wasson et al. 2003).

Introduction of alien species

The establishment of alien fish species is a recognised threat to freshwater fish both globally (Dudgeon et al. 2006; Malmqvist and Rundle 2002) and in Australia (Lintermans 2013a). For some species the evidence is inferred as many alien fish (e.g. salmonids) became established before the distribution and abundance of native fish was documented. However, the number of alien fish species continues to rise, mainly through the release of ornamental species (Lintermans 2004b, 2013a).

The diets of *M. australasica* and alien trout species are similar and competition is likely (Jackson 1981, Lintermans 2006). Trout are also known to prey upon *M. australasica* juveniles (Butcher 1967, S. Kaminskas pers. comm.) and may prey upon larvae (Ebner et al. 2007). Initial research has developed a genetic method for detecting *M. australasica* presence in salmonid stomachs, but further laboratory and field testing is required to establish sensitivity and false detection (both negative and positive) probabilities (MacDonald et al. 2014). Other introduced fish species such as Carp, Goldfish, Redfin Perch and Oriental Weatherloach will also have dietary overlap with *M. australasica* (e.g. Battaglene 1988; Cadwallader 1978). In the Lachlan River system *M. australasica* appears to disappear from streams after the invasion and spread of Redfin Perch but the mechanism for this impact (competition, predation, disease) is unclear.

A major impact of alien species on *M. australasica* is the introduction or spread of diseases and parasites to native fish species. The most serious disease threat to *M. australasica* is Epizootic Haematopoietic Necrosis Virus (EHNV) with experimental work by Langdon (1989b) demonstrating that *M. australasica* was one of several species found to be extremely susceptible to the disease. This virus, unique to Australia (and currently endemic to this region), was first isolated in 1985 on Redfin Perch (Langdon et al. 1986). It is characterised by sudden high mortalities of fish displaying necrosis of the renal haematopoietic tissue, liver, spleen and pancreas (Langdon and Humphrey 1987). EHNV is endemic to the upper Murrumbidgee Catchment (Whittington et al. 2011), where it has been recorded from most of Canberra urban lakes (Whittington et al. 1996). The spread of EHNV has been aided by its relatively resistant characteristics and the ease with which it can be transmitted from one geographical location to another on nets, fishing lines, boats and other equipment. Langdon (1989b) found that the virus retained its infectivity after being stored dry for 113 days. Once EHNV has been recorded from a waterbody it is considered impossible to eradicate. The virus is absent from the Cotter River upstream of the enlarged dam (Whittington et al. 2011) but the potential for the virus to be introduced through contaminated fishing gear or illegal movement of Redfin Perch is high (Lintermans 2012).

Cyprinus carpio or *Perca fluviatilis* are considered to be the source of the Australian populations of the parasitic copepod *Lernaea cyprinacea* (Langdon 1989a) 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* commonly recorded on *M. australasica* in the Cotter Reservoir (Lintermans unpublished data).

Changing climate

The uplands of the ACT (above ~500 m elevation) are generally characterised by seasonal rainfall patterns with maximum precipitation in winter–spring and 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 Representative Concentration Pathways 4.5 (RCPs) 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).

Fires

Studies on the Cotter River have shown that river regulation has exacerbated the effects of fires and sediment addition. A North American study documented increases in summer water temperatures of 8–10°C following fire, due to the increased light reaching streams as a result of the removal of riparian vegetation (Minshall et al. 1989). Almost 840 km of streamside vegetation was burnt in 2003 with only 31% of stream length likely to have retained its riparian canopy cover (Carey et al. 2003). the loss of riparian zone vegetation likely results in increased stream temperature.

Significant erosion and sediment input to the Cotter River and tributaries occurred following the fires (Starr 2003, Wasson et al. 2003). Even though water turbidity levels can recover relatively rapidly (Harrison et al. 2014) coarser sediment addition can significantly change fish habitats in the long term as pools fill with gravels and cobbles.

Other impacts on aquatic communities include increased clearing for fire breaks leads to bare earth and erosion risk, the use of fire retardants adjacent to streams, the installation of water sources for fire control (dams) or pumping from streams and the escape of controlled burns.

Genetic bottlenecks and impoverishment

Historically, translocation between threatened species populations has not been pursued because of concern over outbreeding depression, but it is now realised that such concerns are deterring management actions to boost or reinforce population size and may be contributing to local population loss (Frankham 2010, Weeks et al. 2011), with translocation now an increasingly common management practice for threatened freshwater fish in Australia (Lintermans et al. 2015).

Cormorant predation

The population of Great Cormorants on the enlarged Cotter Reservoir since it began to fill fluctuates between 20 and 35 birds over the late spring to late autumn period when the species is present (Broadhurst et al. 2015). The effective population size for *M. australasica* in Cotter Reservoir (before its enlargement) was estimated to be between 14 and 65 (Farrington et al. 2014), so the daily consumption of a single *M. australasica* by Great Cormorants alone could represent a substantial proportion of the breeding population.

APPENDIX 4: FURTHER INFORMATION ABOUT CONSERVATION AND MANAGEMENT

Protection

Given that at some ACT sites *M. australasica* has declined to extremely low or undetectable levels, and acknowledging that the species is long-lived (maximum known age 26 years) and that recovery of large-bodied fishes can take decades (see Koehn et al. 2013, Lintermans 2013b), it should be assumed that the species is present at any site where it has previously occurred since 1990 unless this is disproved by rigorous annual survey over at least five years or the habitat has been destroyed.