Australian Government

Department of the Environment and Energy

NSW GOVERNMENT

Department of Primary Industries

National Recovery Plan for the Macquarie Perch (*Macquaria australasica*)

May 2018

Prepared by: Department of the Environment and Energy

Made under the *Environment Protection and Biodiversity Conservation Act 1999*

The Species Profile and Threats Database pages linked to this recovery plan is obtainable from: http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl

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Cover page: Cover page: Macquarie perch (*Macquaria australasica)* Luke Pearce, New South Wales Department of Primary Industries

Disclaimer

General Acknowledgements

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In particular, the Department acknowledges the considerable input of the New South Wales Department of Primary Industries who provided much of the information contained within this recovery plan. Additionally, the Department acknowledges the effort provided by researchers and conservation experts, including academics, Non-Government Organisations, Australian Government and State Government staff, and members of the public, who contributed to and provided advice on the recovery plan's preparation. Particularly, this extends to the participants of the workshop held to discuss and review the recovery plan and actions required.

Acknowledgement of Traditional Owners and Country

The Australian Government acknowledges Australia's Traditional Owners and pays respect to Elders past and present. We acknowledge the deep spiritual, cultural and customary connections of Traditional Owners to the Australian land and sea country, including the Macquarie perch.

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Figures & Tables

1 Summary

Macquarie perch (*Macquaria australasica*)

Family:	Percichthyidae
IBRA Bioregions:	Sydney Basin, South Eastern Highlands, Australian Alps, NSW South Western Slopes, Riverina, Victorian Midlands
Conservation status:	Statutory *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth): Endangered *Fisheries Management Act 1994* (New South Wales): Endangered *Flora and Fauna Guarantee Act 1988* (Victoria): Threatened *Nature Conservation Act 2014* (Australian Capital Territory): Endangered Non-statutory *Action Plan for South Australian Freshwater Fishes 2009 list*: Extinct *Advisory List of Threatened Vertebrate Fauna in Victoria 2013 list*: Endangered *IUCN Red List of Threatened Species*: Data Deficient
Distribution and habitat:	Remaining viable, **self-sustaining natural populations** within the species' natural range: ***New South Wales*** - Abercrombie River upstream of Lake Wyangala (upper tributary of the Lachlan River catchment); - upper Murrumbidgee River below 'Cooma Gorge' and upstream of Gigerline Gorge; - Hawkesbury-Nepean river system and Georges River (east coast catchments); - Adjungbilly Creek in the Tumut River catchment (upper Murrumbidgee River catchment); - Mannus Creek (upper Murray River catchment). ***Australian Capital Territory*** - Cotter River and Reservoir above Cotter Dam and below Bendora Dam.

Distribution and habitat: cont…

Victoria:

- upper reaches of Mitta Mitta River catchment above Dartmouth Dam, including in Lake Dartmouth (where it is also stocked);
- Buffalo River (Ovens River catchment);
- King Parrot and Hughes creeks (both within the Goulburn River catchment)
- Broken River itself above and below Lake Nillahcootie and in Holland's Creek (in the Broken River catchment).

Translocated populations:

New South Wales

- Mongarlowe River (upper Shoalhaven River catchment);
- Cataract Reservoir in the (upper Hawkesbury-Nepean system).

Australian Capital Territory:

- Molonglo River between the ACT border and the Queanbeyan River confluence (upper Murrumbidgee River catchment).
- Cotter River in and above Corin Dam (upper Murrumbidgee River catchment).

Victoria:

- Yarra River catchment;
- lower and middle reaches of the Ovens River (along with stocked individuals) and in Lake William Hovell on the King River (Ovens River catchment);
- Seven Creeks (Goulburn River catchment).

Stocked populations:

New South Wales:

- Retreat River (upper Abercrombie/Lachlan system);

Victoria:

- Expedition Pass Reservoir (upper Loddon River catchment).
- Lake Dartmouth in the Mitta Mitta River catchment (where there is a natural population of the species).
- lower and middle reaches of the Ovens River (along with translocated individuals), between Oxley Flats and Rocky Point.

- Goulburn River, in the middle reaches of the Goulburn River between Molesworth and Trawool.
- Yea River (upper Goulburn River catchment).

Habitat critical for survival:

Habitat critical to the survival of the Macquarie perch is described as:

- all areas within the species' range which are characterised by flowing runs or riffles and small complex rock piles;
- the current area of occupancy of the species (including historically translocated populations in Cataract Reservoir and the Mongarlowe River in New South Wales and the Yarra River in Victoria);
- any newly discovered locations within the species' natural range which hold populations that extend the area of occupancy for the species;
- unoccupied habitat within the species' natural range into which the species could disperse, be stocked or be translocated.

Recovery plan objective and strategies:

The overarching objective of this recovery plan is to:

> Ensure the recovery and ongoing viability of Macquarie perch populations throughout the species' range (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers).

The recovery plan sets out six recovery strategies that build toward this overarching objective:

1. Conserve existing Macquarie perch populations (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers).
2. Protect and restore Macquarie perch habitat.
3. Understand and address threats to Macquarie perch populations and habitats.
4. Establish additional Macquarie perch populations within the species' natural range.
5. Improve understanding of the biology and ecology of the Macquarie perch and its distribution and abundance.
6. Increase participation by community groups in Macquarie perch conservation.

Recovery team:

Recovery teams provide advice and assist in coordinating actions described in recovery plans. They include representatives from organisations with a direct interest in the recovery of the species, including those involved in funding and those participating in actions that support the recovery of the species. The Macquarie Perch Recovery Team has the responsibility of providing advice, and coordinating and directing the implementation of the recovery actions outlined in this recovery plan. The membership of the recovery team may include individuals with relevant responsibility and expertise from Department of the Environment and Energy (DoEE), relevant state governments, as well as experts from research institutions and consultancies, and private researchers; membership may change over time.

Criteria for success:

This recovery plan will be deemed successful if, within 10 years, most of the following have been achieved:

- Populations of Macquarie perch have increased in size and/or distribution at each known location.
- Self-sustaining populations of Macquarie perch have been established at locations in its natural range where it once historically occurred but no longer occurs.
- A long-term population monitoring strategy has been implemented and is ongoing for the Macquarie perch in the Australian Capital Territory, New South Wales and Victoria.
- There is improvement in understanding of what threat mitigation is required to recover the Macquarie perch.
- There is implementation of threat mitigation measures to protect known Macquarie perch populations.
- Macquarie perch can be reliably bred in closed-life cycle hatcheries, which are supplemented with broodstock from the wild, as appropriate, to maintain genetic diversity.
- Genetic diversity of the Macquarie perch increases or remains the same.

Criteria for failure:

This recovery plan will be deemed to have failed if; within 10 years, the following have occurred:

- The number of populations of Macquarie perch has decreased.
- No strategy for population monitoring has been developed or conducted for the species and population trends are not known in any or all of the Australian Capital Territory, New South Wales or Victoria.
- Little understanding of threat mitigation has been achieved to recover the Macquarie perch.
- Little advancement in the implementation of a wide-range of threat mitigation measures (above current levels or activities) has occurred to protect known Macquarie perch populations.
- Little advancement in success of closed-life cycle breeding within hatcheries.
- The conservation status of the Macquarie perch has declined during the life of the plan.
- Genetic diversity of Macquarie perch decreases.

2 Introduction

This document constitutes the Australian National Recovery Plan for the Macquarie Perch (*Macquaria australasica*). The plan considers the conservation requirements of the species across its range and identifies the actions to be taken to ensure the species' long-term viability in nature, and the parties that will undertake those actions. This is the first National Recovery Plan for Macquarie perch.

The Macquarie perch is a moderate sized, large eyed, secretive freshwater fish native to the cooler middle-upper reaches of the Murray-Darling Basin (Butcher 1967; Lake 1978; Lintermans 2007). The species was originally described from specimens collected from the Macquarie River in New South Wales, but has long since disappeared from that part of the Murray-Darling Basin. Museum records also exist for Macquarie perch from the Murray River in South Australia but the species is now presumed extinct from the lower Murray River (Hammer & Walker 2004). Macquarie perch are now found as far north as the Abercrombie River in the Murray-Darling Basin, as well as the eastern coastal, Hawkesbury-Nepean, Georges and Shoalhaven river systems in New South Wales (Harris & Rowland 1996; Lintermans 2007). Translocated populations originating from individuals sourced from the Murray-Darling Basin are known in Cataract Reservoir and the Mongarlowe River, in the Hawkesbury-Nepean and Shoalhaven river systems respectively. In Victoria, populations are known from the Mitta Mitta, Ovens and Broken river catchments and several tributaries in the Goulburn River catchment, in addition to a translocated population in the Yarra River (Lintermans 2007).

The Macquarie perch was once an important and valued species for recreational fishing, and some recreational fishing is currently permitted in Victoria. However, the Macquarie perch has undergone a long-term decline in abundance; populations have become fragmented and the species is now absent from much of its former range

The national recovery plan summarises the current state of knowledge of the Macquarie perch and contains detailed information on the threats being faced by this species. The plan also provides a list of actions and strategies to assist in the recovery and viability of wild Macquarie perch populations throughout the species' range by focusing government, community and Indigenous groups support and involvement.

An accompanying Species Profile and Threats Database (SPRAT) page provides additional information on the Macquarie perch. The SPRAT page is available at: http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl

3 Species Information

3.1 Names

Common name: Macquarie perch

Other historical and current common names: mountain perch, Murray perch, Macquarie's perch, black perch, black bream, Goulburn bream, silver-eye or white-eye, goggle eyes, humpy back, butterfish and snub-nosed perch.

The Macquarie perch was probably known as Wunnumberu (pronounced 'Wanambiyu') by the Dhudhuroa who lived along the upper Murray River and lower Kiewa and Mitta Mitta rivers (Trueman, 2011). Other possible names are Nooraderri and Gubir by the Wiradjuri who lived in the area bordered by the Lachlan, Macquarie and Murrumbidgee rivers (Trueman, 2011; About NSW, 2013).

Scientific name: *Macquaria australasica* (Cuvier 1830)

3.2 Conservation status

The Macquarie perch is listed in the Endangered category in the threatened species list under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Species can also be listed as threatened under state and territory legislation. The Macquarie perch is listed under both the Australian Capital Territory *Nature Conservation Act 2014* and the New South Wales *Fisheries Management Act 1994* as 'Endangered'. It is also listed as 'threatened' in Victoria under the *Flora and Fauna Guarantee Act 1988* and 'presumed extinct' in South Australia under the *National Parks and Wildlife Act 1972*. For up-to-date information on the listing status of this species under relevant state or territory legislation, see http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl

The Macquarie perch was eligible for listing under the EPBC Act as on 16 July 2000 as it was listed as Endangered under Schedule 1 of the preceding Act, the *Endangered Species Protection Act 1992* (Cwlth). The main factors that make the species eligible for listing in the Endangered category are that the Macquarie perch has experienced past decline and the threats impacting the species may not have ceased and that it has a restricted geographic distribution which is severely fragmented and continued decline has been observed at a number of locations in recent years.

3.3 Stock structure

Macquarie perch has several genetically divergent lineages across its range. Because of morphological and genetic differences between Murray-Darling Basin and eastern Macquarie perch (Hawkesbury-Nepean and Shoalhaven) there were calls for revising the taxonomic status to recognise the Shoalhaven, Hawkesbury-Nepean and Murray-Darling Basin as separate species (Dufty 1986; Faulks et al., 2010; Faulks et al., 2011; Pavlova et al., 2017a; 2017b).

Genetic analysis of complete mitochondrial genome sequences of 25 individuals by Pavlova et al. (2017b) found that differentiation among the Murray-Darling Basin, Hawkesbury-Nepean and Shoalhaven lineages supported emerging speciation, which had been inferred previously (Dufty 1986; Faulks et al., 2011; Pavlova et al., 2017a). However, there is no evidence that reproductive barriers have evolved between the Murray-Darling Basin and the Hawkesbury-Nepean Macquarie perch (Faulks et al., 2011; Pavlova et al., 2017b). A population of Macquarie perch has been established in Cataract Reservoir (Hawkesbury-Nepean system) derived solely from translocated individuals from the Murray-Darling Basin. Some individuals from this population have dispersed downstream of Cataract Dam and have hybridised with the natural Hawkesbury-Nepean lineage occurring in the Cataract River (Faulks et al., 2011; Pavlova et al., 2017b). Genetic analysis of microsatellite markers indicates that this dispersal may still be ongoing (Pavlova et al., 2017a). The Murray-Darling Basin and Hawkesbury-Nepean lineages diverged approximately 385 000 to 119 000 years ago (Pavlova et al., 2017b). There additionally appears to be divergence within the Hawkesbury-Nepean system, with the southern Hawkesbury-Nepean diverging from the northern Hawkesbury-Nepean approximately 191 000 to 58 000 years ago (Pavlova et al., 2017b).

An individual collected from the Kangaroo River (Shoalhaven system), prior to the presumed extinction of the Shoalhaven River lineage was found to be highly differentiated from both the Hawkesbury-Nepean and Murray-Darling Basin lineages (Pavlova et al., 2017b), supporting a long term evolutionary trajectory of the Shoalhaven lineage. Analysis of mitochondrial lineage divergence showed that the Shoalhaven Basin diverged from the common ancestor of the Murray-Darling Basin and Hawkesbury-Nepean around 1 332 000 to 419 000 years ago (Pavlova et al., 2017b).

Genetic analysis of microsatellite markers shows that, with two exceptions, all Murray-Darling Basin populations form independent genetic clusters, indicating a strong effect of genetic drift (loss of genetic diversity) due to population isolation (Pavlova et al., 2017a; 2017b), consistent with earlier studies (Faulks et al., 2011; Nguyen et al., 2012). The two exceptions were: Holland’s Creek and Lake Dartmouth in one cluster, likely reflecting recent stocking of Holland’s Creek with fish derived from Lake Dartmouth, and; the Lachlan and Abercrombie rivers (which are connected) in one cluster, in which there appears to be unidirectional gene flow from the Abercrombie River to the Lachlan River (Faulks et al., 2011), however the Lachlan River population appears extinct above Lake Wyangala (NSW DPI pers. comm., 2016; Pearce et al., 2017). Similar patterns of populations forming independent genetic clusters have been shown in the Hawkesbury-Nepean system (Pavlova et al., 2017a).

Given the current taxonomic status, this recovery plan remains relevant to all lineages of Macquarie perch.

3.4 Description

The Macquarie perch is a moderate sized, elongated, oval shaped, laterally compressed fish with large silvery-white eyes, a small mouth and a rounded tail. The snout is tapered and the upper jaw slightly overhangs the lower jaw. There are conspicuous pores on the lower jaw. Macquarie perch have a concave nape similar to, but not as distinct as, golden perch (*Macquaria ambigua*). They are similar in appearance to golden perch, Australian bass (*Macquaria novemaculeata*) and estuary perch (*Macquaria colonorum*). Juveniles closely resemble several pygmy perch species found in eastern Australia (*Nannoperca* spp.) (Family Percichthyidae).

The colour of Macquarie perch within the Murray-Darling Basin varies from almost black or dark silvery-grey, dark bronze to pale bluish grey or green-brown above, with off-white below. Fins sometimes have a purplish or yellowish tinge. Coastal drainage fish often have grey-brown, buff and dark grey patches.

Size varies greatly between Murray-Darling Basin and coastal drainage populations, with Murray-Darling fish reaching up to 550 mm and 4 kg (but are uncommon today over 1.5 kg), while coastal drainage fish rarely reach over 190 mm with a maximum recorded size of 253 mm (Lake 1959; 1978; Battaglene 1988; Harris & Rowland 1996; Douglas et al., 2002; Bruce et al., 2007; Knight & Bruce 2010; Lintermans & Ebner 2010).

Figure 1: *Typical adult Macquarie perch from the Murray-Darling Basin*

Photo – Luke Pearce, NSW Department of Primary Industries.

Figure 2: *Typical adult Macquarie perch from the Hawkesbury-Nepean system*

Note the substantially smaller adult size of the Hawkesbury/Nepean specimen (~17 cm) compared to the MDB specimen (~30 cm).

Photo – Andrew Bruce, NSW Department of Primary Industries

4 Biology and Ecology

4.1 Age and growth

Growth rates of Macquarie perch vary between and within populations (Appleford et al., 1998; Tonkin et al., 2014; 2017b). Sizes of individuals vary greatly between the Murray-Darling Basin and Hawkesbury-Nepean populations, with the Basin individuals having greater potential maximum body sizes and weights (Harris & Rowland 1996). Murray-Darling Basin populations have been reported to grow from 7–10 mm (hatched larvae) to 370 mm in length in the first five years of life (Harris & Rowland 1996; Lintermans 2002; 2007; Kearns et al., 2012b). In east coast populations individuals greater than 190 mm in length are rare, with a maximum recorded size of 253 mm and 0.29 kg (Harris & Rowland 1996; Bruce et al., 2007; Knight & Bruce 2010).

Size at first sexual maturity varies between lake and river populations, with a study comparing fish from selected riverine tributaries in the Murray-Darling Basin and resident fish from Lake Dartmouth finding that both males and females of river populations tend to mature at a much smaller size, yet at the same age, than fish resident in the lake (Appleford et al., 1998). Still, size at a given age is likely to vary within Macquarie perch populations, especially once individuals are older than three years (Cadwallader 1984). Males are reported to mature at two years of age and at 210 mm and females at three years of age and 300 mm (Lake 1967a). However, it has become evident through later research that size is not a reliable indication of age because local conditions may induce the species to breed at smaller or larger sizes. Estimates of mature females as small as 100 mm total length have been made based on the length-at-age relationships formulated by Douglas et al. (2002). In the Cotter River in the Australian Capital Territory, males mature at about 140–150 mm and in Lake Dartmouth mature males have been recorded as small as 117 mm (Lintermans 2007).

The maximum age potential for Macquarie perch is at least 30 years (Tonkin/Vic DELWP unpub. data, cited in ARI pers. comm., 2017) and could potentially be older. The species is relatively long-lived, recent reports of fish from Victoria aged up to 28 and 30 years for males and females respectively (Tonkin/Vic DELWP unpub. data, cited in ARI pers. comm., 2017).

Age and growth studies of Macquarie perch from Lake Dartmouth were undertaken by Cadwallader (1984), Douglas et al. (2002) and Tonkin et al. (2014). The initial research by Cadwallader (1984) found after eggs hatch, growth can be rapid, with a five-year-old fish being 380 mm.

4.2 Habitat

Historically, using the altitudinal zonation definitions of the ‘Sustainable Rivers Audit’ (Davies et al., 2008; 2012; MDBA 2017), which were utilised by Trueman (2011), across the Murray-Darling Basin the Macquarie perch was abundant in the upland zones of rivers (400–700 m a.s.l.), sometimes extending into the montane zone (>700 m a.s.l.). The species was usually abundant in slope zones (200–400 m a.s.l.); and occurred sporadically in lowland habitats (<200 m a.s.l.), generally at higher altitudes of the lowland zone (Trueman 2011).

The species was historically locally abundant in the Barmah Lakes and the Edward River, on the New South Wales/Victoria border, showing that it could inhabit lowland areas (Trueman 2011). However, evidence indicates it was rare in the Murray River, downstream of Barmah Lakes, and almost unknown in the South Australian reaches of the Murray River (Cadwallader 1979;

Lintermans 2007; Trueman 2011). Overall, the historical evidence and the breeding biology of the Macquarie perch indicate it was a species primarily of the upland and slope zones in New South Wales, but in Victoria the species did extend in high abundances into lowland zones of the major tributaries of the Murray River Trueman 2011). The Victorian tributaries of the Murray River do not have the relatively long stretches of river length in the lowland zone as do the New South Wales Murray-Darling Basin rivers such as the Murrumbidgee, Lachlan and Macquarie.

In Seven Creeks, Victoria, Cadwallader (1979) noted that Macquarie perch were found where aquatic vegetation was usually present with additional cover provided by large boulders, debris and overhanging banks; and where steep rock faces, well vegetated banks and open eucalypt woodland typically provided shade. Brumley et al*.* (1987) found that Macquarie perch habitat sites in rivers consisted of a rubble substrate of small boulders, pebbles and gravel. Additionally, water depth was between 0.2–0.9 m (usually 0.4–0.6 m) and water velocity was between 0.3–0.6 m/sec. Brumley et al. (1987) also found that habitat areas often have a pool (usually 15–30 m long and at least 1.5 m deep) immediately upstream and fast-flowing broken water immediately downstream. Within Seven Creeks, the species still occurs in the middle reaches from below Polly McQuinns Weir downstream to habitats below Gooram Falls (ARI pers. comm., 2017), and individuals are thought to be in good condition in areas where deep refuge habitat from predators was accessible.. Upstream of Polly McQuinns Weir, the species is likely to be extinct (Stoessel 2009). Until recently, adults in the Cotter River catchment in the Australian Capital Territory principally resided within Cotter Reservoir rather than the river (Ebner & Lintermans 2007; Ebner et al., 2008) but that was probably due to the lack of riverine habitat available to the species given the barrier posed by Vanitys Crossing (Broadhurst et al., 2012; 2013). Within the Cotter Reservoir adults use emergent macrophytes for shelter and juveniles are associated with rock piles (Ebner & Lintermans 2007).

Preferred juvenile habitat in rivers is not well documented. Juveniles of 10–30 mm length inhabit pools in the Cotter River and are benthic and/or semi-pelagic during the day and inactive at night (Ebner & Lintermans 2007; Ebner et al., 2008; 2009; Broadhurst et al., 2012).

Reflecting of its records in the uppermost and high altitudinal parts of the Murray-Darling catchments it once occurred (Trueman 2011), Macquarie perch can tolerate relatively cold water temperatures. It has been measured to be living in temperatures as low as at least 4°C in in the Cotter River in the Australian Capital Territory (ACT Gov pers. comm., 2017) and living in the upper Murrumbidgee River at Kissops Flat where water temperatures regularly drop under 4°C in winter (Lintermans unpub. data., cited in Lintermans pers. comm., 2017).

A recent study of the Macquarie perch population in Lake Dartmouth found that growth and recruitment were highest during years of refilling, when amongst other variables, water temperatures were low. The study considered the influence of low water temperatures on high growth not surprising given the species' natural occupancy of cool, upland streams (Tonkin et al., 2014). Observational evidence indicates that the Macquarie perch in aquaria show signs of severe illness or stress once temperatures reach 26°C or above (Lintermans unpub. data, cited in Lintermans pers. comm., 2017), consistent with observations of broodstock in ponds perishing when water temperatures exceeded 27°C (Trueman pers. comm., cited in Trueman 2007).

The species requires a temperature rise in spring months, generally to at least 16°C for spawning to occur, but it is possible that they can spawn at lower temperatures (Cadwallader & Rogan 1977; Harris & Rowland 1996; Lintermans 2007; Koster et al., 2014; Tonkin et al., 2016a). Recent observations of the species in King Parrot Creek and the Yarra River found that temperature had a significant positive influence on spawning intensity, with the greatest abundance of eggs recorded when mean daily water temperatures exceeded 18 C (Tonkin et al., 2016a).

Historical records indicate that Macquarie perch inhabited many types of riverine habitat that have now been extensively modified. However, Gilligan et al. (2010) summarising research in the Lachlan River proposed that Macquarie perch are –

> ”… riverine fish most abundant in reaches > 200m altitude. The species is heavily dependent on the availability of flowing mesohabitats (runs and/or riffles) and small complex rock piles (aggregations of 0.5–1 m diameter boulders) to provide cover. Extensive lengths of undercut banks in reaches with low coverage of flowing mesohabitats or limited small complex rock cover are detrimental. Depth, substratum type, riparian vegetation cover and aquatic macrophyte cover have little influence on the probability that Macquarie perch will occupy a reach.”

A strong positive association of Macquarie perch abundance/biomass in Hughes Creek has been recently reported between within stream woody habitat, riparian vegetation and water depth (Tonkin et al., 2016c).

The removal of rock and woody snags, introduction of aquatic pests, siltation and degraded water quality have likely contributed to the loss of quality habitat for Macquarie perch. Given that Macquaire perch lay eggs which settle into interstitial spaces between rocks and pebbles (Cadwallader & Rogan 1977; Cadwallader 1978; Tonkin et al., 2010), low silt coarse spawning substrates are critical for egg development. It is worth noting that the introduced fish species, brown and rainbow trout, also require such substrates (Harris 1995) potentially competing for habitat in areas where these species co-occur with Macquarie perch.

Habitat critical to the survival of the Macquarie perch can therefore be described as all areas within the species’ range which are characterized by flowing runs or riffles and small complex rock piles, and in some waterways, instream woody habitats.

4.3 Reproductive biology

In Murray-Darling Basin rivers, Macquarie perch tend to spend most of their time in deep holes and move to spawn during spring and early summer (from September through to mid-January) when water temperatures range between 16–20°C (Koehn & O’Connor 1990a; Ingram et al., 2000; Gilligan 2005; Tonkin et al., 2010; 2016a). Fish in lakes or impoundments tend to aggregate at the mouths of suitable feeder streams awaiting appropriate water temperatures (>16.5°C). When the water reaches the required temperature the fish move to appropriate riffle habitat to spawn and then return to the lake or impoundment upon completion of spawning activities or when water temperatures fall below 16.5°C (Wharton 1968; Cadwallader & Rogan 1977; Cadwallader 1977; 1979).

While historical observations indicated that Macquarie perch have a preference for spawning in upper reaches of catchments in Victoria and the Shoalhaven River (Bishop 1979; Cadwallader 1979), recent observations have indicated that populations are reproducing at locations both upstream and downstream of Goorum Falls in the Seven Creeks system in Victoria (ARI unpub. data, cited in ARI pers. comm., 2017). Running ripe Macquarie perch were collected from the Barmah Lakes area during studies in 1937 suggesting that the species may be able to spawn in some circumstances in lowland conditions (Cadwallader 1977), though the requirement for silt-free substrates probably remains.

Murray-Darling Basin Macquarie perch have estimates of age and size at sexual maturity varying from 1–2 years and 117–210 mm for males and 3–4 years and 100–300 mm for females (Cadwallader 1984; Douglas et al., 2002; Lintermans 2007; Tonkin et al., 2009). Fish from the coastal eastern drainages tend to have a smaller size at sexual maturity. Ripe females of 100 mm total length have been reported from the Hawkesbury-Nepean and Shoalhaven river systems in New South Wales (Dufty 1986) and ripe males as small as 80 mm total length have been captured in the Georges River (Knight 2010; Knight & Bruce 2010). Observations of running ripe males have been observed in a shallow, riffle area at the tail end of a large pool in the Georges River, and contrastingly running ripe females have been observed attempting to move upstream in the Kowmung River and at Pheasants Nest Weir (which now has a fishway) on the Nepean River (Knight & Bruce 2010).

Fecundity is estimated at 32 000 eggs per kilogram of fish (Wharton 1973) hence a large (3.5 kg) female may produce up to 110 000 eggs. Eggs are cream coloured, approximately 1–2 mm in size and adhesive, and are usually found amongst gravel and stones in riffle areas approximately 50–75 cm deep with a flow rate of less than 1 m/s. Hatching usually occurs after 10–11 days at water temperatures ranging from 15–17°C (Lintermans 2007). Newly hatched yolk sac larvae shelter amongst pebbles (Cadwallader & Rogan 1977).

Macquarie perch larvae in the Cotter River above Cotter Reservoir in the Australian Capital Territory have been observed during snorkelling surveys schooling in deep sections of river pools which have little to no surface flow along steep rock faces in the upper water column (at depths less than 1 m; Broadhurst et al., 2012). As they grew and became juvenile fish, they developed strong associations with the benthic substrates of boulders, cobbles or large woody debris at the head and tail of pools in relatively shallow water, where some surface flow is present (Broadhurst et al., 2012).

Macquarie perch have been particularly problematic to breed in captivity, requiring flowing water, and typically have relied on the collection of wild breeding stock (Trueman 2007; Farrington et al., 2014). However, there has been some recent success for captive breeding programs of the species by the New South Wales Narrandera Fisheries Centre hatchery, using a new approach employing an artificial stream to coax both males and females into breeding condition (NSW DPI 2010). Until this development, hatchery programs for the species have generally relied on capturing spawning-run fish from the wild (NSW DPI 2010), inducing individuals to spawn through the injection of artificial hormones to collect the eggs and sperm.

4.4 Behaviour

While anglers regularly capture the species during daylight, it is thought that Macquarie perch search for food more actively at night (Lintermans 2006a, Ebner & Lintermans 2007, Ebner et al., 2009; Thiem et al., 2013). Nevertheless, whilst the species is generally regarded as quite cryptic and docile (Lintermans 2007), during reproduction fish form dense aggregations at the base of pools and within riffles (Cadwallader & Rogan 1977; Tonkin et al., 2010). During such times fish also become quite aggressive, making the species particularly vulnerable to predation and anglers (Tonkin et al., 2009).

In the Cotter Reservoir, Australian Capital Territory, Macquarie perch have been shown to inhabit deeper water depths during the warmer summer months in comparison with other seasons (Thiem et al., 2013). Diel geographical range movements were significantly higher in winter than other seasons, probably due to having to move larger distances to encounter the same quantity of prey items, such as decapods which are in lower abundance during winter (Thiem et al., 2013).

Studies on Macquarie perch in Lake Eildon and Lake Dartmouth in Victoria, found that as water temperatures rose in spring months towards 16°C, fish began migrating to upstream regions of the lake ready to move into inflowing streams once the surface water temperature rose above this level (Cadwallader & Rogan 1977; Tonkin et al., 2010). Oral history recordings about the species, including those gathered from Indigenous groups such as the Yorta Yorta people, noted schooling and migration as a general trait of the species (Trueman 2011). Many of the oral histories described a strong, but not unpleasant, odour produced by the species that signified to some fisherman the presence of these large aggregations of the species in waterways (Trueman 2011). Research in the upper Murrumbidgee River has found the species moving both up and downstream to spawn (McGuffie unpub. data, cited in Lintermans pers. comm., 2017). However, unlike the large migrations observed for impoundment populations in Eildon and Dartmouth lakes, recent studies of Macquarie perch movement and spawning in riverine habitats in Victoria have reported only localised movement and spatial spawning patterns, with restricted home ranges, in King Parrot Creek and the Yarra River (Koster et al., 2014; Kearns et al., 2015; Tonkin et al., 2016a).

4.5 Diet

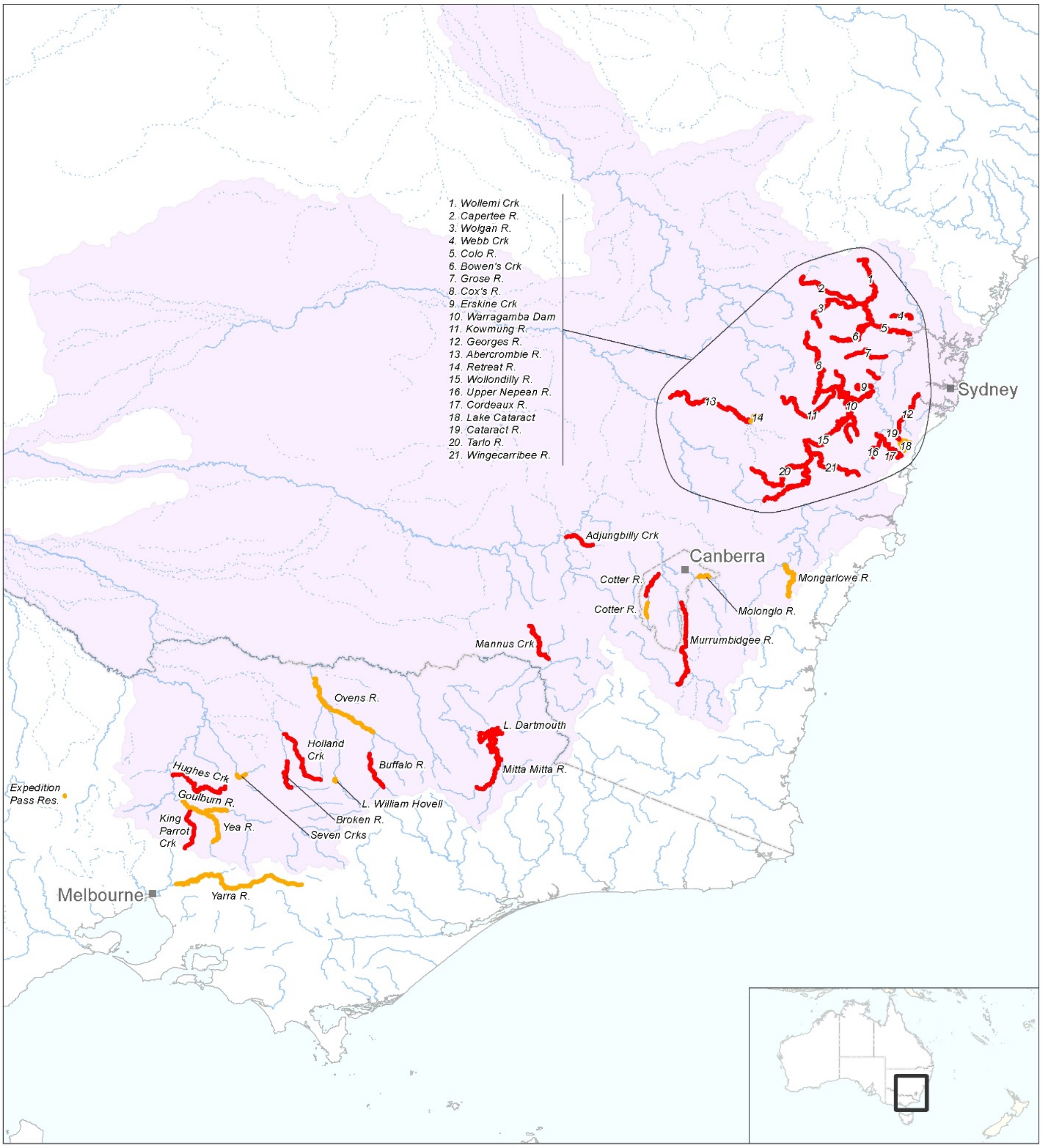
Macquarie perch and trout cod (*Maccullochella macquariensis*) are the only two Australian species of the Family Percichthyidae, which exhibit a relatively sub terminal mouth. A sub terminal mouth typically indicates benthic feeding habits in fish species. Laboratory observations have shown that Macquarie perch feed using a sucking action; evidenced by the frequent occurrence of sand grains, gravel and detritus in stomach analyses of the species (Cadwallader & Eden 1979). Macquarie perch predominantly feed upon benthic aquatic insects and insect larvae, particularly beetles, mayflies, caddis flies and midges. Decapod crustaceans (shrimp and crayfish) are also an important food source with other known prey including dragonfly larvae, molluscs and small fish (McKeown 1934; Butcher 1945; Cadwallader & Eden 1979; Battaglene 1988; Lintermans 2006a; Norris et al., 2012). Indeed, the high high abundance of Decapoda may be a significant factor in maintaining the Macquarie perch population in Cotter Reservoir (Norris et al., 2012). In lakes and impoundments cladocerans (water flea crustaceans) can also be a significant dietary item (Cadwallader & Douglas 1986; Lintermans 2007; Norris et al., 2012) and in Cataract Reservoir small Dipterans (true fly larvae) were found to be the most important prey for the species (Norris et al., 2012). The cladoceran, *Moina* spp., followed by calanoids, chironomids and cyclopoids were the most abundant prey in the stomachs of juvenile Macquarie perch reared in fertilised earthen aquaculture ponds (Ingram & De Silva 2007).

The composition of diet for Macquarie perch in impoundments fluctuates depending on water level, and feeding activity is known to increase in times of flooding when fresh ground is made available (McKeown 1934; Cadwallader & Douglas 1986; Battaglene 1988). Macquarie perch have been found to feed on terrestrial invertebrates, such as arthropods and annelids, when the water levels of Lake Dartmouth rose rapidly over areas which had previously not been inundated (Cadwallader & Douglas 1986). There has been little evidence of feeding on terrestrial items from other studies focussing on riverine populations (Cadwallader & Rogan 1977; Cadwallader & Eden 1979; Lintermans 2006b).

The abovementioned study of the Lake Dartmouth population found that there was no obvious relationship between size of Macquarie perch and size of food items (Cadwallader & Douglas

1986). This is in contradiction to riverine populations of the species in the Canberra region, where ontogenetic changes in diet have been observed: as individuals mature, the importance of decapods increases and the importance of dipterans (true flies) decreases (Lintermans 2006b). Macquarie perch prey in riverine populations in the Canberra region is dominated by the shrimp (*Paratya australiensis*) and freshwater prawn (*Macrobrachium australiense*) (Lintermans 2006b).

5 Distribution and Populations



km 0 50 100 150 200 250

Map produced by: the Environmental Resources Information Network, Department of the Environment and Energy.

Species distribution information from: Department of the Environment and Energy (2016). *'Draft National Recovery Plan for Macquarie Perch* (Macquaria australasica), Commonwealth of Australia, Canberra.

Contextual data sources: from the Department of the Environment and Energy, Geoscience Australia, Public Sector Mapping Agency, Department of Agriculture, Commonwealth Scientific and Industrial Research Organisation and the Australian Bureau of Statistics.

Caveat: The information presented in this map has been provided by a range of groups and agencies. While every effort has been made to ensure accuracy and completeness, no guarantee is given, nor responsibility taken by the Commonwealth for errors or omissions, and the Commonwealth does not accept responsibility in respect of any information or advice given in relation to, or as a consequence of, anything containing herein.

Self-sustaining native populations
Translocated and stocked populations
Historic range
Cities & Towns
State Border
Major Perennial Rivers
Major Non-perennial Rivers

6/11/2017

Figure 3*: Current and historical distribution of Macquarie perch in south-eastern Australia*

5.1 Historical distribution

The natural, historical geographical distribution of the Macquarie perch include all major river systems in the southeastern part of the Murray-Darling Basin in New South Wales, the Australian Capital Territory and Victoria and the two eastern draining systems, the Hawkesbury-Nepean and the Shoalhaven, in southeasternNew South Wales (Figure 3). Within the Murray-Darling Basin, the species once ranged from the Macquarie River catchment in New South Wales in the north, where the type specimen was caught, southwards and then west in Victoria to the Loddon River catchment in central Victoria in the south (Cadwallader 1981; Faulks et al., 2010; Trueman 2011). In between these two catchments, the species was present in the Lachlan, Murrumbidgee, Murray, Mitta Mitta, Kiewa, Ovens, Goulburn-Broken and Campaspe river catchments (Cadwallader 1981). In eastern draining river catchments in New South Wales, the species was naturally found from the Hawkesbury-Nepean in the north, south to the Shoalhaven river catchment, including the Georges River catchment which occurs between these two (Faulks et al., 2010). In South Australia, it was likely that the species was scarce in the lower Murray River (Trueman 2011).

The population in the Queanbeyan River and in Googong Reservoir (its dam across the Queanbeyan River completed in 1979) is considered to be effectively extinct (Lintermans pers. comm., 2015). Upstream of Googong Reservoir, a translocated population was established in the upper Queanbeyan River soon after the completion of the dam (Lintermans 2013a). The fish were translocated from Googong Reservoir after monitoring showed that natural breeding was no longer occuring in the reservoir due to a waterfall preventing access to riverine habitats (Lintermans 2013a). This population was considered to have declined based on observations from net surveys for the species between 2001–2006, and given there was no evidence of detectable recruitment since 2001 (Lintermans 2013a). Monitoring of the upper Queanbeyan River since 2006 has only detected a single individual (in 2007), and it is likely that the species is now effectively extinct in this catchment (Lintermans 2013a; Lintermans pers. comm., 2015).

In the Murray-Darling Basin, Macquarie perch are typically found in the cool, upper reaches of river catchments (Cadwallader 1981; Lintermans 2007; Trueman 2011), however recent analysis of oral history records, newspaper records and photographs has identified that in some Victorian catchments the species was also once considered abundant in the mid to lower reaches (Trueman 2011). A summary analysis of these historical records made the conclusion that in New South Wales and the Australian Capital Territory, the species was most abundant in upland zones. In Victoria the species was most abundant in slopes zones of river catchments but it was also noted that the species could not reach the higher ‘upland’ and ‘montane’ elevations in some catchments due to waterfall barriers, therefore possibly influencing the analysis (Trueman 2011). In the Ovens and Goulburn river catchments in Victoria especially, the species was commonly caught in lagoons in the ‘slopes’ and ‘lowland’ zones (Trueman 2011).

While analysis of the oral history records has concluded that the species was most abundant in upland and slopes zones of river catchment in the Murray-Darling Basin, there are a number of reliable records of the species having once been common in some of the lowland habitats of the Victorian rivers connecting to the Murray River (Cadwallader 1977; 1981; Mallen-Cooper & Brand 2007; Trueman 2011).

5.2 Present natural distribution

While there are existing populations of Macquarie perch in the Murray-Darling Basin and in eastern drainage catchments in New South Wales (Figure 3), populations are often small and geographically isolated (Lintermans 2007; Faulks et al., 2010; Pavlova et al., 2017a). The species is now absent from much of its former range. In New South Wales, the species still occurs in parts of the Lachlan, Murrumbidgee in the Murray-Darling Basin, and in the east coast catchments, the Hawkesbury-Nepean system and the Georges River (Lintermans 2007; Faulks et al., 2010). In the Australian Capital Territory, the species still occurs in the Cotter River catchment, which flows into the Murrumbidgee River, and the Murrumbidgee River itself, however it is now only in extremely low abundance in the Murrumbidgee River (Lintermans 2007; Lintermans unpub. data, cited in Lintermans 2013a). In Victoria, the species still occurs in the Mitta Mitta, Ovens and Goulburn-Broken river catchments (Lintermans 2007) (Figure 3).

The populations of Macquarie perch in impoundments such as Lake Eildon, Victoria (its dam completed in 1929 in the Goulburn River catchment) and Lake Burrinjuck, New South Wales (its dam completed in 1928 in the Murrumbidgee River catchment) initially sustained significant recreational fishing pressure but ultimately declined dramatically, with the species now extinct from both reservoirs (Cadwallader & Rogan 1977; Douglas et al., 2002; Lintermans 2006a; 2007; 2012). The Macquarie perch population within Lake Dartmouth, Victoria (its dam completed in 1979 in Mitta Mitta river catchment) also underwent a major decline, but has shown recent signs of recovery following increased reservoir productivity and increased restrictions on recreational catch (Hunt et al., 2011, Tonkin et al., 2014). Within 12 years of the completion of Dartmouth Dam, the species disappeared from the Mitta Mitta River downstream of the dam (Koehn et al., 1995; Lugg & Copeland 2014).

New South Wales and Australian Capital Territory

Below Cotter Dam (original dam completed in 1915 across the Cotter River, Murrumbidgee River catchment), Macquarie perch are sometimes recorded in the Cotter River and individuals are likely to have originated from the upstream reservoir (Lintermans 2002). Above the dam, Macquarie perch are now found in Cotter Reservoir and for a possible 27 km of the Cotter River upstream of the reservoir and downstream of Bendora Reservoir, now that a fishway has been installed at Vanity's Crossing since 2001 and Pipeline Crossing since 2012 (Lintermans 2002; 2007; Ebner & Lintermans 2007; Lintermans 2012; Broadhurst et al., 2013).

A targeted survey undertaken in 1998 and 1999 failed to locate Macquarie perch in any of the Yass, Bredbo, Numeralla, Kybean, and Big Badja rivers of the Murrumbidgee River catchment (Lintermans 2002), where they once occurred. The survey recorded in very low numbers in the Goodradigbee River and reasonable numbers in the upper Murrumbidgee River from Cooma to Yaouk (approximately 1100 m a.s.l) (Lintermans 2002). The population in the Goodradigbee River is now considered extinct following a major bushfire in the catchment followed by a large rain event (NSW DPI pers. comm., 2017). More recent surveys indicate a small population persists in the upper Murrumbidgee River near 'Cooma Gorge' at Binjura Nature Reserve (upstream of Cooma and downstream of Tantangara Dam) (unpub. data., cited in Lintermans pers. comm., 2017).

No Macquarie perch have been reported from downstream of Wyangala Dam (dam completed in 1935 across the Lachlan River) for many decades (Trueman pers. comm., cited in Gilligan et al., 2010). Sampling in the Lachlan River catchment upstream of Wyangala Dam between 2006–2008, reported catching no Macquarie perch in the impoundment waters itself, but found Macquarie perch to be proportionally the most common large native fish in the Abercrombie and the Lachlan rivers (Gilligan et al., 2010). However, it appears likely that the species is extinct from the Lachlan River upstream of Lake Wyangala (Pearce et al., 2017). The species has not been detected in the Lachlan River above Lake Wyangala since 2008 (NSW DPI pers. comm., 2016).

Natural populations of Macquarie perch still occur in the east coast catchments of the Hawkesbury-Nepean river system and the Georges River (Faulks et al., 2010). It is likely that the natural population that once occurred in the Shoalhaven River is now extinct, with the last known population in the catchment, in the Mongarlowe River, presumed to be a result of translocated individuals from the Murray-Darling Basin (Harris & Rowland 1996; Lintermans 2008; Faulks et al., 2010). A recent analysis of the only available individual genetic sample for the Shoalhaven River lineage (caught in the Kangaroo River) was homozygous at 90 per cent of loci, which suggests that loss of genetic variation and individual inbreeding accompanied extinction of the endemic Shoalhaven lineage (Pavlova et al., 2017a). Where Macquarie perch persist in eastern catchments, they mostly occur in waterways upstream of where Australian bass populations are located (Harris & Rowland 1996).

Victoria

Recent observations have shown self-sustaining native populations of Macquarie perch are still present in Victoria in the upper tributaries of the Goulburn-Broken river system (King Parrot, Hughes, Holland's creeks and the Broken River), the Ovens River catchment (including the Buffalo River tributary) and the upper Mitta Mitta River (including Lake Dartmouth) (ARI 2007; Ayres 2009; Hunt et al., 2011; Nguyen et al., 2012; Tonkin et al., 2014; Kearns & Tonkin 2015). While recent surveys have detected a few individuals in the Goulburn River 2.5 km downstream from the King Parrot Creek confluence (near Kerrisdale) (GBCMA 2015; Kearns & Tonkin 2015), adults are rare in the Goulburn River and it is too early to see the benefits of stocking. Anecodotal reports from fishers indicate that a small native population also persists upstream and downstream from Lake Nillahcootie in the Broken River (Kearns & Tonkin 2015).

Genetic work on Macquarie perch in Victoria has identified relatively low levels of genetic diversity within discrete populations occurring there (Nguyen et al., 2012; Pavlova et al., 2017a). All Victorian populations of Macquarie perch represent different genetic clusters except individuals from Holland's Creek and Lake Dartmouth, potentially due to the stocking Holland's Creek with fish from Lake Dartmouth (Pavlova et al., 2017a).

5.3 Translocated populations

A number of translocations of Macquarie perch have occurred within and outside its former natural range. Viable populations of fish sourced from the Murray-Darling Basin now exist in the Yarra River in Victoria (outside its natural range), in the Mongarlowe River (in the former natural range of the Shoalhaven River lineage) and in Cataract Reservoir (in the former natural range of the Hawkesbury-Nepean lineage) in New South Wales.

These translocated populations of Macquarie perch represent important sources for translocations back into existing populations given they contain important genetic diversity no longer present in the remaining Murray-Darling Basin (Pavlova et al., 2017a). These populations and the habitat they occur within, should be protected and restored. If these populations collapse, an important part of the genetic heritage of the species would be lost forever.

New South Wales and the Australian Capital Territory

Outside natural range translocations

Macquarie perch were translocated from the Murray-Darling Basin (most likely from the Murrumbidgee River) to the Mongarlowe River, and the Shoalhaven River itself at Nithsdale, on multiple occasions in the late-1800s (likely to be the 'perch' referred to in the *Sydney Mail*, 22 April 1876, p. 530; *Goulburn Evening Penny Post*, 1 June 1897, p. 4). The translocated population in the Mongarlowe River once flourished, but has declined considerably since the 1970s (Lintermans 2008). The species was also translocated to Cataract Reservoir (Nepean River catchment) and the Nepean River itself near Sydney using fish captured from the Berembed Weir area of the Murrumbidgee River in around 1916 (SFD 1914; 1923).

Historically, Macquarie perch were translocated from the upper Murrumbidgee River near Cooma to two locations in the Snowy River (Stead 1913). The species has not since been recorded from the Snowy River.

Within natural range translocations

A number of translocations of Macquarie perch within its natural range have occurred in the Australian Capital Territory and surrounding parts of New South Wales. Individuals were translocated to the Queanbeyan River upstream of Googong Reservoir in New South Wales and the Cotter River to the area upstream of Vanitys Crossing before a fishway was installed at this barrier (Lintermans 2006a; 2006b; 2013a). Both of these translocations have been ultimately unsuccessful in creating viable, long-term, self-sustaining populations.

There have been translocations of Macquarie perch from Cotter Reservoir to the Cotter River above Corin Dam (at 1000 m a.s.l.) commencing in 2006 and to the Molonglo River in Kowen Forest commencing in 2007 (Lintermans 2013b; ACT Gov pers. comm., 2017). However, while survival has been detected, recruitment has not been detected at either location to date (Lintermans 2013b; Todd & Lintermans 2015; ACT Gov pers. comm., 2017).

Victoria

In the past, Macquarie perch were translocated, most likely in batches containing a mixture of other 'perch species' such as golden perch and silver perch (*Bidyanus bidyanus*), widely within and outside its natural distribution in Victoria (Cadwallader 1981).

Outside natural range translocations

It is considered that the species was introduced to the Yarra River catchment in 1857 from upper parts of King Parrot Creek via the upper Plenty River which ultimately flows into the Yarra River (Wilson 1857) and further translocations of approximately 18 000 individuals between 1909–1927 from various waterways, one of the source locations being recorded as Goulburn Weir (Cadwallader 1981; Barnham 1989; NFA pers. comm., 2017) for recreational fishing opportunities.

Within natural range translocations

Macquarie perch were naturally found in Seven Creeks near Euroa up to a natural barrier in the form of the Gooram Falls. During 1921/22 juvenile Macquarie perch were translocated upstream of the falls to near Strathbogie from the Seven Creeks itself and from the Goulburn River at Cathkin and have persisted as a self-sustaining population from downstream of Polly McQuinns

Weir to around the Galls Gap Road's westernmost crossing of the waterway (Kearns & Tonkin 2015). Other translocated populations were established in the Barwon, Latrobe and Wannon rivers but these are all now considered extinct (Cadwallader 1981; ARI pers. comm., 2017).

In western Victoria, still within the Murray-Darling Basin and to the west of the its natural, historical distribution, Macquarie perch were translocated into the Wimmera River catchment and into the Loddon River catchment, which likely represented the most western catchment containing natural populations at the time of European settlement, but these populations were likely supplemented with translocated Macquarie perch as early as 1873 (Trueman 2011). Fish sourced from the Goulburn River were translocated into the Bet Bet Creek, Tullaroop Creek and Lake Daylesford in the Loddon River catchment in the 1930s (Cadwallader 1981). Fish sourced mainly from the Goulburn River were also translocated into waterways within the Wimmera River catchment between about 1910–1930s (Cadwallader 1981). The species is considered extirpated from the Wimmera River catchment (Lintermans 2007; Vic DELWP pers. comm., 2015). Recent stockings have occurred in Expedition Pass Reservoir, which is part of the Loddon River catchment (see below in '5.4 Stocked populations').

Recently, there has been translocation of sub-adult individuals from the Lake Dartmouth population in the Mitta Mitta River catchment to the middle reaches of the Ovens River in addition to stocked juveniles/fingerlings (see below in '5.4 Stocked populations') with the aim of establishing a range of age and developmental stages that are similar to those which exist in natural populations (Vic DEPI 2014a). Recent surveys have demonstrated that both translocated and stocked fish are surviving with some evidence of natural recruitment (Vic DELWP unpub. data, cited in ARI pers. comm., 2017). There have also been individuals translocated from Lake Dartmouth to Lake William Hovell, a dammed reservoir on the King River (Ovens River catchment) in Victoria (Vic DEDJTR 2015a).

5.4 Stocked populations

Until recently, most hatchery programs for Macquarie perch have relied on capturing spawning-run fish from the wild (NSW DPI 2010) and inducing individuals to spawn through the injection of artificial hormones to collect the eggs and sperm. While the species can live in impoundments, as a truly riverine species it requires fast-flowing water with gravel-cobble substrates to breed (Cadwallader & Rogan 1977; Appleford et al., 1998; Lintermans 2007; 2013).

The requirement for flowing water conditions to stimulate breeding in Macquarie perch is supported by the many failures of impoundment populations to be self-sustaining. Research on the now extinct Queanbeyan River population of the species found evidence of recruitment until 2001 but not thereafter, and this may have been the effect of the millennium drought (between 1997–2010) (Lintermans 2013a). The millennium drought would have reduced the frequency of available fast-flowing conditions in the waterway available to the species, and also decreased opportunities for fish to move between habitats in the river, and this could explain the persistent breeding failure since 2001 (Lintermans 2013a).

There have been a number of breeding investigations for Macquarie perch to support a hatchery production source. Early attempts were made in the early-1900s to artificially propagate Macquarie perch in New South Wales with little success (Trueman 2007). There are also reports of a backyard hatchery operating in the Heidelberg area in Victoria which successfully spawned captive Macquarie perch in the 1930s, however the exact procedure used was never disclosed (Trueman 2007). Observations made by a landowner in 1976 on his property at Strathbogie in Victoria, who kept Macquarie perch in small dams noticed a pair of fish engaging in spawning activity near where a small perennial brook entered the pond they were kept within (Trueman 2007). Unsuccessful attempts were made by the Victorian Government between the late-1950s to early-1960s to produce juvenile Macquarie perch from broodstock sourced on their annual spawning run from the Goulburn and Jamieson rivers upstream of Lake Eildon (Trueman 2007). Research on developing hatchery produced Macquarie perch began in 1978 at the Narrandera Fisheries Centre (formerly the Inland Fisheries Research Station (IFRS)) in New South Wales trialling hormonal treatments to induce spawning with limited success (Ingram et al., 1994). The New South Wales Government halted its captive breeding research on the species in 1990 until the early-2000s, due to this lack of success (Ingram et al., 1994; NSW DPI 2010). Trials beginning in 1983 at Snobs Creek Fish Hatchery in Victoria, involved catching males and running-ripe females from Lake Dartmouth during their annual spawn run into the inflowing Mitta Mita River (Gooley & McDonald 1988; Trueman 2007). Hormonal treatments were administered to the captured fish at the hatchery, however there was limited success in producing large numbers of juveniles (Trueman 2007). In 1994, the independent group – Native Fish Australia (Victoria) (NFA Vic), were able to induce spawning of Macquarie perch sourced from the Yarra River, at hatchery facilities provided by La Trobe University and reared 5000 juveniles to a size of 25 mm for release into the Yarra River near Warrandyte (Trueman 2007). This was the first reported example of Macquarie perch completing final oocyte maturation and ovulation under artificial conditions (Trueman 2007). NFA Vic intends on breeding Macquarie perch in 2017 for stocking into Victorian catchments (NFA pers. comm., 2017).

The Narrandera Fisheries Centre has had success in breeding the species in captivity, using a new approach employing an artificial stream with flowing water and coarse substrates to coax both males and females into breeding condition (NSW DPI 2010). The Victorian program at Snobs Creek Fish Hatchery was halted in the mid-1990s, primarily due to difficulties in attaining mature fish in spawning condition captured from Lake Dartmouth (Gray et al., 2000; Ingram et al., 2000). Fingerling production for stocking recommenced in 2010 (Vic DEDJTR 2015b), and the successful induction of spawning and hatching of larvae from captive-held broodstock at Snobs Creek Fishery Hatchery occurred in 2010 and 2011, however results were still inconsistent and further research is needed to refine the methods (Ho & Ingram 2012). Between 1986–1997 approximately 456 000 juveniles, sourced from production at the Snobs Creek Fish Hatchery, were released into nine sites throughout the Murray-Darling Basin (Ingram et al., 2000). Since 2000, an approximately 165 000 juveniles have been stocked into Victorian waters (see below).

New South Wales and the Australian Capital Territory

Captive breeding trials using broodstock collected from the Abercrombie River (Lachlan River catchment) in 2008 successfully bred Macquarie perch in 2010 in a purpose built pond with artificial stream habitat without the use of "ripe"/spawning run fish (Pearce et al., 2017). In 2011 and 2012, 136 and 7500 Macquarie perch were stocked into the Retreat River, a tributary of the Abercrombie River (Pearce et al., 2017). The Retreat River was chosen for these stockings given it provides a suitable refuge from redfin, as a waterfall acts as a natural barrier to redfin migrating upstream from areas where they are present (Pearce et al., 2017). A third release of 11 700 fingerlings into the same stretch of the Retreat River occurred in 2014, and broodfish were released into the nearby Bolong River, also a tributary of the Abercrombie River (Pearce et al., 2017). In 2017, the first evidence of recruitment from these stocked individuals was detected with juveniles collected from the Retreat River (NSW pers. comm., 2017; Pearce et al., 2017). Fingerling production has since ceased at the Narrandera Fisheries Centre.

Victoria

Recent stockings of Macquarie perch fingerlings into Victorian waters as part of the Victorian Fish Stocking Program include:

- 2017 – 5000 into Expedition Pass Reservoir (Farraday) and 8300 in February into the Ovens River (Oxley Flats to Rocky Point).
- 2016 – 3000 in January into Expedition Pass Reservoir (Farraday) and 6400 into the Ovens River (Oxley Flats to Rocky Point).
- 2015 – 5000 in February into Expedition Pass Reservoir (Farraday); 12 750 in February into the Goulburn River (Molesworth to Trawool), and; 13 600 in February into the Ovens River (Oxley Flats to Rocky Point).
- 2014 – 5000 in February into Expedition Pass Reservoir (Farraday); 27 500 in February into the Goulburn River (Molesworth to Trawool), and; 40 500 in February into the Ovens River (Myrtleford area).
- 2013 – 5000 in January into Lake Dartmouth (Dartmouth); 5000 in January into Expedition Pass Reservoir (Farraday); 6320 in January into the Goulburn River (above Nagambie Lake to Seymour), and; 6320 in January into the Ovens River (Myrtleford area)
- 2012 – 3620 in January into Expedition Pass Reservoir (Farraday).
- 2011 – 3000 in February into Expedition Pass Reservoir (Farraday); 1325 into the Ovens River at Rocky Point and 1325 at Whorouly Bridge, and; 2650 into William Hovell Lake (Cheshunt South).
- 2010 – 2800 in February and 500 in March into Expedition Pass Reservoir (Farraday) and 250 into Holland’s Creek (Tatong) in February (Gray 2010; Vic DEPI 2014a; 2014b; Vic DEDJTR 2015b; VFA 2017).

Fingerlings have also been previously stocked in the Upper Coliban Reservoir near the town of Tylden (Lintermans, 2007), however this population is likely extirpated (Vic DELWP pers. comm., 2017).

The small Macquarie perch population in Yea River is likely to be derived from the stockings which occurred there in the 1980s and 90s (Kearns & Tonkin 2015). At least three age cohorts have been observed there, confirming natural recruitment is occurring, albeit at very low levels (Kearns & Tonkin 2015).

6 Decline and Threats

6.1 Decline

There was a lack of focussed scientific studies when the main declines for Macquarie perch occurred between the 1920–1960. The best known work of early accounts of the fish fauna of the Murray-Darling Basin was conducted by Colonel John O. Langtry between 1949–1950 (Cadwallader 1977). Langtry’s study focussed on lowland habitats and, as Langtry notes, followed significant changes to the native fish compositions in the system already (Cadwallader 1977; Trueman 2011).

However, the research of oral histories, newspaper records and photographs undertaken by Trueman (2011), obtained more records in the Murray-Darling Basin of Macquarie perch than for any other individual species, which suggests that its abundance was ‘prolific’ in the first 100 years of European settlement of Australia. Trueman (2011) uses an approach referred to as ‘historical triangulation’, which is becoming increasingly accepted in documenting environmental change in ecological studies. Triangulation refers to the practice of using two or more sources to verify observations, and its use is well established in the social sciences and is used by doctors when evaluating patient history (Robertson et al., 2000). Oral histories are particularly powerful for river management in Australia, in that they provide information that precedes formal agency or research institution records (Boulton et al., 2004). Trueman (2011) utilised photographs, newspaper stories and supporting accounts to verify oral recollections of lay observers (oral histories). For Macquarie perch, this historical research uncovered, and also confirmed that significant declines in the species’ populations were evident by the early twentieth century in some areas, and that widespread population extinctions occurred between 1920–1960 (Trueman 2011).

The conclusions of Trueman’s (2011) research for Macquarie perch are supported by the work of the “Sustainable Rivers Audit” (SRA), which undertook a systematic assessment of the health of all river ecosystems in the Murray-Darling Basin for the Murray-Darling Basin Authority. The assessment was undertaken on each of the 23 major river valleys in two reports, SRA1 using data collected between 2004–2007 and SRA2 between 2008–2010 (Davies et al., 2008; 2012). ‘Rarity’ scores were developed by an expert panel for each fish species based on the likelihood of a species being found at a site, using the SRA sampling methods, if the encompassing altitudinal zone is in ‘Reference Condition’ (i.e. that is in a ‘condition that would be likely to prevail now had there been no significant human intervention in that region’) (Davies et al., 2008; 2012).

By the end of the 1960s, endemic populations in New South Wales and the Australian Capital Territory were largely restricted to the upper Lachlan and Murrumbidgee river catchments, with a small population persisting in Mannus Creek in the upper Murray River catchment (Trueman 2011; Long 2017). In Victoria by the end of the 1960s, relict populations were restricted to the slopes and upland zones of the Mitta Mitta, Ovens and Goulburn-Broken river catchments (Trueman 2011).

New South Wales and the Australian Capital Territory

Only five individuals were caught in two catchment valleys, the Goulburn and the Murrumbidgee river valleys, in sampling for the Sustainable Rivers Audit of the Murray-Darling Basin between 2004–2007 (Davies et al., 2008) and 12 individuals were caught in three valleys, the Broken, the Goulburn and the Murrumbidgee, between 2008–2010 (Davies et al., 2012).

Macquarie perch were captured regularly in the Macquarie River catchment in New South Wales until the 1950s but historical research indicates that the species had disappeared and become extinct in the catchment by the 1960s (Trueman 2011). The estimate of the species’ abundance in the Macquarie River catchment at the time of European settlement were rated as: rare in the lowland zone of the Macquarie River catchment; common in the slopes zone, and; abundant in both the upland and montane zones of the catchment (Trueman 2011). SRA1 and 2 recorded no Macquarie perch in surveys at 21 sites across the catchment both in 2007 and 2009 (Davies et al., 2008; 2012). SRA rarity scores for the species in the Macquarie River catchment were: absent in the lowland zone; occasional in the slopes zone; common in the upland and montane zones (these zones were merged in the SRA analysis for the Macquarie River catchment) (MDBA 2017).

For the Lachlan River catchment, historical research indicates that Macquarie perch initially flourished in Lake Wyangala in the 1930s soon after its construction (Trueman 2011). However, the species experienced a decline in the Abercrombie and Lachlan rivers above Lake Wyangala in the 1950s and 1960s, while downstream of Wyangala Dam decline was noted in the 1930s (Trueman 2011). It is almost certain that the species is now extinct in the Lachlan River downstream of Wyangala Dam (Gilligan et al., 2010). The estimate of Macquarie perch abundance in the Lachlan catchment at the time of European settlement were rated as: absent from the lowland zone; occasional from the slopes zone, and; abundant from both the upland and montane zones (Trueman 2011). SRA1 and 2 recorded no Macquarie perch in surveys at 28 sites across the catchment both in 2006 and 2009 (Davies et al., 2008; 2012). SRA rarity scores for Macquarie perch in the Lachlan River catchment were: absent in the lowland zone; occasional in the slopes zone, and; common in the upland and montane zones (Davies et al., 2008; MDBA 2017). While Macquarie perch were not caught in the Lachlan River catchment during the SRA1 and 2 surveys (Davies et al., 2008), the species is known to occur in parts of the Abercrombie River (Pearce et al., 2017). The species has not been recorded in the Lachlan River upstream of Lake Wyangala since 2008 where it is now considered extinct (NSW DPI pers. comm., 2016; Pearce et al., 2017). There have been stockings of the species into the Retreat River betweem 2011–2014 and recruitment has been detected from these stocked individuals (Pearce 2013; Pearce et al., 2017).

For the Murrumbidgee River catchment, historical research indicates that for the majority of the catchment the Macquarie perch declined in abundance between the 1930s–1960s and by the 1980s had become rare in many parts of the catchment (Trueman 2011). Initially, the species flourished in Lake Burrinjuck after its construction in the early-1900s until at least the 1950s (Trueman 2011), and indications are that it remained common in the lake until the 1980s, as the species was reported as abundant there in 1986 (Burchmore et al., 1988). and then declined to the point that by the 1970s it could only be caught during spawning migrations into upstream areas and by the 1980s it was considered rare (Trueman 2011). The species declined sharply in the Murrumbidgee River upstream from Lake Burrinjuck in the Australian Capital Territory during the 1980s (Lintermans 2002). A relict population of the species continues to remain strong in the Cotter Reservoir on the Cotter River in the Australian Capital Territory (Lintermans 2012; Farrington et al., 2014). The species is now considered extinct in the Queanbeyan River upstream of Googong Reservoir (the Queanbeyan River is a tributary of the Molonglo River, which in turn is a tributary of the upper Murrumbidgee River) (Lintermans pers. comm., 2015). A translocated self-sustaining population had persisted in the Queanbeyan River and had shown signs of recruitment until the early 2000s but declined thereafter (Lintermans 2013a). The estimate of Macquarie perch abundance at the time of European settlement for the Murrumbidgee River catchment were rated as common from the lowland zone and abundant from the slopes, upland and montane zones (Trueman 2011).

SRA1 and 2 recorded three and 10 Macquarie perch individuals in surveys at 28 sites across the Murrumbidgee River catchment both in 2007 and 2008 respectively (Davies et al., 2008; 2012). SRA rarity scores for the species in the catchment were: rare in the lowland zone; occassional in the slopes zone, and; common in the upland and montane zones (MDBA 2017).

For the Upper Murray River catchment, historical research indicates that the Macquarie perch declined in abundance from the time of World War I to the 1930s (Trueman 2011). The species was abundant in the area near Khancoban in New South Wales until the 1930s when they became sparse (Harris et al., 2006; Trueman 2011). The species is likely to have disappeared from the upper Cudgewa Creek catchment in Victoria, which flows into the Upper Murray River, after about 1920 (Trueman 2011). This trend appears to be consistent with records further downstream, within the Murray River and creeks near Burroweye and Towong, where recordings of Macquarie perch seem to decline until the 1930s (Trueman 2011). The exception seems to be Mannus Creek, where it appears a population of Macquarie perch have persisted and were rediscovered in early-2017 (Long 2017). Downstream on the Upper Murray River near Albury, the species was common in the late-1920s but underwent a dramatic decline shortly after that time (Trueman 2011). In general, very few historical records exist for native fish in the montane zone of the Upper Murray River (upstream of the Tom Groggin campground which is close to the New South Wales-Victoria border within the New South Wales' Kosciuszko National Park) (Trueman 2011). Much of the Upper Murray River occurs within the slopes zone. Macquarie perch abundance has been estimated at the time of European settlement for the Upper Murray River catchment as: abundant in the slopes zone, and; common in both the upland and montane zones (Trueman 2011).

SRA1 and 2 recorded no Macquarie perch in surveys at 21 sites across the Upper Murray River catchment both in 2005 and 2008 (Davies et al., 2008; 2012). SRA rarity scores for the species in the catchment were: common in the slopes zone; occasional in the upland zone, and; rare in the montane zone (MDBA 2017).

The middle or Central Murray River catchment, stretching from Wentworth in the west (very near to the the confluence of the Murray and Darling rivers) to Albury-Wodonga in the east, is unusual for assessment of Macquarie perch abundance, as this part of the river is entirely zoned as lowland for purposes of Trueman's 2011 analysis. Historical research indicates a consistent trend of the species' decline in abundance occurring during the 1930s and becoming severely 'depleted' by the 1950s (Trueman 2011). The species had completely disappeared from most of the Central Murray River catchment by the 1970s (Trueman 2011). The stretch of river between Tocumwal eastwards to Yarrawonga was an exception where the species was common until about 1950, then declined in abundance until they had disappeared in this area by the end of the 1980s (Cadwallader 1977; Trueman 2011). The estimate of Macquarie perch abundance at the time of European settlement for the Central Murray River catchment were rated as: rare in the Murray River between Wentworth eastwards to the Wakool River confluence; common between the Wakool River confluence eastwards to Echuca (Campaspe River confluence); abundant between Echuca eastwards to Albury-Wodonga in these lowland zones of the Murray River (Trueman 2011). SRA1 and 2 recorded no Macquarie perch in surveys at 21 sites across the Central Murray River catchment both in 2005 and 2008 (Davies et al., 2008; 2012). SRA rarity scores for the species in the catchment were: rare in the lower zone (Wentworth eastwards to Murrumbidgee River confluence); occasional in the middle zone (Murrumbidgee River confluence eastwards to Hume Dam), and; rare in the Edwards-Wakool anabranch zone (MDBA 2017). Long term fish monitoring in the Murray River between Yarrawonga and Cobram between 1999–2017 has not detected the species in this reach (Lyon et al., 2014; ARI unpub. data, cited in ARI pers. comm., 2017).

For eastern Macquarie perch, which occurred in the Hawkesbury-Nepean, Georges and Shoalhaven catchments at the time of European settlement and for some time afterwards (Faulks et al., 2010; 2011; Pavlova et al., 2017a; 2017b), the species is still present in fragmented populations in the upper Hawkesbury-Nepean catchment, in tributaries of Lake Burragorang (the lake formed by Warragamba Dam) and the Warragamba River and tributaries of the Nepean River (Knight 2010) and tributaries of the Colo River, which flows into the

Hawkesbury River (Faulks et al., 2011). The natural population in the Shoalhaven River catchment declined rapidly during the late-1990s, genetic analysis of the an individual captured in the Kangaroo River was homozygous at 90 per cent of loci, which suggests that loss of genetic variation and individual inbreeding accompanied extinction of the endemic Shoalhaven lineage (Pavlova et al., 2017a). However, a translocated population remains in the Shoalhaven catchment in the Mongarlowe River derived from individuals from the Murray-Darling Basin (Faulks et al., 2010; 2011). The Mongarlowe River population has declined dramatically since it was first studied in the 1970s (Bishop 1979; Lintermans 2008). A translocated population persists in Cataract Reservoir near Bulli Tops on the Cataract River, a tributary of the upper Nepean River. This population is of Murray-Darling Basin origin and it appears that individuals from this Reservoir population have dispersed downstream where some interbreeding with the naturally occurring Hawkesbury-Nepean lineage is evident (Faulks et al., 2011; Pavlova et al., 2017a). There is no evidence of interbreeding within Cataract Reservoir (Pavlova et al., 2017a).

Victoria

For the Mitta Mitta River catchment, historical research indicates that for the majority of the catchment, Macquarie perch declined in abundance between in the 1930s and by the end of the World War II the species was rare in the catchment above the Larsens Creek confluence (before Lake Dartmouth was made) and by the 1950s had become scarce throughout the catchment and until the 1970s had contracted to the area of the Dart Creek/River confluence (also now swamped by Lake Dartmouth) and had become rare in many parts of the catchment (Trueman 2011). Soon after Lake Dartmouth was constructed and flooded in the 1970s, the population of Macquarie perch initially flourished becoming reasonably abundant and supporting a recreational fishery (Hunt et al., 2011; Trueman 2011). Below the Lake Dartmouth dam wall, Macquarie perch disappeared in the Mitta Mitta River within twelve years of its completion in 1979 (Koehn et al., 1995; Lugg & Copeland 2014). A decline in the species' abundance then was observed for Lake Dartmouth between the mid-1980s–2000 (Douglas et al., 2002; Hunt et al., 2011). The estimate of Macquarie perch abundance at the time of European settlement for the Mitta Mitta River catchment were rated as: abundant from both the slopes zone and upland zones, and; common from the montane zone (Trueman 2011). Recreational fishing of the species is currently permitted in Lake Dartmouth, with a daily bag limit of one fish, but the Victorian Government has tightened regulations associated with catching the species by increasing the legal minimum length from 250 mm to 300 mm in 2000, and then to 350 mm in 2004 (Hunt et al., 2011, Vic DEDJTR 2015c). There have been recent indications that the Lake Dartmouth population is recovering following years of higher rainfall that have resulted in greater inflows to the lake between 2008–2013, leading to increased biological productivity in the impoundment (Tonkin et al., 2014). SRA1 and 2 recorded no Macquarie perch in surveys at 21 sites across the Mitta Mitta River catchment both in 2005 and 2008 (Davies et al., 2008; 2012). SRA rarity scores for the species in the catchment were: common in the slopes and upland zones, and; rare in the montane zone (MDBA 2017).

For the Kiewa River catchment, historical research indicates that for the slopes zone of the catchment, Macquarie perch were abundant until a massive fish kill in 1939 in the catchment, initiated by extensive bushfires in the catchment in February (Rhodes 1999; Trueman 2011). The steep gradient between the slopes zone and the upland and montane zones of the Kiewa catchment is thought to have prevented access of Macquarie perch, and other native fish species, to these higher areas (Trueman 2011). It is now considered that the species is extinct in the Kiewa River catchment. The estimate of Macquarie perch abundance at the time of European settlement for the Kiewa River catchment were rated as: abundant from the slopes zone, and; absent from the upland and montane zones (Trueman 2011). SRA1 and 2 recorded no Macquarie perch in surveys at 21 sites across the Kiewa River catchment both in 2006 and 2009 (Davies et al., 2008; 2012). SRA rarity scores for the species in the catchment were: occasional in the lowland zone, and occasional in the slopes zone, and; absent from the upland and montane zones (these zones were merged in the SRA analysis for the Kiewa River catchment) (MDBA 2017).

For the Ovens River catchment, historical research indicates that, for the upland zone, Macquarie perch and other native fish were scarce since the early-1900s, with the exception of the Buffalo River where the species remained in good populations until fish kills following extensive bushfires in 1939 (Trueman 2011). For the slopes area of the catchment, Macquarie perch declined during the 1920s and 1930s and had disappeared from many areas by the 1940s (Trueman 2011). In the lowland areas of the catchment, the species declined during the 1930s and 1940s to the point where they were scarce during the late-1940s (Trueman 2011). The montane zone in the Ovens River catchment is essentially isolated from lower elevations of the catchment by steep gradients and waterfalls at the base of Mount Buffalo and the Wabonga Plateau, and given that there is no information for larger native species in this zone, it is considered that Macquarie perch and other native species were prevented access to it (Trueman 2011). The estimate of Macquarie perch abundance at the time of European settlement for the Ovens River catchment were rated as: abundant from the lowland, slopes and upland zones, and; absent from the montane zone (Trueman 2011). SRA1 and 2 recorded no Macquarie perch in surveys at 26 sites in 2007 and 28 sites in 2010 across the Ovens River catchment (Davies et al., 2008; 2012). SRA rarity scores for the species in the catchment were: common in the lowland zone; occasional in the slopes and upland zone; and; absent in the montane zone (MDBA 2017). The species was detected in low abundances in the Buffalo River upstream of Lake Buffalo up until 2011, but there have been no surveys since (ARI pers. comm., 2017).

For the Goulburn-Broken river catchments, historical research indicates that, for the majority of this major river system, Macquarie perch had declined during the 1920s and had disappeared from most of the Goulburn-Broken river catchments by the 1950s (Trueman 2011). There were a few exceptions though, such as the Yea River King Parrot, Hughes and Seven creeks, in the Goulburn River catchment, and the lower Broken River near Benalla and Nalinga, where populations remained at least until the 1970s. A relict population has remained in the lower reaches of King Parrot Creek downstream of Flowerdale, but the species had disappeared from its upper reaches in the early 1900s, this population having been the source for the 1857 translocation to the Yarra River catchment (Wilson 1857; Trueman 2011). In Lake Eildon, which was initially filled by the construction of the Eildon Weir on the Goulburn River in 1929 and then expanded in 1956, the Macquarie perch population initially flourished but subsequently declined and went extinct by the late-1960s (Cadwallader & Rogan 1977; Trueman 2011). After the construction of Lake Nillahcootie on the upper Broken River in 1967, a population of Macquarie perch has continued to persist and the species was recorded in low abundance in 2016 above and below the lake (ARI unpub. data, cited in ARI pers. comm., 2017). Populations in Ryan and Holland's Creeks declined until the 1960s and became scarce (Trueman 2011). The estimate of Macquarie perch abundance at the time of European settlement for the Goulburn-Broken river catchments were rated as: abundant from the lowland and slopes zones; common in the upland zone, and; rare from the montane zone (Trueman 2011). Self-sustaining populations still exist in Holland's Creek near the township of Tatong in the Broken River catchment and in the lower to middle reaches of Hughes Creek, upstream of the township of Avenel, in the Goulburn River catchment (ARI 2007; Raymond et al., 2008).

SRA1 and 2 recorded zero and one Macquarie perch individual in surveys at 19 and 18 sites across the Broken River catchment both in 2004 and 2007 respectively (Davies et al., 2008; 2012). The one caught in 2007 surveys was recorded within the merged slopes/upland/montane zone (Davies et al., 2012). SRA rarity scores for the species in the Broken River catchment were: occasional in the lowland zone, and; occasional in the merged slopes/upland/montane zone (MDBA 2017). SRA1 and 2 recorded two and one Macquarie perch individuals at 21 sites across the Goulburn River catchment in 2005 and 2008 respectively (Davies et al., 2008; 2012). The two recorded in 2004 were within the upland zone, the one recorded in 2007 from the lowland zone (Davies et al., 2008; 2012). SRA rarity scores for the species in the Goulburn River catchment were: common in the lowland and slopes zones, and; common in the merged upland/montane zone (MDBA 2017).

For the Campaspe River catchment, historical research indicates that, for the lowland and slopes zones, Macquarie perch had declined in the years leading up to the early-1940s, such that translocations to the Coliban River (a tributary of the Campaspe River) from the Broken River were made in 1936 and 1962 (Cadwallader 1981; Trueman 2011). Only a very small percentage of the catchment is classified in the montane zone and waterfalls, such as Mitchells and Coliban falls, are considered to have blocked access of larger native fish species, including Macquarie perch, to upland zones and higher (Trueman 2011). The estimate of Macquarie perch abundance at the time of European settlement for the Campaspe River catchment was rated as common from the lowland zone and abundant in the slopes zone; and absent from the upland and montane zones, probably as a result of the presence of Mitchells and Coliban falls (Trueman 2011). SRA1 and 2 recorded no Macquarie perch in surveys at 21 sites in 2006/07 and 2009 across the Campaspe River catchment (Davies et al., 2008; 2012). SRA rarity scores for the species in the catchment were: occasional in the lowland; common in the slopes zone, and; rare in the merged upland/montane zone (MDBA 2017).

For the Loddon River catchment, historical research indicates that, for the lowland and slopes zones, Macquarie perch had declined in the late-1800s until they were virtually extinct by the 1930s (Trueman 2011). The Loddon River catchment is considered to have undergone the most severe environmental disturbance of all Victorian catchments during the Victorian Gold Rush years (circa 1850–1900), due to its proximity to the Victorian goldfields and the consequences of mining sludge and tailings being discharged into its waterways, and the impacts from increased siltation from the introduction of hydraulic sluicing of alluvium loosing massive quantities of topsoil in the Castlemaine district (Scott 2001). There have been recent stockings of the species into Expedition Pass Reservoir near Castlemaine in the upper catchment (Gray 2010; Vic DEPI 2014a; 2014b; Vic DEDJTR 2015b; VFA 2017). The estimate of Macquarie perch abundance at the time of European settlement for the Loddon River catchment was rated as rare from the lowland zone and abundant in the slopes zone; and rare from the upland zone which is probably a result of the presence of many waterfalls in the upper Loddon River catchment (Trueman 2011). Only a few small streams penetrate into the montane zone of the Loddon River catchment and there are no records of larger native fish being present in this zone (Trueman 2011). SRA1 and 2 recorded no Macquarie perch in surveys at 20 sites in 2004 and 18 sites in 2007 across the Loddon River catchment (Davies et al., 2008; 2012). SRA rarity scores for the species in the catchment were: rare in the lowland, and; occasional in the merged slopes/upland/montane zone (MDBA 2017).

6.2 Threats

6.2.1 Habitat degradation

Habitat degradation can include processes such as sedimentation and destruction and/or removal of rock and woody habitats (snags) essential for egg development and hatching stages of Macquarie perch.

Native fish fauna in the upper reaches of Murray-Darling Basin catchments, such as the Macquarie perch, which release eggs at downstream ends of pools to wash into riffle zones and settle into interstitial spaces between rocks and pebbles (Cadwallader & Rogan 1977; Cadwallader 1978; Tonkin et al., 2010), have probably been the most directly affected by increased sedimentation (Harris 1995). Sedimentation has been considered has one of the most important reasons for the decline of Macquarie perch populations (Cadwallader 1978; 1979).

While sediment and other suspended materials in the water column are natural components of rivers and streams, as erosion and decay processes will deliver sediment to streams even in pristine landscapes, land-use changes (especially poorly-managed agricultural practices, proliferation of rabbits in the late-1800s/early-1900s, forestry, road construction and maintenance, mineral extraction, construction activities and increased fire frequency or catastrophic bushfires) have resulted in an increase in anthropogenic fine sediment deposition in Australia (Walker et al., 1986; Waters 1995; Burkhead et al., 1997; Wood & Armitage 1997; NSW DPI pers. comm., 2017). Sedimentation is one of the most widespread physical disturbances degrading the habitats within Australian rivers (Commonwealth of Australia 1996, cited in Harris & Silveira 1999). Since European settlement, river sediment loads are estimated to have increased by 10–50 fold, with gully, riverbank and sheet erosion delivering, on average, over 120 million tonnes of sediment to Australian streams each year (NLWRA 2001). Increased levels of sediment can adversely affect many aspects of freshwater ecosystems by reducing water quality, modifying the morphology, ecology and physical form of streams and altering the physical, physiological and behavioural responses of aquatic flora and fauna (Boulton & Brock 1999; Lintermans 2013c).

Catastrophic bushfires are of particular concern to remaining Macquarie perch populations. Direct impacts of bushfire on freshwater environments are increased temperatures (Hitt 2003), increased pH (Cushing Jr. & Olson 1963) and increases in nutrients from smoke and ash inputs (Bayley et al., 1992; Earl & Blinn 2003). A study in Montana recorded water temperature rises of nearly 10°C caused by a high-severity wildfire (Hitt 2003). pH increased in a stream in Washington State from 7.8 to 11.1 with temperature increase immediately following weed burning on its banks (Cushing Jr. & Olson 1963). Potassium, and phosphorus and nitrogen compounds such as ammonium, nitrate, soluble reactive phosphorus, all increase in concentration within streams immediately following a fire (Bayley et al., 1992; Earl & Blinn 2003). Mortalities of freshwater fish from these direct impacts following bushfire have been generally confined to smaller order streams, such as the ones which Macquarie perch are known to inhabit (Cushing Jr. & Olson, 1963; Lyon & O'Connor 2008). It is considered that Macquarie perch in King Parrot Creek were heavily impacted by the Black Sunday Bushfires in 2009 where more than half the King Parrot Creek catchment was burnt (Kearns 2009, cited in. ARI pers. comm., 2017). The Goodradigbee River population disappeard following a major bushfire and subsequent large rainfall event in the late-1990s/early-2000s (NSW DPI pers. comm., 2017).

A secondary, or indirect, impact following bushfire is the increased sediment load (often referred to as a 'sediment slug') which can follow rainfall events and subsequent run-off from recently burnt ground and is often widespread (Benda et al., 2003; Meyer & Pierce 2003; Smith et al., 2011; Goode et al., 2012). A sediment slug following large bushfires in 2003 in the southern Murray-Darling Basin had major negative impacts to freshwater fish in streams in the region, including native fish (Lyon & O'Connor 2008), and while no Macquarie perch were sampled in the study despite being known from surveyed catchments, it is plausible that the species also was negatively affected as recorded for other native species in the study. In the Australian Capital Territory, the 2003 fires and subsequent rainfall caused the mortality of Macquarie perch in the Murrumbidgee and Cotter rivers (Carey et al., 2003). Following the 2009 Black Saturday Bushfires in Victoria, Macquarie perch individuals were captured from King Parrot Creek and translocated to the Snobs Creek Hatchery to protect them from the sediment slugs (Kearns 2009; Kearns et al., 2012a, both cited in ARI pers. comm., 2017; Kearns et al., 2012b; Lintermans et al., 2014). There was concern that the fires, which burnt up to the water edge of King Parrot Creek across half the catchment, would cause a sediment slug, amongst other direct and indirect effects, to form in King Parrot Creek (Kearns et al., 2012b). At the time of rescuing fish so that they could be translocated, signs of physical stress were evident with fish kills documented as likely the result of reduced water quality (Kearns 2009 cited in ARI pers. comm., 2017). It appears that Macquarie perch do not spawn evenly across habitats (Tonkin et al., 2016a) and have preference for specific sites within King Parrot Creek (Kearns et al., 2012b). Sedimentation, loss of riparian vegetation and bank erosion are all evident in King Parrot Creek, and for recovery of the species to occur, protection of spawning habitats will be greatly assisted if there is focussed action on riparian restoration and bank stabilisation to reduce sediment loads into this waterway (Kearns et al., 2012b).

Gravel beds are important habitat areas for Macquarie perch spawning, feeding and as refuge areas for juvenile fish (Lintermans 2007). Berkman & Rabeni (1987) found that fish species requiring clean cobble/gravel in riffle zones for spawning declined as fine sedimentation of substrates increased. For Salmonid species which rely on cobble/gravel for spawning, fine sediment was also found to impair the gas exchange of developing eggs by adhering to the surface of the egg (Chapman 1988). Overseas studies have found high concentrations of fine sediment increases exposure of fish to predators and physical disturbance through destruction of shelter, physical structures and hiding places, for example smothering of aquatic macrophytes (Brookes 1986; Mol & Ouboter 2004).

Deposited coarse sediment can fill deep holes, create barriers and alter stream morphology leading to wider, shallower profiles. Infilling of deep holes removes thermal refuges that many Australian native fish species, such as the Macquarie perch, rely upon during the summer and autumn months, and reduces their ability to withstand drought events (Cadwallader 1978; Coats et al., 1985). Furthermore, the nutrients and toxic substances attached to sediment particles also pose a threat to Australian native fish species (Cadwallader 1978; 1979; Lintermans 1991a; ACT Gov 1999; Horner 2000; Burton et al., 2004). Silt and clay particles can absorb, transport and store metal contaminants (Stone & Droppo 1994) so that deposited sediments act as a sink for heavy metals, with contaminated sediment potentially continuing to pose a pollution problem long after land disturbances first occurred (Trimble 1981; Mol & Ouboter 2004). Large geomorphic impacts have been observed in Hughes Creek where important habitats for Macquarie perch, including riffles, deep pools and instream woody habitats have been buried, leading to the formation of a uniform, wide, shallow-flowing sand bed stream (Kearns & Tonkin 2015; Erskine 2016).

High levels of suspended sediment will reduce light penetration leading to reduced primary productivity, submergent macrophytes, food and habitat availability for fish (Edwards 1969; Petts

1984; Power 1984; Brookes 1986; Van Nieuwenhuyse & LaPerriere 1986; Schälchli 1992; Davies et al., 1992; Richards & Bacon 1994). Suspended sediments may impact fish directly by clogging gill rakers and gill filaments leading to death (Bruton 1985). Suspended sediment will also affect the efficiency of hunting, particularly in the case of visual feeders (Vinyard & O'Brien 1976; Bruton 1985; Ryan 1991) and may also affect spawning success of fish by rendering visual courtship signals less effective (Burkhead & Jelks 2001).

In addition to sedimentation, snags (woody and rocky) have a critical role to play in the ecological functioning of rivers. Snag structures can consist of whole trees, limbs, root masses, boulders and rocks that are partly or totally submerged. Snag structures provide complex and diverse habitat for native fish and invertebrates including cover from predation, refuge from high velocity flows and feeding sites (Bilby & Likens 1990; O'Connor 1991; Crook & Robertson 1999; Treadwell et al., 1999). Snags also play a significant role in promoting different habitat elements including scour pools, bars, islands, and side-channels. Conversely removal of snags can lead to a range of detrimental effects on stream morphology including increased flow velocity, bed degradation, channel enlargement and direct loss of fish habitat (Erskine & Webb 2003). In general, associations between instream woody habitat are much stronger for fish occupying more lowland waterways, such as Murray cod (*Maccullochella peelii*), compared to those occupying smaller, more upland waterways (Tonkin et al., 2016c). However, strong positive associations were recently reported between the abundance/biomass of Macquarie perch in Hughes Creek and instream woody habitat, riparian vegetation and water depth (Tonkin et al., 2016c).

Since the mid 19th Century, thousands of snags have been removed from Australian streams and rivers, especially within the Murray-Darling Basin, in an effort to stabilise rivers (Erskine 1990; 1992; 2001) and to increase river navigability, flood mitigation and increase channel efficiency (Gippel 1995, Erskine & Webb 2003). In Victoria, recent instream woody habitat volumes have been found, on average, to be 41 per cent lower than reference levels (Tonkin et al., 2016b). Given the objectives of such works, including navigation, flood mitigation and channel efficiency, it seems likely that the most intensive snag removal programs concentrated on lowland reaches, likely within stretches of rivers in the southern Murray-Darling Basin where Macquarie perch were present.

Therefore in the short term resnagging is necessary in specific areas, while in the longer term the restoration of riparian vegetation is essential to ensure future supplies of snags. Resnagging some areas of riverine habitat has been recommended as an action under other national threatened species recovery plans (Brown et al., 1998; NMCRT 2010). A works program established and initiated in 2008 in Holland's Creek whereby "rock-seeding", riparian re-vegetation, rock-bar installation and the insertion of snags into the creek aimed to increase habitat availability and complexity and provide refuge for native fish (Raymond & Ryall 2017a).

In streams degraded by sedimentation and sand slugging, natural debris which once would drop into channels and provide shelter and refuge for invertebrate food items for Macquarie perch, is swallowed by the sand or swept away due to a lack of branches and logs that can hold debris in water (Schetzer 2017). Recent trials undertaken at Hughes Creek using in-stream installations of paired garden stakes led to an increase in invertebrate densities and diversity (Schetzer 2017). The novel technique presents a low-cost, low-maintenance option for habitat improvement for native fish which feed on them, like Macquarie perch.

Riparian vegetation is important to freshwater fish like Macquarie perch as it can help conserve freshwater biodiversity by re-establishing linkages between riparian systems and stream fish

(Pusey & Arthington 2003). The interception of terrestrial sediments and nutrients by the riparian zone has important consequences for stream fish, maintaining habitat structure, water clarity and food-web structure (Pusey & Arthington 2003). A study in Hughes Creek found that Macquarie perch preferred areas within pools that were shaded by overhanging riparian vegetation (ARI 2007). Riparian re-vegetation of areas where Macquarie perch occur, or may potentially occur, is recognised as an important conservation action (Erskine 2016).

6.2.2 Introduced fish species

Introduced fish species may impact on native species in a number of different ways such as: predation (particularly on eggs and larvae); competition for habitat and food resources; habitat degradation; spread of diseases and parasites. Interactions with introduced fish species such as trout (brown (*Salmo trutta*) and rainbow (*Oncorhynchus mykiss*)) and redfin (*Perca fluviatilis*) have been identified as likely causes in the decline of the Macquarie perch (Cadwallader 1978; 1996; Gilligan 2005; Lintermans 2007). Furthermore, introduced fish species may bring new parasites and diseases which could potentially threaten native species (Cadwallader & Lawrence 1990; Arthington 1991; Abramovitz 1996; Cadwallader 1996; Arthington & McKenzie 1997; Horwitz et al., 1998; Lintermans 2007). For more information on this threat refer to section 6.2.5 below. Introduced fish have also been implicated in the local extinction and altered community structure of macroinvertebrates which are major food resources for native fish (Bruton 1995, Horwitz et al., 1998, Lintermans 2007).

Stocking introduced fish species for recreational fisheries, including trout (brown and rainbow) and redfin, has occurred widely in Macquarie perch range states and territory of New South Wales, the Australian Capital Territory, Victoria and South Australia during the past 120 years (Arthington & McKenzie 1997; Lintermans 2013c). Other species which were originally introduced to Australia for acclimatisation so that they could be recreationally fished for were brook char (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*), tench (*Tinca tinca*), roach (*Rutilus rutilus*) and European carp (*Cyprinus carpio*) (Lintermans 2004).

Brown and rainbow trout were introduced and established in southeastern Australia during the second half of the 19th Century and populations have persisted, and stockings have continued to today, for over 100 years (Wilson 1879; Nicols 1882; Lake 1957; 1967; Cadwallader 1996; Arthington & McKenzie 1997; Lintermans 2004). From as early as the 1930s, observations of stomach contents from fish in New South Wales showed that both rainbow trout and brown trout preyed upon items very similar to the items which Macquarie perch prey upon, indicating the risk of competition for food resources (McKeown 1934; Butcher 1945; Butcher 1967; Cadwallader 1978). Futher, from as early as the 1940s, there were reports of brown trout eating small Macquarie perch (Butcher 1945; 1967). The dietary overlap that has been observed between Macquarie perch, European carp and rainbow trout is now well recognised (Butcher 1945; Cadwallader 1978; 1979; Jackson 1981; Battaglene 1988; Koehn & O'Connor 1990b; Lintermans 2006a).

Concern was expressed by J.O. Langtry during his 1949–1950 surveys and by others later about the ability for native fish and trout to coexist (Butcher 1967; Cadwallader 1977; Rhodes 1999) and the impacts of 'incessant' trout stocking in the Murray-Darling Basin and that little information on the composition of native fauna was available before the first trout introductions were made (Cadwallader 1978). Rhodes (1999) in recollecting discussions with older men in the northeast of Victoria during his time as a fisheries officer, noted the correlation between the increasing presence of trout following stocking efforts, and the decline of 'white eye' in the catches of recreational fishers in the upper Murray region, especially around the 1930s. In analysing the disappearance of Macquarie perch in Lake Eildon, Cadwallader & Rogan (1977) drew attention to the stocking of more than 750 000 rainbow trout and more than 250 000 brown trout were liberated into the lake between 1958–1967, and predation and competition with introduced fish species (including redfin, goldfish (*Carassius auratus*) and tench) was considered as one the of three factors (the other two factors were considered to be large harvests during spawning time and habitat change) in the species disappearance.

There is an increasing awareness of the risk that trout may pose to Macquarie perch recovery and brown trout is considered by the New South Wales Fisheries Scientific Committee as a contributing factor in the decline of Macquarie perch (NSW FSC 2008). While Ebner et al. (2007) report no evidence of trout predation on juvenile Macquarie perch in the "upstream" parts of Cotter Reservoir (as opposed to Cotter River itself), they importantly note that juvenile Macquarie perch were absent from the survey area. Gilligan (2005) correlates the decline of Macquarie perch in the early-1980s in the upper Murrumbidgee River with the first year of a series of very large releases of rainbow trout in the area starting in 1980. High numbers of brown and rainbow trout have been observed around spawning aggregations of Macquarie perch in the Mitta Mitta River and were likely preying on larval and juvenile stages (Tonkin et al., 2009).

The incidence and severity of trout predation on Macquarie perch has only been assessed through visual examination of trout stomach contents. This is unlikely to detect egg or larval predation on Macquarie perch, and such life stages are highly disgestible and are likely only to be visually identifiable for several hours after ingestion (MacDonald et al., 2014). While documented occurrences of predation on Macquarie perch are scarce, there have been almost no studies commissioned in Australia into the physical examination or DNA-assays of trout gut contents in the few remaining locations where Macquarie perch still co-occur. Research commenced into this approach (MacDonald et al., 2014) but ceased as a result of a lack of funding.

Redfin are a fast-breeding, voracious predatory fish introduced to mainland Australia in the 1860s originating from stock from the United Kingdom (Weatherley 1963b; Weatherley 1977; Cadwallader & Backhouse 1983; Lintermans 2007). The species is now widely distributed through the southern part of the Murray-Darling Basin, being restricted to water temperatures less than 31°C (Weatherley 1963a; 1963b; 1977). The species can live in a wide variety of habitats, but generally prefer still or slow-flowing waters such as lakes, dams, billabongs, swamps and slower moving streams and rivers (NSW DPI 2017). Redfin are known to prey on many small and juvenile native species (Clunie et al., 2002). Direct predation on trout cod juveniles was reported by undertaking gut analysis of redfin from Seven Creeks (Kearns et al., 2012a, cited in ARI pers. comm., 2017), where a population of Macquarie perch also occurs. Cadwallader & Rogan (1977) noted the appearance of redfin in Lake Eildon, Victoria attributed predation on juvenile Macquarie perch by redfin as a contributing factor to their decline. In the Australian Capital Territory, the decline of Macquarie perch in the Murrumbidgee River is closely correlated with the increase in redfin (ACT Gov. pers. comm., 2017). Redfin were first discovered in the Lachlan River above Lake Wyangala in 2005, and since have proliferated the entire length of the upper Lachlan River (Pearce 2013). The remnant population which occurred in the Lachlan River is now extinct (NSW DPI pers. comm., 2017). A recent laboratory study did show that Macquarie perch are able to recognise and respond to the threat of predation posed by redfin (Brown & Morgan 2015). Victoria's largest population of Macquarie perch occurs in Lake Dartmouth where no redfin occur as yet (ARI pers. comm., 2017).

European carp were first introduced into Australia as early as the 1860s, but these strains showed no signs of spreading (Shearer & Mulley 1978). The 'Boolarra strain' was imported illegally into Victoria from Germany in the 1950s, and in the 1960s was illegally introduced into watercourses in the Murray-Darling Basin and quickly spread throughout (Rhodes 1999; Koehn et al., 2000). European carp now dominate freshwater systems across the Murray-Darling Basin, and it has become the most abundant large freshwater fish in southeastern Australia (Koehn 2005; Davies et al., 2012). European carp disturb native fish habitats by raising turbidity and destroying submergent macrophytes (Roberts et al., 1995; Roberts & Sainty 1996; Villizi et al., 2014). European carp larvae feed upon similar prey items as larvae of two other species of native fish, Murray cod and golden perch (Tonkin et al., 2006), so it is possible that the same competition exists for Macquarie perch. Large carp were observed trailing groups of Macquarie perch in spawning habitats in the Mitta Mitta River upstream from Lake Dartmouth, and were video filmed filtering gravel (Tonkin et al., 2009). These behaviours could suggest feeding on Macquarie perch eggs, however, gut analysis of six individuals did not reveal any eggs (Tonkin et al., 2009). These samples were kept pending future investigation using genetics (Tonkin et al., 2009).

Eastern gambusia (*Gambusia holbrooki*), native to the Gulf of Mexico, were introduced to Australia in the mid-1920s to control mosquito larvae (Cadwallader & Backhouse 1983; Lloyd & Tomasov 1985; Arthington 1991). The fish was distributed widely around Australia during World War II to military camps. It is now found widely across the Murray-Darling Basin (Lintermans 2007). Although there are no direct studies on the impacts of Eastern gambusia on Macquarie perch, they are known to harass and impact other species of fish through fin-nipping and eat fish eggs and juveniles (Koehn & O’Connor 1990a;b; Bayley & Li 1992; Arthington & McKenzie 1997), and have been observations have been made of fin-nipping on native southern pygmy perch (*Nannoperca australis*) (Tonkin et al., 2011), thus may similarly impact juvenile Macquarie perch.

Targeted removal of the introduced species redfin and European carp in Seven Creeks during September 2014 has contributed to an increased abundance and successful recruitment of Macquarie perch within this waterway (ARI unpub. data, cited in ARI pers. comm., 2017).
The impact of introduced fish species on Macquarie perch is likely to have been significant and has contributed to the widespread decline of the species. If introduced fish species such as salmonids, redfin, eastern gambusia and European carp continue to increase in numbers and proliferate in areas where Macquarie perch live and breed, the species will decline further and recovery will be extremely difficult.

6.2.3 Barriers to fish movement

Human made structures such as dams, weirs and regulators are known to impede migration and prevent completion of life cycles of freshwater fish species (Cadwallader 1978; Faragher & Harris 1994; Thorncraft & Harris 2000; Gilligan et al., 2005), such as the Macquarie perch. Instream barriers can prevent fish moving between spawning and feeding areas as well as interrupting gene flow and fragmenting fish populations (Lintermans 2013c; NSW DPI 2013a). The fragmented range of Macquarie perch makes the species particularly vulnerable to local extinctions (Morrongiello et al., 2011), especially considering the loss of genetic diversity in the remaining populations (Faulks et al., 2011; Nguyen et al., 2012; Pavlova et al., 2017a; 2017b). Recent genetic research is suggesting that smaller remaining Macquarie perch populations in the Murray-Darling Basin are likely to face inbreeding depression without management intervention (Pavlova et al., 2017a). The three historically translocated populations, in Cataract Reservoir and in the Mongarlowe and Yarra rivers, are of important conservation value given that these contain genetic diversity no longer present in their Murray-Darling Basin sources

(Pavlova et al., 2017a; Pavlova pers. comm., 2017). These populations represent important populations for use in future translocations.

The unimpeded passage of fish throughout streams is considered crucial for migration, re-colonisation, general movement and habitat selection (Koehn & O'Connor 1990b; MDBC 2004). It is also crucial for maintaining large effective population sizes, preventing loss of genetic diversity and promoting species ability to adapt to novel environments, including water flows, thermal regimes and climate change (Pavlova et al., 2017a). A large number of major barriers to fish movement exist in the Murray-Darling Basin (Table 1), with many more smaller barriers also known in catchments where Macquarie perch occur.

Table 1*: Major physical fish barriers by catchment within the current distributional range of Macquarie perch*

River catchment	Dam
Macquarie	Chifley, Burrendong dams
Lachlan	Wyangala Dam
Murrumbidgee	Tantangara, Cotter, Bendora, Corin, Scrivener, Captain's Flat, Googong, Yass, Burrinjuck, Talbingo and Blowering dams
upper Murray	Khancoban Pondage and Hume dams
Mitta Mitta	Dartmouth Dam
Ovens	Buffalo Dam
Broken	Nillahcootie and Benalla dams
Goulburn	Eildon Weir
Hawkesbury-Nepean	Cataract, Nepean, Avon and Warragamba dams
Shoalhaven	Tallowa Dam

Until 2001, the one viable population of Macquarie perch in the Australian Capital Territory found in the Cotter River catchment was restricted from accessing habitats more than 6 km upstream of the Cotter Reservoir by a road crossing (Vanitys Crossing) (Broadhurst et al., 2013). In 2001, a rock-ramp fishway was constructed at Vanitys Crossing to allow Macquarie perch to migrate upstream (Ebner & Lintermans 2007; Ebner et al., 2008; Broadhurst et al., 2013). Subsequent research found that a road culvert was also likely impassable Macquarie perch (Starrs et al., 2011), and a second fishway was constructed at this road crossing, approximately 8 km upstream of Vanitys Crossing.

The construction of Googong Dam in 1978 is considered to have caused the extirpation of the Macquarie perch from the lower Queanbeyan River (i.e. from where the Googong Dam wall is now to the weir near the centre of Queanbeyan itself) (Lintermans 2002). It is likely that Burrinjuck and Wyangala Dams had similar effects on probable populations in the Murrumbidgee and Lachlan rivers downstream of these structures.

When considering fish barriers, not only 'physical' structures should be examined but also other barriers such as 'hydraulic' (e.g. areas of high velocity flow or turbulence or low flows/water levels) and ‘chemical’ (areas where chemical discharge causes avoidance by fish). Barriers may ocassionally have benefits for Macquarie perch in some instances by impeding the movement of pests (e.g. redfin and carp) and diseases (epizootic haematopoietic necrosis virus (EHNV)), from contacting ‘quarantined’ Macquarie perch populations (Lintermans 2012). Therefore, there is a clear need to balance connectivity with the exclusion of pests and diseases and their vectors (Langdon 1989a; Lintermans 2005).

Genetic diversity has been found to be higher in the Macquarie perch populations occurring in locations with a higher river slope, which correlates to a higher frequency of the species preferred ‘riffle’ habitat (Faulks et al., 2011). Additional correlations have been found whereby more genetically diverse individuals have been sampled at areas further downstream from a barrier, had larger flow-path lengths upstream and those which occurred in streams that are colder in winter (Pavlova et al., 2017a). However, man-made barriers, of which there are many in Murray-Darling Basin areas which Macquarie perch once inhabited, degrade habitat and impede dispersal, which has likely lowered the genetic diversity in the species (Faulks et al., 2011).

The impact of barriers may be local and immediate. For example, a new barrier may prevent a local population of Macquarie perch from diurnal movements to/from feeding and sheltering locations. Barriers may also introduce longer term impacts including preventing access to spawning beds or refuges on a seasonal basis or by altering flows and stream morphology and their ability to sustain a Macquarie perch population.

6.2.4 Altered flow and thermal regimes

In their natural state, inland rivers were characterised by variable flow patterns and reasonably consistent cyclic increases and decreases in temperature seasonally. Native species, such as the Macquarie perch, were adapted to these flow and thermal patterns. Large impoundments and water diversion/extraction has altered these natural flow and temperature patterns (Walker 1985; Kingsford 2000; Lintermans 2013c).

Flow in the coastal rivers of New South Wales where the Macquarie perch occurs, is generally more consistent however altered flow regimes as a result of large dams and impoundments also have a major impact on Macquarie perch ecology. River regulation has resulted in changes in the size of flows; seasonality of flow patterns; frequency and duration of floods; timing, variability and predictability of flows; rates of rise and fall of water levels; and surface and subsurface water levels (Walker 1985; Kingsford 2000; Lintermans 2013c).

A study surveying sites in the Yarra River detected only very low spawning and recruitment indicators in 2008/09, and this apparent failure in this season was linked to the low flow conditons in the river (King & Mahoney 2009). However, a recent study on five Victorian populations of Macquarie perch (in the Yarra River, Lake Dartmouth, King Parrot Creek, Hughes Creek and Seven Creeks) found lower levels of recruitment in years where there was higher discharge in the months of November and December (Tonkin et al., 2017b). The November-December period corresponds with the core egg and larval period for the species (Tonkin et al., 2017b). Therefore, it may be important for regulators to avoid sudden, sharp increases in discharge during the spawning period for Macquarie perch.

By the end of the 1970s all of the major river catchments in New South Wales, the Australian Capital Territory and Victoria where the Macquarie perch occurs were regulated with large dams to store and control the flow of water for primary resources and domestic supply. The regulation of water flow by the operation of in-stream structures generally reduces the flow of water downstream and reduces the frequency and magnitude of natural flooding (Walker 1985; ASEC 2001; NSW FSC 2002; Magilligan et al., 2003). Water is delivered to users who depend on reliable and predictable water supplies often at the expense of the ecological needs of fish communities.

Remnant populations of Macquarie perch in the Murray-Darling Basin generally occur either in and/or above impoundments or in unaltered catchments. Reduced flows caused by drought and water extraction may impact by reducing size of key refuge pools in streams and access to key riffle habitats which are important for spawning. Fish surveys in lower Hughes Creek found Macquarie perch in poor condition and displaying signs of severe stress as a direct result of low flows (Kearns 2009, cited in Lintermans et al., 2014). Consequently, 32 adult fish were translocated to Victorina Government hatchery facilities and then re-released into Hughes Creek when water quality had improved (Lintermans et al., 2014).

The exceptions are small populations of Macquarie perch below Cordeaux Dam in the Cordeaux River and the upper Murrumbidgee River in areas downstream of Tantangara Dam ('Cooma Gorge'). If flow regulation were to mimic natural flow regimes, while avoiding sudden, extreme flooding events, these populations of Macquarie perch would more than likely respond positively.

Studies suggest that any impounded water body over five metres in depth can undergo thermal stratification, except those reservoirs where average yearly inflow volume exceeds the reservoir volume by a factor of 10 or more (Harleman 1982). Warm water is less dense than cooler water, and therefore 'floats' above denser cooler water (Bayly & Williams 1973). Since most impoundments are only equipped with bottom release valves only cold water can be released downstream, causing 'cold water' or 'thermal pollution' (Koehn 2001; Ryan et al., 2001; Astles et al., 2003; Preece 2004; Sherman et al., 2007).

Regulation of flows through controlled release from storages, which is often the release of cold water, and water extraction have vastly changed the hydrology and thermal regimes of river systems, causing widespread degradation and are considered to be severely impacting upon native fish in the Murray-Darling Basin (Koehn & O'Connor 1990a; Faragher & Harris, 1994; Koehn et al., 1995; Gehrke et al., 1999; Koehn 2001; Phillips 2001; Astles et al., 2003; MDBC 2004). Cold water pollution has the effect of reducing annual temperature ranges, delaying the timing of summer temperature peaks, eliminating the natural rapid temperature rise in spring and also severely reducing the difference between annual maximum and minimum temperature (Lugg 1999; Ryan et al., 2001). In Lake Eildon, it was found that Macquarie perch required the water temperature to rise to 16.5°C before spawning could occur (Cadwallader & Rogan 1977), and it was considered that the colder water of the Reservoir and extent of flooding were severely impacting the species ability to reproduce in this catchment (Cadwallader 1978). Macquarie perch spawning was detected in the Yarra River at water temperatures of approximately 17°C (King & Mahoney 2009). A recent study showed a positive influence on spawning intensity in two riverine populations in King Parrot Creek and the Yarra River, with the greatest abundance of eggs recorded when mean daily water temperatures exceeded 18°C between late-October and early-December (Tonkin et al., 2016a). A laboratory study on the effect of temperature on <24 hour and one-week old Macquarie perch larvae found that <24 hour individuals were significantly affected by water temperatures below 12°C, while one-week old individuals were comparatively resilient (Raymond & Ryall 2017b).

Seasonal variation in water temperature is an important trigger for many native freshwater fish species to spawn (Milton & Arthington 1983; 1984; 1985; Koehn & O'Connor 1990b). Most native species breed over the warmer months and require relatively warm temperatures to induce spawning (Lake 1967b; Llewellyn 1971; Rowland 1983; Cadwallader & Gooley 1985).

A 2002 study demonstrated that the egg survival of a number of native species including Murray cod, golden perch, silver perch and freshwater catfish (*Tandanus tandanus*) was reduced by temperatures below 15°C (Lyon et al., 2002). Koehn et al. (1995) attribute the loss of species such as Murray cod and Macquarie perch in the Mitta Mitta River downstream of Dartmouth Dam to coldwater pollution. Thermal pollution affects fish populations by preventing seasonal warming to critical spawning temperatures, temperature shock to eggs and larvae following sudden high volume releases, inhibited activity, growth, and disease resistance, reduced egg and larval survival, and delayed maturity (Burton & Raisin 2001; Koehn 2001; Astles et al., 2003). In Australia, the most widely recognised effect of thermal pollution is that of depressed summer temperatures on native fish populations (Ryan et al., 2001).

Cold water pollution is likely to have had a significant impact on the distribution of the Macquarie perch. Cold water releases occur annually during critical spawning intervals and threatens the survival of Macquarie perch juveniles and eggs. Reduction of cold water pollution through strategies to reduce temperature stratification of water storages and/or to release water that more closely resembles the natural flow and temperature regime of rivers are likely to have a positive effect on the Macquarie perch.

6.2.5 Disease and parasites

The globally-widespread disease – Epizootic Haematopoietic Necrosis Virus (EHNV) represents a serious threat to Macquarie perch. EHNV was first isolated in Australia from juvenile redfin, sourced from Lake Nillahcootie in 1984, near Benalla in northeastern Victoria (Langdon et al., 1986). Potential carriers (vectors) for EHNV include redfin and rainbow trout (Whittington et al., 1999; 2007).

In New South Wales, EHNV was first detected in redfin in Blowering Dam and Lake Hume in 1986 and then was subsequently found in specimens in Burrinjuck Dam in 1990, from Lake Burley Griffin in 1991 and 1994 and from Googong Reservoir in 1994 (Whitting et al., 1996). These historical outbreaks suggest that the distribution of EHNV in redfin has extended upstream in the Murrumbidgee River system (Whittington et al., 1996). It is highly likely that the upstream Murrumbidgee River, Googong Reservoir/Queanbeyan River (now extirpated) populations of Macquarie perch were exposed to the virus (Lintermans 2006b). It has also been detected in farmed rainbow trout populations on properties in New South Wales and Victoria during late-1980s and 1990s (Whittington et al., 1994; 1999). The movement of infected trout fingerlings containing a low number of individuals with a subclinical infection was probably the most common means of spread of EHNV within the aquaculture industry (Whittington et al. 2010).

The presence of EHNV is thought to be a major impediment to recovery of populations of Macquarie perch in the Australian Capital Territory (Lintermans 1991b) and it has been suggested that EHNV may have been a cause for the decline of Macquarie perch in Lake Eildon in Victoria (Langdon 1989b). Experimental work in the 1980s demonstrated that Macquarie perch was one of several species extremely susceptible to the disease with 100 per cent mortality (Langdon 1989a; 1989b). Other native fish species found experimentally to be susceptible to EHNV include silver perch, Murray cod, golden perch and mountain galaxias (*Galaxias olidus*), and other introduced fish species include Atlantic salmon and eastern gambusia (Langdon et al., 1986; Langdon 1989b; Gray et al., 2000).

EHNV is characterised by sudden high mortalities of fish displaying necrosis of the renal haematopoietic tissue, liver spleen and pancreas (Langdon & Humphrey 1987). EHNV is a fast spreading and robust virus. The mechanisms of spread are uncertain in redfin but are likely to include the movement of the virus on structures such as nets, boats and gear, movement of live fish or frozen bait fish by recreational fisherman, movement with migrating fish and transmission by piscivorous birds (Whittington et al., 1996). There may be an as yet undiscovered natural host that is responsible for infection of redfin, or redfin may simply amplify the infection in an ecosystem (Whittington & Hyatt 1998). Langdon (1989b) found EHNV retained infectivity after 113 days of dry storage and Whittington et al. (1996) found similar results after freezing fish carcasses for at least a year.

Given that EHNV is known to cause direct 100 per cent mortality to Macquarie perch (Langdon 1989a; 1989b) and could be also causing indirect mortality by severely disabling feeding and predator evasive abilities and is apparently highly virulent, past impacts on populations have likely been immediate and catastrophic and may have not been detected adequately due to insufficient awareness. It appears that redfin may be developing a resistance (or reducing infection rates) to EHNV (Whittington et al., 2011), but further research is required to ascertain whether Macquarie perch are also developing resistance to the virus.

The ecto-parasitic copepod species, *Lernaea cyprinacea* (or anchor worm), is a widespread parasite, having been accidentally transferred as a result of human translocation of its cyprinid hosts, notably carp and goldfish, with the expansion of aquaculture (Kabata 1979, cited in Bond 2004). Lernaea is a large, highly modified and specialised copepod that parasitises the gills and skin of fish (Rowland & Ingram 1991). In Australian native fish, the attachment of Lernaea is generally in the gill cavity or at or near the base of fins (Rowland & Ingram 1991). When Lernaea leaves the host fish, a red lesion up to 10 mm long remains at the prior attachment site (Rowland & Ingram 1991). Lernaea has been observed on ‘young of the year’ Macquarie perch in Cotter Reservoir and in the upper Murrumbidgee River and it is presumed it is impacting recruitment success (Lintermans unpub. data, 2017, cited in Lintermans pers. comm., 2017; NSW DPI pers. comm., 2017). Attachment of the parasite to the caudal fin causes fin split, with the likely impact of reducing swimming capability which is potentially important in predator evasion (Lintermans unpub. data, 2017, cited in Lintermans pers. comm., 2017).

Macquarie perch have been shown experimentally to be highly susceptible to Megalocytivirus infection, which is an emerging threat from the live ornamental fish trade. These viruses represent an array of closely related agents that were first recognised to cause high mortality in aquacultured food and aquarium fish in the 1990s. Megalocytiviruses have low host specificity and appear to be readily carried by freshwater aquarium fish including gouramis, poeciliids and cichlids. In 2003, Dwarf Gourami Iridovirus (DGIV) found in ‘presumably’ imported dwarf gourami (*Trichogaster lalius*) in retail shops in Australia was identical to the causative agent for mass mortality in intensively farmed Murray cod (Go et al., 2006). The susceptibility to DGIV of several other native freshwater fish species was subsequently demonstrated by experimental challenge studies (Rimmer et al., 2016). The studies indicated that naïve native fish populations, including Macquarie perch, would be vulnerable to megalocytiviruses should they enter natural waterways through infected ornamental fish (Rimmer et al., 2016).

A recent study characterised the diversity of major histocompatibility complex (MHC) IIB locus in four Australian freshwater perchichthyid fish, including Macquarie perch (Bracamonte et al., 2015). MHC is a key component of the adaptive immune system and is a promising genetic marker of significance in fitness and adaptive potential. It was found that there was a lack of shared alleles between the Murray-Darling Basin and Hawkesbury-Nepean ecotypes

(Bracamonte et al., 2015). Although larger samples are needed to confirm these results, they might be indicative of distinct selective environments in these two basins leading to ecologically-driven divergence and/or long divergence times between them (Bracamonte et al., 2015). This may indicate the need to manage the threat of disease differently between these two ecotypes, as these may have adapted independently to prevailing parasite fauna.

Currently megalocytiviruses such as infectious spleen and kidney necrosis virus-like viruses (e.g. DGIV) and Red Sea Bream Iridovirus (mainly affects marine finfish species) are exotic to Australia. Limited reports of their detection relate exclusively to the imported ornamental fish industry and trade (Anderson et al., 1993; Go et al., 2006; Rimmer et al., 2015). Import regulations and surveillance activities of domestic ornamental facilities have been designed to reduce the risk of these agents for Australia's native fish species including Macquarie perch and Murray cod. Nevertheless, historical imports of ornamental fish with minimal regulation has led to the establishment of 22 introduced species with wild breeding populations (Lintermans 2004). These feral populations demonstrate a prospective exposure pathway for subclinically infected imported ornamental fish to aquatic environments, with the potential to hinder recovery efforts.

Another disease to affect Macquarie perch is the parasitic protozoan *Chilodonella cyprini*, which was first found in Australia on brown trout in the Snobs Creek Fish Hatchery. It was likely spread to native fish, including Macquarie perch, via the stocking of infected trout into Victorian waters (Cadwallader 1996). European carp, goldfish or eastern gambusia have been likely implicated as the source of, and a vector for, the introduced tapeworm *Schyzocotyle acheilognathi* which has been recorded in native fish species (Dove et al., 1997; Dove & Fletcher 2000). This tapeworm causes widespread mortality in juvenile fish overseas.

6.2.6 Illegal/Incidental capture

With the exception of Lake Dartmouth and the Yarra River (all in Victoria), the taking of Macquarie perch in fishing activities in Australia is prohibited (Vic DEDJTR 2016). In Victoria, there is a closed season for the species between 1 October – 31 December each year, and daily bag/possession limits apply such that recreational fishing take is permitted in Lake Dartmouth and tributaries (1 per day) and the Yarra River and tributaries (2 per day) (DEDJTR 2016). Illegal fishing is recognised as a key threat to native fish management (MDBC 2004). It is illegal to buy, sell or possess Macquarie perch in New South Wales, the Australian Capital Territory and Victoria unless compliant with the fishing rules stated above.

Historically, Macquarie perch were considered a prized table fish (Lake 1971; Trueman 2011). They were once caught in large numbers by recreational fishers targeting spawning migrations (Cadwallader & Rogan 1977). Cadwallader & Rogan (1977) make note of 2 to 3 tonnes of fish removed from Lake Eildon in a single week by targeting a spawning aggregation. With close to 1.6 million recreational fishers across New South Wales, the Australian Capital Territory and Victoria, approximately 24 per cent of whom undertake fishing in inland regions (Henry & Lyle 2003), the risk of illegal fishing remains high to Macquarie perch.

Tonkin et al. (2017a) explored the impact of recreational fishing on the historically translocated population of Macquarie perch in the Yarra River. There has been a gradual reduction in size and abundance of fish since 2010 (Tonkin et al., 2017a). It is highly likely that increased recreational fishing pressure is a major mechanism in the decline in adult fish in the Yarra River (Tonkin et al., 2017a).

The Macquarie perch's tendency to form spawning aggregations makes the species particularly susceptible to fishing at particular times of the year and targeting of these aggregations by fishers in the past has almost certainly contributed to the species' decline (Cadwallader & Rogan 1977; Cadwallader 1978; Harris & Rowland 1996).

Studies undertaken on other Percichthyidae species have found that the stress of being caught and released in recreational fishing activity can cause hidden, delayed impacts such as reduced gonad development and reproductive potential (Hall et al., 2009a), and fish that are gut-hooked are more likely to die than fish that are mouth hooked (Van Der Walt et al., 2005; Hall et al., 2009b). Even if accidental capture occurs and fish are correctly identified and returned to the water, injury and stress may result (Van Der Walt et al., 2005; Hall et al., 2009a; 2009b). Anecodotal reports suggest that large numbers of Macquarie perch can be taken at a time using bait (GACA pers. comm., 2017) which undoubtedly carries an increased risk of gut-hooking compared to other methods such as artificial lure or fly. Conversely, there is good evidence to suggest that if fish are mouth hooked, handled carefully and returned to the water promptly they are likely to survive.

Illegal fishing is likely to remove mature adult fish from the population. At a genetic level, it is possible that persistent selective removal of larger individuals ('trophy fish') from a population will cause an evolutionary shift in population characteristics with smaller size at maturity being an advantage and hence becoming the dominant phenotype (Conover & Munch 2002). High levels of illegal fishing may constitute negative impacts to the species.

6.2.7 Chemical water pollution

Chemical water pollution can be derived from point source and non-point sources and may be derived from sources such as run-off from agricultural, rural and industrial development, and acid mine drainage. Water pollution is related to land use; the development of intensive agriculture, mining, rural industries and urban development have contributed to water pollution across the Murray-Darling Basin and in the eastern catchments where Macquarie perch occur (MDBC 2003).

For many of the extant populations, pollution is probably of low risk given that the populations exist within national parks, wilderness areas and nature reserves such as the Lake Dartmouth and Mitta Mitta River, Buffalo River and Cotter River populations in the Murray-Darling Basin and populations in Webbs Creek, Colo, Grose, Kowmung rivers, Wongawilli Creek, Cordeaux and Cataract rivers in the Hawkesbury-Nepean system. Conversely, some remaining populations of Macquarie perch exist adjacent to land use types where there are livestock grazing, production and plantation forestry, perennial horticulture of vine and tree fruits, irrigated modified pastures and grazing modified pastures. These include populations in King Parrot Creek, Yea River, Holland's and Hughes , Murrumbidgee River, Adjungbilly and Mannus creeks, Lachlan and Abercrombie rivers in the Murray-Darling Basin and the populations in the Mongarlowe and Cox's rivers Hawkesbury-Nepean system.

A further source of pollution threatening the recovery of some Macquarie perch populations includes mining and domestic effluent disposal. In particular, Macquarie perch in the Hawkesbury-Nepean system are at risk from current, proposed and past mining activities (NSW DoP 2008). Effluent from underground coal mining is saline and acidic and subsidence caused by longwall mining cracks river beds and releases iron flock from ground water. Disused and historic mine sites are a source of acid mine drainage and heavy metal contaminants (NSW DoP 2008). The population of Macquarie perch in the Molonglo River is likely to have been removed (along with all other fish species) through heavy metal contamination from the collapses of the Captains Flat Mine tailings dam between the 1930s–1940s (Lintermans 2002).

Pollution has the potential to affect all aspects of the life history of the Macquarie perch. Of particular concern are endocrine disrupting chemicals such as pesticides, sewage effluent and plasticisers. The most prominent effect of endocrine disruption in fish is in the reproductive system affecting gonaopodium development, demonstrated in fish such as eastern gambusia (Batty & Lim 1999; Pait & Nelson 2002). The introduction of chemicals and biodegradable material to water has obvious effects on fish, depleting dissolved oxygen levels resulting in fish kills. From what is known of fish at a similar trophic level a healthy level of dissolved oxygen for Macquarie perch would be in the order of 7.5 mg/L and above (Davis & Cornwell 2008). Fish kills for Macquarie perch were reported from Hughes Creek in Autumn 2009 when dissolved oxygen dropped below 3 mg/L as a result of low flows and other poor water quality factors (Kearns 2009, cited in ARI pers. comm., 2017).

Poor water quality is also likely to affect Macquarie perch feeding, breeding and migration. Poor water quality is likely to lead to a lowered immune system in fish making them susceptible to disease (see also section 6.2.5). There are also many effects on the fish that may be unknown such as the bio-accumulation of fat-soluble chemicals. Poor water quality is also likely to limit the expansion of Macquarie perch into other areas.

6.2.8 Climate change

Freshwater environments, and the organisms that inhabitat them, are particularly vulnerable to climate change because they are isolated and fragmented within a terrestrial landscape (Morrongiello et al., 2011). Surface water, which determines the quality and availability of aquatic habitat depends heavily on rainfall and temperature regimes which will drastically change under climate change predictions (Carpenter et al., 1992; Hobday & Lough 2011). Climate change projections for the Murray-Darling Basin predict increases in temperature and evaporation and less rainfall and snowfall, which will likely result in reduced runoff to rivers and wetlands especially in the southern Basin (CSIRO 2008; Dunlop & Brown 2008; Morongiello et al., 2011). Median runoff is predicted to decline by up to 12 per cent and flood frequency is predicted to decrease (Balcombe et al., 2011). However, extreme events such as storms (and associated floods) and droughts are projected to rise in frequency and/or intensity under climate change (Aldous et al., 2011; Hobday & Lough 2011). As are extreme fire weather events, with the resultant greater risks of secondary water pollution and sedimentation (Morongiello et al., 2011).

Tonkin et al. (2017b) suggests that most remnant populations of Macquarie perch, which are now predominantly isolated within small tributary systems characterised by highly variable flows, face a heightened risk of poor recruitment periods, particularly under climate change predictions. Extreme flow events during the spawning period in these areas are likely to negatively impact upon recruitment frequency and adult survival (Tonkin et al., 2017b).

With predictions for longer and more severe dry spells as a result of climate change, drought impacts are likely to further stress freshwater fish populations in southeastern Australia (Crook et al., 2010). Reductions in run off due to climate change will further fragment freshwater habitats and fish populations, leading to reduced ‘fitness’ (Balcombe et al., 2011). Climate change, coupled with the impacts of existing land and water use, could further significantly change freshwater ecosystems in the Murray-Darling Basin unless on ground conservation actions are undertaken (Pittock & Finlayson 2011). Additional declines in water quantity and quality will have an adverse impact on existing freshwater ecosystems (Pittock & Finlayson 2011).

The general effects of climate change on freshwater systems will likely be increased water temperatures, decreased dissolved oxygen levels, and the increased toxicity of pollutants (Ficke et al., 2007). Generally, Australian freshwater fish are predicted to be impacted by climate change by increased rates of habitat loss and fragmentation, surpassing of physiological tolerances and the spread of introduced species (Morongiello et al., 2011). Water temperatures are especially important to freshwater fish as all are exothermic, hence body temperatures are identical to environmental temperatures (Ficke et al., 2007). Increased water temperatures are likely, on average, to decrease dissolved oxygen levels, given that cold water has the potential to hold more dissolved oxygen than hot water (Ficke et al., 2007). Macquarie perch are particularly vulnerable to local extinction under climate change scenarios given the species already fragmented range (Morrongiello et al., 2011). Some introduced fish species are likely to benefit from warmer temperatures, habitat degradation and increased modification of natural flow regimes, whereas others will be detrimentally affected by increases in flow ephemerality, disturbance and the surpassing of physiological tolerances (Booth et al., 2011; Morrongiello et al., 2011).

Freshwater fish in the Murray-Darling Basin have been particularly affected by the changes to flow regimes and biological connectivity associated with water-resource development and climate change will place further stress on these species (Balcombe et al., 2011). However, there is some thought that climate change may potentially benefit Macquarie perch in the southern Basin, as increased temperatures may lead to increased abundances in areas where the species has been impacted by cold-water pollution. It could be that in areas where water temperatures become too hot for introduced salmonids and stocked populations cannot persist, Macquarie perch populations may benefit (Balcombe et al., 2011). However, contrary to this is that increased temperatures may affect timing of zooplankton emergence which may have implications for Macquarie perch larval recruitment success (Balcombe et al., 2011) and that more genetically diverse individuals have been in streams which are colder in winter indicating that the species may be susceptible to warmer winters and climate warming may further exacerbate loss of genetic diversity (Pavlova et al., 2017b).

7 Current Management Practices

As the Macquarie perch is listed in the Endangered category of the threatened species list (Part 13) under the EPBC Act it is considered a Matter of National Environmental Significance (MNES) (Part 4), and any action that may have an impact on MNES must be referred to the Minister of the Environment for approval. The Department of the Environment and Energy, as the Australian Government department responsible for administering the EPBC Act, maintains a suite of interactive tools that allow users to search, find and generate reports on information and data describing MNES, including the Macquarie perch.

In New South Wales and the Australian Capital Territory, the Macquarie perch is totally protected. In New South Wales it is illegal to catch and keep, buy, sell, possess or harm Macquarie perch without a specific permit or licence (NSW DPI 2005), and significant penalties apply under Division 4 and 4A of the *Fisheries Management Act 1994*. In the Australian Capital Territory, it is an offence to kill, injure or endanger, take, keep, sell or offer to sell Macquarie perch under the *Nature Conservation Act 2014*. In Victoria, fishing for Macquarie perch is still permitted in the Yarra River where a bag limit of 2 individuals per day applies, and in Lake Dartmouth where a bag limit of 1 individual per day applies (Vic DEDJTR 2016). Fishing for Macquarie perch in all other waterways where it occurs in Victoria is prohibited (Vic DEDJTR 2016). The species is listed as threatened and protected under the Victorian *Flora and*

Fauna Guarantee Act 1998, by which it cannot be taken or kept without an order, licence or permit. A Governor in Council "Flora and Fauna Guarantee (Taking, Trading In or Keeping of Listed Fish) Order" made under section 53(2) of the *Flora and Fauna Guarantee Act 1998* allows for the take of Macquarie perch in the Yarra River catchment and Lake Dartmouth (and tributaries). A minimum size limit of 35 cm applies and a closed season to the taking of the species applies between 1 October – 31 December each year.

8 Recovery Objectives and Strategies

8.1 Recovery plan objective

The objective of this national recovery plan is to ensure the recovery and ongoing viability of Macquarie perch populations throughout the species' range (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers).

8.2 Recovery plan strategies

The strategies to achieve the recovery plan objective are to:

1. Conserve existing Macquarie perch (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers);
2. Protect and restore Macquarie perch habitat;
3. Understand and address threats to Macquarie perch populations and habitats;
4. Establish additional Macquarie perch populations within the species' natural range;
5. Improve understanding of the biology and ecology of the Macquarie perch and its distribution and abundance; and
6. Increase participation by community groups in Macquarie perch conservation.

9 Actions to Achieve the Objective

Actions identified for the recovery of the Macquarie perch are described below. It should be noted that the objective is long-term and may not be achieved prior to the scheduled five-year review of the recovery plan. Priorities assigned to actions should be interpreted as follows:

Priority 1:	Taking prompt action is necessary to mitigate the key threats to the Macquarie perch and also provide valuable information to help identify long-term population trends.
Priority 2:	Action would provide a more informed basis for the long-term management and recovery of the Macquarie perch.
Priority 3:	Action is desirable, but not critical to the recovery of the Macquarie perch or assessment of trends in that recovery.

Strategy 1 – Conserve existing Macquarie perch populations (including historically translocated populations in Cataract Reservoir and the Mongarlowe and Yarra rivers)

On ground actions

Table 2: *Strategy 1 Actions*

Action	Description	Priority	Performance Criteria	Responsible Agencies *and potential partners*	Indicative Cost **priority 1 only*
1a	Protect Macquarie perch from competition with and predation by introduced fish species.	1	• Avoid or minimise stocking of salmonids and other introduced fish species into areas where Macquarie perch are known to occur. • Implement programs to reduce populations of introduced fish in habitats where Macquarie perch occur. • A management plan is developed for introduced fish species that impact Macquarie perch, including European carp, eastern gambusia, redfin and trout.	State/territory governments, research community	$500 000
1b	Ensure that the impacts of recreational fishing are minimised.	1	• Self-sustaining populations are listed as 'no-take' species. • Where take is allowed of stocked impoundment populations, management measures are in place to protect wild, self-sustaining populations from illegal fishing (i.e. compliance measures have been implemented so that fish from stocked populations can be identified). • In waters where taking Macquarie perch is prohibited but taking other species is permitted, management measures have been implemented to reduce or prohibit the use of bait. • The use of seasonal fishing closures to all fishing (not just for Macquarie perch) is implemented in areas which are known for Macquarie perch spawning migrations.	State/territory governments, research community	$150 000
1c	Protect Macquarie perch populations from outbreaks of disease and parasites.	2	• Effective development of treatment and immunisation techniques for EHNV and *Lernaea* (aka 'anchor worm') has occurred. • Hygiene protocols and immunisation techniques have been developed and implemented for hatcheries and translocation events to protect Macquarie perch populations (and populations of other threatened native fish species) from outbreaks of ENHV and *Lernaea* (aka 'anchor worm').	Australian and state/territory governments, research community	-

1d	Restore Macquarie perch population connectivity by conducting regular assisted gene flow (i.e. translocations) in order to decrease inbreeding, prevent further loss of genetic diversity by drift and improve adaptive potential (consistent with EPBC Act requirements).	1	• Translocations have been undertaken to improve genetic diversity within Macquarie perch populations, which have been demonstrated with a high-degree of certainty to be successful long-term without significant adverse impacts on the species. • Translocation projects are developed with full consideration of the relevant requirements of the EPBC Act (translocation policy statement[1] etc.) and a comprehensive translocation plan is prepared consistent with the IUCN Translocation Guidelines[2]. These projects may require referral under the EPBC Act.	Australian and state/territory governments, research community	$100 000
1e	Develop a emergency management response plan for rescue translocations (consistent with EPBC Act requirements).	2	• An effective management plan is developed to guide rescue translocations consistently or as appropriate to the system where the Macquarie perch population exists (i.e. in the event of bushfire, drought, pollution, poor water quality). • Management plan considers the relevant requirements of the EPBC Act (translocation policy statement[1] etc.) in relation to translocation activity.	Australian and state/territory governments, research community, local governments.	-

Strategy 2 – Protect and restore Macquarie perch habitat

On ground actions

Table 3: *Strategy 2 Actions*

Action	Description	Priority	Performance Criteria	Responsible Agencies *and potential partners*	Indicative Cost **priority 1 only*

2a	Undertake priority habitat rehabilitation, restoration and enhancement work.	1	• Where physically possible, fish passage is restored to locations where Macquarie perch are currently impeded by anthropogenic fish barriers, and means of excluding movement of introduced fish species is accounted for.
			• Restore riffle habitats in areas below water storages and offtakes to promote spawning areas by concentrated effort to remove sand slugs or by providing environmental flows to scour sediment loads.
			• Rehabilitate riparian vegetation.
			• Reinstate large rock and woody snags in channels.
			• Spawning activity is recorded following trials/installation of artificial habitat, which may include but is not limited to:
			  • sand/silt excavation
			  • gravel/shale depositing
				State/territory governments	$2 000 000

[1] *See Environment Protection and Biodiversity Conservation Act 1999 (Cth) Policy Statement – Translocation of Listed Threatened Species–Assessment under Chapter 4 of the EPBC Act. Accessible at – http://www.environment.gov.au/resource/epbc-act-policy-statement-translocation-listed-threatened-species-assessment-under-chapter*

[2] *See IUCN 'Guidelines for Reintroductions and Other Conservation Translocations. Accessible at – https://www.iucn.org/content/new-guidelines-conservation-translocations-published-iucn*

			• "rock seeding" • rock bar installation • bank stabilisation and riparian re-vegetation		
2b	Seek to provide appropriate flow regimes in all waters where Macquarie perch occur below water storages or offtakes.	2	• Improve daily and monthly hydrological regimes to river flows to provide a more natural and optimal state for where some Macquarie perch populations occur (as informed by data from Action 5c below). • Provide improved hydrological regimes in spring in areas where Macquarie perch occur (as informed by data from Action 5c below), while avoiding large, sudden increases in discharge which may negatively impact upon egg survival and larval recruitment especially in the months from late-October to early-December.	Australian and state/territory governments, research community	-
2c	Undertake works to minimise cold water pollution.	2	• Modify outlet works on dams where Macquarie perch are known to occur downstream so that cold water is not released and natural temperature regimes are restored.	Australian and state/territory governments	-
2d	Improve in-stream habitat to improve productivity of lower food web.	2	• Investigate in-stream installations of paired wooden garden stakes and/or snags to promote the collection of instream debris to promote insect, mollusc and other invertebrate populations.	State/territory governments, local governments, non-government organisations	-

Strategy 3 – Understand and address threats to Macquarie perch populations and habitats

Research and on ground actions

Table 4: *Strategy 3 Actions*

Action	Description	Priority	Performance Criteria	Responsible Agencies *and potential partners*	Indicative Cost **priority 1 only*
3a	Investigate methods to promote spawning and recruitment activity of Macquarie perch in naturally occurring and stocked populations.	1	• Monitoring has been established to detect spawning activity of Macquarie perch in both naturally, self-sustaining populations and stocked populations and is correlated against the habitats available to the population.	Australian and state/territory governments, research community	$60 000
3b	Better understand competition and predation on Macquarie perch by introduced fish species.	1	• Gut-analysis studies have been undertaken on all introduced fish species in areas where they co-exists with self-sustaining populations of Macquarie perch (i.e. where Macquarie perch are reproducing and producing larvae and juveniles). • Studies have been undertaken on the factors impacting prey availability for Macquarie perch, including the competition for prey by all introduced fish species.	Research community	$90 000

3c	Increase the confidence that the viruses and pathogens impacting Macquarie perch are all identified and known.	2	• Protocols and/or guidelines are established for identifying and/or detecting newly discovered, newly introduced, or poorly known viruses and pathogens which may be impacting this species. • Greater certainty is established about the number and types of viruses and pathogens impacting this species.	Australian and state/territory governments, research community	-
3d	Increase understanding of the degree of impact parasites are having on Macquarie perch populations.	2	• Collection and examination protocols for aquatic parasites are established. • Assessments of fish kills have been undertaken to ascertain, with much greater confidence than has been undertaken to date, whether aquatic parasites were responsible, or partly responsible.	State/territory governments, research community	-
3e	Research best practice for habitat restoration.	2	• Improve the resilience of the species by increasing refugia available, measured by increased abundance/biomass.	State/territory governments, research community, local governments, non-government organisations	-

Strategy 4 – Establish additional Macquarie perch populations within the species' natural range.

Research and on ground actions

Table 5: *Strategy 4 Actions*

Action	Description	Priority	Performance Criteria	Responsible Agencies *and potential partners*	Indicative Cost **priority 1 only*
4a	Refine and improve captive breeding techniques for Macquarie perch.	1	• Hatchery production of fingerlings is able to operate with broodstock periodically sourced from the wild, yet maintained for multiple breeding events in captivity, rather than capturing spawning run individuals each year from the wild. • Broodstock in captivity are replaced, or replenished, regularly to maintain or increase genetic diversity and are consistent with guidelines for hatchery production of other native fish species. • Genetic diversity of fingerlings should be maximized by crossing genetically diverse unrelated fish and maximizing broodstock fish combinations (e.g. using multiple males per female). • Hatchery production of Macquarie perch is subject to a Health Management Plan, such as that defined in the NSW DPI "Hatchery Quality Assurance Program" (Rowland & Tully 2004). • Large numbers of fingerlings are produced each year for stocking into wild waters, comparable with other successfully bred		

			hatchery native fish, such as Murray cod, trout cod, golden perch and silver perch.		

4b	Undertake a conservation stocking program for Macquarie perch.	1	• Sites known to have held the species previously, but where the species is now extinct, are stocked with fingerling Macquarie perch.
			  • Where this occurs, steps should be taken to reduce/eliminate stocking of introduced fish species as per Action 1a.
			  • Steps should be taken to improve habitat conditions in these areas.
			• Sites within natural distribution and historically translocated populations established outside the natural distribution (Yarra and Mongarlowe rivers and Cataract Reservoir) known to have populations of the species are stocked with fingerling Macquarie perch, in a manner to promote genetic diversity.
			• Self-sustaining populations are re-established at sites where the species has previously been extirpated from.
				Australian and state/territory governments, research community, local governments, non-government organisations	$250 000

Strategy 5 – Improve understanding of the biology and ecology of the Macquarie perch, and its distribution and abundance

Research actions

Table 6: *Strategy 5 Actions*

Action	Description	Priority	Performance Criteria	Responsible Agencies *and potential partners*	Indicative Cost **priority 1 only*
5a	Implement a long term monitoring program for the Macquarie perch which is able to record the size and importance of natural, self-sustaining populations and stocked populations.	1	• Permanent monitoring sites are established across the Murray-Darling Basin in appropriate locations where the Macquarie perch is known, or likely, to occur. • Regular and effective monitoring is undertaken at permanent monitoring sites. • A population model for Macquarie perch across the Murray-Darling Basin and eastern rivers is established, being informed by monitoring data. • Population trends are reported on a regular basis to detect sudden fluctuations. • Identify Macquarie perch populations that are of high conservation priority, which may be identified, but not limited to, populations that are key source populations for breeding or dispersal; populations necessary for maintaining or improving genetic diversity and/or populations that are near the limit of its range. Genomics analyses may be used to answer outstanding questions. • eDNA technology has been utilised to detect populations.	Australian and state/territory governments, local governments, non-government organisations	$125 000

5b	Increase understanding of spawning and recruitment ecology of the Macquarie perch and its relationship to habitat.	2	• Components of instream habitat that are critical to successful spawning and recruitment are identified and documented/mapped.	Australian and state/territory governments, research community	-
5c	Increase understanding of how the Macquarie perch's life cycle is related to flow and temperature.	2	• Critical times during the year are identified when increased flow and temperature changes are important for life cycle events to occur naturally. • Based on findings, environmental water is managed appropriately and cold water pollution is effectively managed for Macquarie perch in areas where populations are being affected, where possible.	Australian and state/territory governments, research community	-
5d	Investigate the fate of released fingerlings.	1	• Survival rates have been approximated from tag/recapture surveys or using genomics analyses. • Assessments have been completed on whether stockings have established viable, self-sustaining populations.	Australian and state/territory governments, research community	$60 000

Strategy 6 – Increase participation by community groups in Macquarie perch conservation

On ground actions

Table 7: *Strategy 6 Actions*

Action	Description	Priority	Performance Criteria	Responsible Agencies *and potential partners*	Indicative Cost **priority 1 only*
6a	Raise awareness for the conservation status of Macquarie perch in the community.	1	• Information materials are targeted to resource managers and across all levels of government. • Information materials are distributed, specifically targeting anglers to enhance identification of Macquarie perch. • A reporting system is established for sightings of the species. • Improved awareness regarding the Macquarie perch's conservation status and threats impacting the species, and the benefits of recovering the species, amongst the community, including recreational fishers, land owners and managers, natural resource management groups, acclimatisation societies. • Indigenous and community groups are involved in aspects of Macquarie perch recovery including for example, habitat restoration activities, stocking; research and monitoring programs. • Recreational fishers and associated communities are made aware of the historical abundance of Macquarie perch	Australian and state/territory governments, research community, local governments, non-government organisations	$75 000

			and the once sizeable fisheries it sustained. Messaging to include the potential for strong future economic, social and tourism opportunities likely to arise in relation to fishing for the species should the species recovery significantly.		
6b	Engage with private landholders and land managers responsible for the land adjacent to waterways which populations occur and encourage these key stakeholders to support the conservation of the Macquarie perch.	2	• Develop education/awareness raising products. • Landholders with river or creek frontage to water with Macquarie perch inhabiting are aware of the species' conservation and management requirements. • Information products distributed to educate industry and farmers about the risks various pollutants pose to waterways containing Macquarie perch.	Australian and state/territory governments, research community, local governments, non-government organisations	-

10 Duration and Cost of the Recovery Process

It is anticipated that the recovery process will not be achieved prior to the scheduled five year review of the recovery plan. The *National Recovery Plan for the Macquarie Perch (*Macquaria australasica*)* (2017) will therefore remain in place until such time as the Australian populations of Macquarie perch have improved to the point at which the species no longer meet threatened species status under the EPBC Act.

The cost of implementation of this plan should be incorporated into the core business expenditure of the affected organisations and through additional funds obtained for the explicit purpose of implementing this recovery plan. It is expected that state and Commonwealth agencies will use this plan to prioritise actions to protect the species and enhance its recovery, and that projects will be undertaken according to agency priorities and available resources. Whilst only Priority 1 actions are costed in this recovery plan (refer to Table 8), this should not deflect from any proposal to undertake Priority 2 actions. All actions are considered important steps towards ensuring the long-term survival of the species.

Table 8: *High priority recovery actions (Priority 1 as identified in Section 9) and estimated costs in ($000's)*

Note: These estimated costs are for the first five years of implementation and do not take into account inflation over time.

Action	**Cost**					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
1a. Protect Macquarie perch from competition with and predation by introduced fish species.	$100 000	$100 000	$100 000	$100 000	$100 000	$500 000
1b. Ensure that the impacts of recreational fishing are minimised.	$50 000	$50 000	$50 000	-	-	$150 000
1d. Restore Macquarie perch population connectivity by conducting regular assisted gene flow (i.e. translocations) in order to decrease inbreeding, prevent further loss of genetic diversity by drift and improve adaptive potential (consistent with EPBC Act requirements).	$20 000	$20 000	$20 000	$20 000	$20 000	$100 000
2a. Undertake priority habitat rehabilitation, restoration and enhancement work.	$400 000	$400 000	$400 000	$400 000	$400 000	$2 000 000
3a. Investigate methods to promote spawning and recruitment activity of Macquarie perch in naturally occurring and stocked populations.	-	-	$20 000	$20 000	$20 000	$60 000
3b. Better understand competition and predation on Macquarie perch by introduced fish species.	$30 000	$30 000	$30 000	-	-	$90 000
4a. Refine and improve captive breeding techniques for Macquarie perch	$20 000	$20 000	$20 000	$20 000	$20 000	$100 000
4b. Undertake a conservation stocking program for Macquarie perch.	$50 000	$50 000	$50 000	$50 000	$50 000	$250 000
5a. Implement a long term monitoring program for the Macquarie perch which is able to record the size and importance of natural, self-sustaining populations and stocked populations.	$25 000	$25 000	$25 000	$25 000	$25 000	$125 000
5d. Investigate the fate of released fingerlings.	-	-	$20 000	$20 000	$20 000	$60 000
6a. Raise awareness for the conservation status of Macquarie perch in the community.	$15 000	$15 000	$15 000	$15 000	$15 000	$75 000
TOTAL	$710 000	$710 000	$750 000	$670 000	$670 000	**$3 510 000**

11 Effects on other Native Species and Biodiversity Benefits

By managing south eastern areas of the Murray-Darling Basin for the benefit of the Macquarie perch, many other native aquatic fauna will also benefit. Other EPBC Act listed threatened fish species that currently occur, or potentially could occur in future, in Macquarie perch habitat include the trout cod, Murray cod, silver perch, flathead galaxias (*Galaxias rostratus*) and barred galaxias (*Galaxias fuscus*). Because of the linkages between riparian and in-stream ecosystems, the protection of riparian zones will benefit riparian and in-stream fauna. Functional, intact riparian zones are directly related to high in-stream biodiversity (Boulton & Brock 1999) and contribute to the floristic diversity of off-reserve areas. The implementation of this recovery plan includes a number of potential biodiversity benefits for other species and ecological communities. Macquarie perch in many areas of their natural distribution are part of fish communities in which several other members are under threat. Hence, recovery activities to protect and restore habitats of Macquarie perch should also make an important contribution to the conservation of other native species occupying similar habitat.

Efforts to protect and recover Macquarie perch populations will deliver a range of indirect biodiversity benefits. For example, increasing community awareness about the threatened status of Macquarie perch may assist in raising the profile of threatened species in general and may lead to increased opportunities to conserve and protect threatened species and aquatic biodiversity in the future.

12 Social, Economic and Cultural considerations

The presence of introduced fish species in areas that the Macquarie perch was once common has likely had major impacts on extinct populations, and it is likely that introduced fish species are continuing to threaten the few remaining extant populations of Macquarie perch. The halting of salmonid stocking activities in areas where there are Macquarie perch populations is likely to have some social and economic impact.

Most wild, self-sustaining populations of Macquarie perch are no longer the target of any commercial or recreational fishing activities. The species is protected from take across most of its range, except in Lake Dartmouth (and tributaries) and the Yarra River, where the species did not exist naturally before individuals were first translocated there in 1857 (Wilson 1857).

The increased protection of the Macquarie perch prescribed in this plan is expected to result in recovery of populations, which could allow for fishing activities for the species to resume under appropriate fisheries management oversight, once the species has recovered to a level (across its entire range) in which there would be a strong case for delisting the species from its EPBC Act threatened status. It is predicted that such recovery of the species will present new social and economic opportunities.

In New South Wales, Macquarie perch were a significant source of food and totemic value for Indigenous communities, specifically for the Gamilaroi. The Gamilaroi would not take pregnant or juvenile fish, or spawning run fish. Medium-sized fish were selected as part of their food supply. The Macquarie perch was probably known as Wunnumberu (pronounced 'Wanambiyu') by the Dhudhuroa who lived along the upper Murray River and lower Kiewa and Mitta Mitta rivers (Trueman 2011). Other possible names are Nooraderri and Gubir by the Wiradjuri who lived in the area bordered by the Lachlan, Macquarie and Murrumbidgee rivers (Trueman 2011; About NSW 2013). Implementation of this plan should involve knowledge sharing, participation in education and training relevant to threatened species management and engagement in recovery actions where relevant to aboriginal land management and communities. Indigenous groups will be encouraged to take part in activities that are part of the recovery plan. Opportunities may exist through Australian Government funding schemes and programmes to engage with Indigenous groups and Traditional Owners on biodiversity issues relating to the Macquarie perch. Any proposal that could affect places of cultural importance will need to be discussed in direct consultation with local groups.

Strategy 2 of this recovery plan identifies the protection and restoration of Macquarie perch habitat, of which a major component is providing for appropriate flows (both quantity and quality) where the species occurs. There is a need for recovery activities to work within broader natural resource management programs at a national level as well as at a state and territory level. This recovery plan aims to encourage the adoption of flow regimes conducive to the survival of the Macquarie perch and to maintain a suitable aquatic ecosystem within the species range.

As habitats critical to the survival of the species are identified, there is potential for developments to be restricted under the EPBC Act assessment and approval process. Any measures to assist recovery of this species that involve restrictions on the use of riparian land may result in economic impacts to affected industries. A person who proposes to take an action that will have, or is likely to have; a significant impact on a matter of national environmental significance must refer that action to the Minister for a decision on whether assessment and approval is required under the EPBC Act. For further information on the environment assessment and approval process please refer to: http://www.environment.gov.au/epbc/assessments/process.html

Improved community awareness and support is essential to the conservation and management of the Macquarie perch. Currently, there is a general lack of awareness of issues affecting the recovery and long-term conservation of the species. Some anglers may not be aware of the protected status of Macquarie perch, and the illegal take of the species may be having a detrimental impact in some areas.

13 Affected Interests

Continued liaison with those potentially affected by the implementation of this recovery plan should occur on an ongoing basis. Stakeholders with an interest in the actions proposed in this plan include: Australian and state governments' environment, fisheries and water managing agencies; Indigenous groups; land holders and managers (including industry, farmers/irrigators); recreational fishers; universities; researchers; conservation groups; environmental non-government organisations; local councils; regional natural resource management groups, and; proponents of development in the vicinity of important Macquarie perch habitat. This list, however, should not be considered exhaustive, as there may be other interest groups that would like to be included in the future or need to be considered when specialised tasks are required in the recovery process.

14 Consultation

This plan should be reviewed no later than five years from when it was endorsed and made publically available. The review will determine the performance of the plan and assess:

- whether the plan continues unchanged, is varied to remove completed actions, or varied to include new conservation priorities, and
- whether a recovery plan is no longer necessary for the species' as either conservation advice will suffice, or the species' are removed from the threatened species list.

The review will likely be coordinated by Department of the Environment and Energy in association with relevant Australian and state government agencies and key stakeholder groups such as non-governmental organisations, local community groups and scientific research organisations.

Key stakeholders who may be involved in the review of the performance of the *National Recovery Plan for the Macquarie Perch (*Macquaria australasica*)* include organisations likely to be affected by the actions proposed in this plan and are expected to include:

Australian Government

Department of the Environment and Energy (including the Commonwealth Environment Water Office)

Department of Agriculture and Water Resources

Murray-Darling Basin Authority

State/territory, local governments

New South Wales Department of Primary Industries

New South Wales Office of Environment and Heritage

Victoria Department of Environment, Land, Water and Planning

Victoria Department of Economic Development, Jobs, Transport and Resources

Australian Capital Territory Environment, Planning and Sustainable Development Directorate

South Australian Research and Development Institute

State/Territory Water Holders/Providers

Natural Resource Management Groups/Catchment Management Authorities

Local Land Services

Local Governments

Non-government organisations

Conservation Groups

Local Communities

Indigenous Groups and Traditional Owners

Experts from Universities and other organisations

Recreational Fishers and Associations

Industry and Agricultural (farming) Groups and Associations

15 References

About New South Wales (About NSW) (2013). *Wiradjuri People: About New South Wales*. Viewed: 25 September 2013.
Available on the Internet at:
http://about.nsw.gov.au/encyclopedia/article/wiradjuri-people/

Abramovitz, J.N. (1996). *Imperiled waters, impoverished future: The decline of freshwater ecosystems*. Worldwatch Paper 128, Worldwatch Institute, Washington DC.

Aldous, A., Fitzsimons, J., Richter, B., & Bach, L. (2011). Droughts, floods and freshwater ecosystems: evaluating climate change impacts and developing adaptation strategies. *Marine and Freshwater Research 62*, 223 – 231.

Anderson, I.G., Prior, H.C., Rodwell, B.J., & Harris, G.O. (1993). Iridovirus-like virions in imported dwarf gourami (*Colisa lalia*) with systemic amoebiasis. *Australian Veterinary Journal 70*, 66 – 67.

Appleford, P., Anderson, T.A., & Gooley, G.J. (1998). Reproductive cycle and gonadal development of Macquarie perch, *Macquaria australasica* Cuvier (Percichthyidae), in Lake Dartmouth and tributaries of the Murray–Darling Basin, Victoria, Australia. *Marine and Freshwater Research 49*, 163 – 169.

Arthington, A.H. (1991). Ecological and genetic impacts of introduced and translocated freshwater fishes in Australia. In: Billington, N. & Herbert, P.D.N. (eds.) (1991). "*International Symposium on the Ecological and Genetic Implications of Fish Introductions FIN*" 8, pp. 33 – 43.

Arthington, A., & McKenzie, F. (1997). Review of impacts of displaced/introduced fauna associated with inland waters, *Australia: State of the Environment Technical Paper Series (Inland Waters)*, Department of Environment, Canberra.

Arthur Rylah Institute (ARI) (2007). *An Assessment of the Status of Macquarie Perch, Macquaria australasica, in Hughes Creek, Victoria 2006/2007*. Fish survey report prepared for the Goulburn Broken Catchment Management Authority. Arthur Rylah Institute for Environmental Research, Victorian Department of Sustainability and Environment, Heidelberg.

Arthur Rylah Institute (ARI) (2017). *Personal communication by email to the Department of the Environment and Energy, 1 September 2017*. Arthur Rylah Institute, Department of Environment, Land, Water and Planning, Victoria State Government.

Australian Capital Territory Government (ACT Gov) (1999). *Macquarie Perch (*Macquaria australasica*): An endangered species, Action Plan No. 13.* Environment ACT, Canberra.

Australian Capital Territory Government (ACT Gov) (2017). *Personal communication by email to the Department of the Environment and Energy, 5 July 2017*. Conservation Research Unit, Environment, Planning and Sustainable Development Directorate, ACT Government.

Australian State of the Environment Committee (ASEC) (2001). Australia State of the Environment 2001, Independent Report to the Commonwealth Minister for the Environment and Heritage, CSIRO Publishing on behalf of the Department of the Environment and Heritage, Canberra.

Astles, K., Winstanley, R.K., Harris, J.H., & Gehrke, P.C. (2003). *Experimental study of the effects of cold water pollution on native fish*. NSW Fisheries Final Report Series No. 44, NSW Fisheries, Cronulla.

Balcombe, S.R., Sheldon, F., Capon, S.J., Bond, N.R., Hadwen, W.L., Marsh, N., & Bernays, S.J. (2011). Climate-change threats to native fish in degraded rivers and floodplains of the Murray-Darling Basin, Australia. *Marine and Freshwater Research 62*, 1099 – 1114.

Battaglene, S. (1988). *Macquarie Perch*. Agfact F3.2.5, New South Wales Agriculture and Fisheries.

Batty, J., & Lim, R. (1999). Morphological and Reproductive Characteristics of Male Mosquitofish (*Gambusia affinis holbrooki*) Inhabiting Sewage-Contaminated Waters in New South Wales, Australia. *Archives of Environmental Contamination and Toxicology 36*, 301 – 307.

Bayley, P.B., & Li, H.W. (1992). Riverine fishes. In: Calow, P. & Petts, G.E. (eds.) (1992). *The Rivers Handbook Volume 1*. Blackwell Scientific Publications, pp: 251 – 281.

Bayley, S.E., Schindler, D.W., Beaty, K.G., Parker, B.R., & Stainton, M.P. (1992). Effects of multiple fires on nutrient yields from streams draining boreal forest and fen watersheds: nitrogen and phosphorus. *Canadian Journal of Fisheries and Aquatic Sciences 49*, 584 – 596.

Bayly, I.A.E., & Williams, W.D. (1973). *Inland Water and their Ecology.* Longman, Hawthorn, 314pp.

Benda, L., Miller, D., Bigelow, P., & Andras, K. (2003). Effects of post-wildfire erosion on channel environments, Boise River, Idaho. *Forest Ecology and Management 178*, 105 – 119.

Berkman, H.E., & Rabeni, C.F. (1987). Effect of siltation on stream fish communities. *Environmental Biology of Fishes 18*, 285 – 294.

Bilby, R.E., & Likens, G.E. (1990). The importance of organic debris dams in the structure and function of stream ecosystems. *Ecology 61*, 1107 – 1113.

Bishop, K.A. (1979). *Aquatic communities of an impounded coastal river*. Unpublished Masters Thesis, Macquarie University, NSW, Australia.

Bond, N. (2004). Observations on the effects of the introduced parasite *Lernaea cyprinacea* on a lowland population of small native fish, Mountain Galaxias *Galaxias olidus*. *The Victorian Naturalist 121*, 194 – 198.

Booth, D.J., Bond, N., & Macreadie, P. (2011). Detecting range shifts among Australian fishes in response to climate change. *Marine and Freshwater Research 62*, 1027 – 1042.

Boulton, A., Berney, P., & Panizzon, D. (2004). More than just a good story: Lessons learnt from oral histories of Australian rivers. *Proceedings of the 4th Australian Stream Management Conference, 19 – 22 October 2004, Launceston*, 108 – 113.

Boulton, A.J., & Brock, M.A. (1999). *Australian Freshwater Ecology: Processes and Management*. Gleneagles Publishing, Glen Osmond, South Australia.

Bracamonte, S.E., Smith, S., Hammer, M., Pavey, S.A., Sunnucks, P., & Beheregaray, L.B. (2015). Characterization of MHC class IIB for four endangered Australian freshwater fishes obtained from ecologically divergent populations. *Fish & Shellfish Immunology 46*, 468 – 476.

Broadhurst, B.T., Ebner, B.C., & Clear, R.C. (2012). A rock-ramp fishway expands nursery grounds of the endangered Macquarie perch (*Macquaria australasica*). *Australian Journal of Zoology 60*, 91 – 100.

Broadhurst, B.T., Ebner, B.C., Lintermans, M., Thiem, J.D., & Clear, R.C. (2013). Jailbreak: a fishway releases the endangered Macquarie perch from confinement below an anthropogenic barrier. *Marine and Freshwater Research 64,* 900 – 908.

Brookes, A. (1986). Response of aquatic vegetation to sedimentation downstream from river channelisation works in England and Wales. *Biological Conservation 38*, 352 – 367.

Brown, A., Nicol, S., & Koehn, J. (1998). *Trout cod (*Maccullochella macquariensis*) Recovery Plan*. Aquatic Ecosse Pty. Ltd. & Department of Natural Resources and Environment, Victoria.

Brown, C., & Morgan, J. (2015). Predator recognition and responses in the endangered Macquarie perch (*Macquaria australasica*). *Marine and Freshwater Research 66*, 127 – 134.

Bruce, A., Knight, J., & Creese, B. (2007). *Survey of aquatic threatened species Macquarie perch (*Macquaria australasica*) and Adam's emerald dragonfly (*Archaeophya adamsi*) within the Hawkesbury-Nepean catchment*. Interim report to the Hawkesbury-Nepean Catchment Management Authority by the NSW Department of Primary Industries, Port Stephens Fisheries Centre, NSW.

Brumley, A.R., Morison, A.K., & Anderson, J.R. (1987). *Revision of the conservation status of several species of warmwater fish after surveys of selected sites in Northern Victoria (1982–84)*. Technical Report no. 33, Arthur Rylah Institute for Environmental Research, Department of Conservation, Forests and Lands, Victoria.

Bruton, M.N. (1985). The effects of suspensoids on fish. *Hydrobiologia 125*, 221 – 241.

Bruton, M.N. (1995). Have fishes had their chips? The dilemma of threatened fishes. *Environmental Biology of Fishes 43*, 1 – 27.

Burchmore, J.J., Battaglene, S.C., & Roach, A.C. (1988). *Lake Burrinjuck Fish Management Study: Interim Report*. Unpublished report. NSW Fisheries.

Burkhead, N.M., & Jelks, H.L. (2001). Effects of suspended sediment on the reproductive success of the tricolor shiner, a crevice-spawning minnow. *Transactions of the American Fisheries Society 130*, 959 – 968.

Burkhead, N.M., Walsh, S.J., Freeman, B.J., & Williams, J.D. (1997). Status and restoration of the Etowah River, an imperilled southern Appalachian ecosystem. In: Benz, G.W. & Collins, D.E. (1997). *Aquatic Fauna in Peril: the Southeastern Perspective, Special Publication 1.* Southeast Aquatic Research Institute, Lenz Design and Communications, Decatur, GA, USA. pp. 375 – 444.

Burton, C., & Raisin, G. (2001). Assessment of water temperature regime of the Macquarie River, Central West, New South Wales. In: Phillips, B. (ed.) (2001). *Thermal Pollution of the Murray-Darling Basin Waterways*. Workshop held at Lake Hume 18-19 June 2001, Inland Rivers Network and World Wide Fund for Nature – Australia, Sydney, pp. 45 – 54.

Burton, E.D., Phillips, I.R., & Hawker, D.W. (2004). Trace metals and nutrients in bottom sediments of the Southport Broadwater, Australia. *Marine Pollution Bulletin 48*, 378 – 402.

Butcher, A.D. (1945). *The food of indigenous and non-indigenous freshwater fish in Victoria, with special reference to trout*. Fisheries Pamphlet No. 2, Chief Inspector of Fisheries and Game, Victoria.

Butcher, A.D. (1967). A changing aquatic fauna in a changing environment. *Publications of the International Union for the Conservation of Nature 9*, 197 – 218.

Cadwallader, P.L. (1977). *J.O. Langtry's 1949–50 Murray River Investigations*. Fisheries and Wildlife Paper No. 13. Fisheries and Wildlife Division, Victoria.

Cadwallader, P.L. (1978). Some causes of decline in range and abundance of native fishes in the Murray-Darling River system. *The Proceedings of the Royal Society of Victoria 90*, 211 – 224.

Cadwallader, P.L. (1979). Distribution of native and introduced fish in the Seven Creeks River system, Victoria. *Australian Journal of Ecology 4*, 361 – 385.

Cadwallader, P.L. (1981). Past and present distributions and translocations of Macquarie Perch *Macquaria australasica*, with particular reference to Victoria. *The Proceedings of the Royal Society of Victoria 93*, 23 – 30.

Cadwallader, P.L., & Backhouse, G.N. (1983). *A Guide to the Freshwater Fish of Victoria*. Victorian Government Printing Office, Melbourne.

Cadwallader, P.L. (1984). *Use of scales and otoliths to age Macquarie perch,* Macquaria australasica *(Pisces: Percichthyidae)*. Technical Report Series No. 12, Snobs Creek Freshwater Fisheries Research Station and Hatchery, Arthur Rylah Institute for Environmental Research.

Cadwallader, P.L., & Douglas, J. (1986). Changing food habits of Macquarie perch, *Macquaria australasica* Cuvier (Pisces: Percichthyidae), during the initial filling phase of Lake Dartmouth, Victoria. *Marine and Freshwater Research 37(5)*, 647 – 657.

Cadwallader, P.L., & Eden, A.K. (1979). Observations on the food of Macquarie Perch, *Macquaria australasica* (Pisces: Percichthyidae) in Victoria. *Australian Journal of Marine and Freshwater Research 30*, 401 – 409.

Cadwallader, P.L., & Gooley, G.J. (1985). *Propagation and Rearing of Murray cod Maccullochella peeli at the Warmwater Fisheries Station Pilot Project, Lake Charlegrark*. Fisheries and Wildlife Service, Department of Conservation, Forests and Lands, Victoria.

Cadwallader, P.L., & Lawrence, B. (1990). Fish. In: Mackay, N. & Eastburn, D. (eds.) (1990). *The Murray.* Murray-Darling Basin Commission, Canberra. pp. 317 – 335.

Cadwallader, P.L., & Rogan, P.L. (1977). The Macquarie perch, *Macquaria australasica* (Pisces: Percichthyidae), of Lake Eildon, Victoria. *Australian Journal of Ecology 2*, 409 – 418.

Carey, A., Evans, M., Hann, P., Lintermans, M., MacDonald, T., Ormay, P., Sharp, S., Shorthouse, D., & Webb, N. (2003). *Wildfires in the ACT 2003: Report on initial impacts on natural ecosystems*. Technical Report 17, Environment ACT, Canberra. 80 pp.

Carpenter, S.R., Fisher, S.G., Grimm, N.B., & Kitchel, J.F. (1992). Global change and freshwater ecosystems. *Annual Review of Ecology and Systematics 23*, 119 – 139.

Chapman, D.W. (1988). Critical review of variables used to define effects of fines in redds of large salmonids. *Transactions of the American Fisheries Society 117*, 1 – 21.

Clunie, P., Stuart, I., Jones, M., Crowther, D., Schreiber, S., McKay, S., O'Connor, J., McLaren, D., Weiss, J., Gunasekera, L., & Roberts, J. (2002). *A risk assessment of the impacts of pest species in the riverine environment in the Murray-Darling Basin*. Department of Natural Resources and Environment, Arthur Rylah Institute for Environmental Research, Heidelberg.

Coats, R., Collins, L., Florsheim, J., & Kaufman, D. (1985). Channel change, sediment transport, and fish habitat in a coastal stream: effects of an extreme event, *Environmental Management 9*, 35 – 48.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2008). *Water Availability in the Murray-Darling Basin*. A report from CSIRO to the Australian Government. CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 67pp.

Conover, D.O., & Munch, S.B. (2002). Sustaining fisheries yields over evolutionary time scales. *Science 297(5578)*, 94 – 96.

Crook, D.A., Reich, P., Bond, N.R., McMaster, D., Koehn, J., & Lake, P.S. (2010). Using biological information to support proactive strategies for managing freshwater fish during drought. *Marine and Freshwater Research 61*, 379 – 387.

Crook, D.A., & Robertson, A.I. (1999). Relationships between riverine fish and woody debris: implications for lowland rivers. *Marine and Freshwater Research 50*, 941 – 953.

Crowl, T.A., Townsend, C.R., & McIntosh, A.R. (1992). The impact of introduced brown and rainbow trout on native fish: the case of Australasia. *Reviews in Fish Biology and Fisheries 2*, 217 – 241.

Cushing Jr., C.E., & Olson, P.A. (1963). Effects of weed burning on stream conditions. *Transactions of the American Fisheries Society 92(3)*, 303 – 305.

Cuvier, G. (1830). Des Maquaries, et de la Maquarie de la Nouvelle-Hollande. In: Cuvier, G. & Valenciennes, A. (1830). *Histoire naturelle des poissons. Tome cinquième. Livre cinquième. Des Sciénoïdes*. pp.377 – 381.

Davies, B.R., Thoms, M., & Meador, M. (1992). An assessment of the ecological impacts of inter-basin water transfers, and their threats to river basin integrity and conservation, *Aquatic Conservation: Marine and Freshwater Ecosystems 2(4)*, 325 – 349.

Davies, P.E., Harris, J.H., Hillman, T.J., & Walker, K.F. (2008). *SRA Report 1: A Report on the Ecological Health of Rivers in the Murray–Darling Basin, 2004–2007*. Prepared by the Independent Sustainable Rivers Audit Group for the Murray– Darling Basin Ministerial Council.

Davies, P.E., Stewardson, M.J., Hillman, T.J., Roberts, J.R., & Thoms, M.C. (2012). *Sustainable Rivers Audit 2: The ecological health of rivers in the Murray–Darling Basin at the end of the Millennium Drought (2008–2010).* Prepared by the Independent Sustainable Rivers Audit Group for the Murray-Darling Basin, Murray-Darling Basin Authority, Canberra.

Davis, M.L., & Cornwell, D.A. (2008). *Introduction to Environmental Engineering*, *4th edition.* McGraw-Hill, Sydney.

Douglas, J., Giles, A., & Strongman, R. (2002). *Lake Dartmouth Multi-species Fishery Assessment*. Marine and Freshwater Resources Institute Freshwater Fisheries Report No. 02/2. Marine and Freshwater Resources Institute Department of Natural Resources and Environment, Victoria.

Dove, A.D.M., Cribb, T.H., Mockler, S.P., & Lintermans, M. (1997). The Asian Fish Tapeworm, *Bothriocephalus acheilognathi*, in Australian freshwater fishes. *Marine and Freshwater Research 48(2)*, 181 – 183.

Dove, A.D.M., & Fletcher, A.S. (2000). The distribution of the introduced tapeworm *Bothriocephalus acheilognathi* in Australian freshwater fishes. *Journal of Helminthology 74*, 121 – 127.

Dufty, S. (1986). *Genetic and morphological divergence between populations of Macquarie perch (Macquaria australasica) east and west of the Great Dividing Range*. Honours Thesis, University of New South Wales.

Dunlop, M., & Brown, P.R. (2008). *Implications of climate change for Australia's National Reserve System: A preliminary assessment*. Report to the Department of Climate Change, February 2008. Department of Climate Change, Canberra, Australia.

Earl, S.R., & Blinn, D.W. (2003). Effects of wildfire ash on water chemistry and biota in South-Western U.S.A. streams. *Freshwater Biology 48*, 1015 – 1030.

Ebner, B., Broadhurst, B., Lintermans, M., & Jekabsons, M. (2007). A possible false negative: lack of evidence for trout predation on a remnant population of the endangered Macquarie perch, *Macquaria australasica*, in Cotter Reservoir, Australia. *New Zealand Journal of Marine and Freshwater Research 41*, 231 – 237.

Ebner, B., Clear, R., Godschalx, S., & Beitzel, M. (2009). In-stream behaviour of threatened fishes and their food organisms based on remote video monitoring. *Aquatic Ecology 43(2)*, 569 – 576.

Ebner, B., & Lintermans, M. (eds.) (2007). *Fish passage, movement requirements and habitat use for Macquarie perch*. Final Report to the Department of Agriculture, Fisheries and Forestry Australia. Parks, Conservation and Lands, Canberra, 139 pp.

Ebner, B., Thiem, J., Broadhurst, B., Clear, R., & Frawley, K. (2008). *Delivering environmental flows to large biota*. Final Report to the Department of the Environment, Water, Heritage and the Arts. Parks, Conservation and Lands, Canberra, 48 pp.

Edwards, D. (1969). Some effects of siltation upon aquatic macrophyte vegetation in rivers. *Hydrobiologia* 34, 29 – 37.

Erskine, W.D. (1990). Hydrogeomorphic effects of river training works: the case of the Allyn River, NSW. *Australian Geographical Studies 28*, 62 – 76.

Erskine, W.D. (1992). Channel response to large-scale river training works: Hunter River, Australia. *Regulated Rivers: Research and Management 7(3)*, 261 – 278.

Erskine, W.D. (2001). Geomorphic evaluation of past river rehabilitation works on the Williams River, New South Wales. *Ecological Management and Restoration 2(2)*, 116 – 128.

Erskine, W.D. (2016). *River reaches, historical channel changes and recommended methods to improve Macquarie perch habitat on Hughes Creek, Victoria, May 2016*. Supervising Scientist Report 208, Supervising Scientist, Darwin, Northern Territory.

Erskine, W.D., & Webb, A.A. (2003). Desnagging to resnagging: new directions in river rehabilitation in southeastern Australia. *River Research and Applications 19(3)*, 233 – 249.

Faragher, R.A., & Harris, J.H. (1994). The historical and current status of freshwater fish in New South Wales. *Australian Zoologist 29(3)*, 166 – 176.

Farrington, L.W., Lintermans, M., & Ebner, B.C. (2014). Characterising genetic diversity and effective population size in one reservoir and two riverine populations of the threatened Macquarie perch. *Conservation Genetics 15(3)*, 707 – 716.

Faulks, L.K., Gilligan, D.M., & Beheregaray, L.B. (2010). Evolution and maintenance of divergent lineages in an endangered freshwater fish, *Macquaria australasica*. *Conservation Genetics 11(3)*, 921 – 934.

Faulks, L.K., Gilligan, D.M., & Beheregaray, L.B. (2011). The role of anthropogenic vs. natural in-stream structures in determining connectivity and genetic diversity in an endangered freshwater fish, Macquarie perch (*Macquaria australasica*). *Evolutionary Applications 4*, 589 –601.

Ficke, A.D., Myrick, C.A., & Hansen, L.J. (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries 17*, 581 – 613.

Gehrke, P.C., Astles, K.L., & Harris, J.H. (1999). Within-catchment effects of flow alteration on fish assemblages in the Hawkesbury-Nepean River system, Australia. *Regulated Rivers: Research and Management 15*, 181 – 198.

Gilligan, D.M. (2005). *Fish Communities of the Murrumbidgee catchment: Status and trends*. Fisheries Final Report Series No.75. New South Wales Department of Primary Industries.

Gilligan, D., McGarry, T., & Carter, S. (2010). *A scientific approach to developing habitat rehabilitation strategies in aquatic environments: A case study on the endangered Macquarie perch (Macquaria australasica) in the Lachlan catchment*. Fisheries Final Report Series No. 128. Industry & Investment New South Wales (now incorporating New South Wales Department of Primary Industries).

Gippel, C.J. (1995). Environmental hydraulics of large woody debris in streams and rivers. *Journal of Environmental Engineering 121(5)*, 388 – 395.

Gippsland Angling Clubs Association (GACA). *Personal communication by email to the Department of the Environment and Energy, 1 September 2017*. Gippsland Angling Clubs Association, Marlo, Victoria.

Go, J., Lancaster, M., Deece, K., Dhungyel, O., & Whittington, R. (2006). The molecular epidemiology of iridovirus in Murray cod (*Maccullochella peelii peelii*) in Australia. *Aquaculture 258*, 140 – 149.

Goode, J.R., Luce, C.H., & Buffington, J.M. (2012). Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains. *Geomorphology 139-140*, 1 – 15.

Gooley, G.J., & McDonald, G.L. (1988). *Preliminary study on the hormone-induced spawning of Macquarie perch,* Macquaria australasica *(Cuvier) (Percichthyidae), from Lake Dartmouth, Victoria*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 80. 13 pp.

Goulburn Broken Catchment Management Authority (GBCMA) (2015). *Goulburn River survey nets encouraging results*.
Viewed: 29 May 2015
Available on the Internet at:
http://www.gbcma.vic.gov.au/news_events/goulburn-river-survey-nets-encouraging-results.html

Gray, D. (2010). Perched on the edge of salvation. Published in the *Sydney Morning Herald*, 13 March 2010.
Viewed: 13 August 2015
Available on the Internet at:
http://www.smh.com.au/national/perched-on-the-edge-of-salvation-20100312-q48n.html

Gray, S.C., De Silva, S.S., Ingram, B.A., & Gooley, G.J. (2000). Effects of river impoundment on body condition and reproductive performance of the Australian native fish, Macquarie perch (*Macquaria australasica*). *Lakes and Reservoirs: Research and Management 5*, 281 – 291.

Hall, K.C., Broadhurst, M.K., Butcher, P.A., & Rowland, S.J. (2009a). Effects of angling on post-release mortality, gonadal development and somatic condition of Australian bass *Macquaria novemaculeata*. *Journal of Fish Biology 75(10)*, 2737 – 2755.

Hall, K.C., Butcher, P.A., & Broadhurst, M.K. (2009b). Short term mortality of Australian bass, *Macquaria novemaculeata*, after catch-and-release angling. *Fisheries Management and Ecology 16(3)*, 235 –247.

Hammer, M.P., & Walker, K.F. (2004). A catalogue of South Australian freshwater fishes, including new records, range extensions and translocations. *Transactions of the Royal Society of South Australia 128(2)*, 85 – 97.

Harleman, D.R.F. (1982). Hydrothermal Analysis of lakes and Reservoirs. *Journal of the Hydraulic Division 108*, 302 – 325.

Harris, J.H. (1995). The use of fish in ecological assessments. *Australian Journal of Ecology 20*, 65 – 80.

Harris, J.H., & Rowland, S.J. (1996). Australian freshwater cods and basses. In: McDowall, R. (ed.) (1996). *Freshwater fishes of South-Eastern Australia*. Reed Books, Chatswood, pp. 150 – 163.

Harris, J.H., & Silveira, R. (1999). Large-scale assessments of river health using an Index of Biotic Integrity with low-diversity fish communities. *Freshwater Biology 41(2)*, 235 – 252.

Harris, J., Bowling, L., Keller, R., Keller, R., Kress, J., Lake, P.S., & McPhail, D.C. (2006). *The Tooma River Project — Interdisciplinary probes into ill-defined and unpredictable contamination*. Technical report. CRC for Freshwater Ecology, Canberra.

Henry, G.W., & Lyle, J.M. (2003). *The National Recreational and Indigenous Fishing Survey*. Australian Government Department of Agriculture, Fisheries and Forestry, pp. 1 – 188.

Hitt, N.P. (2003). Immediate effects of wildfire on stream temperatures. *Journal of Freshwater Ecology 18*, 171 – 173.

Ho, H.K., & Ingram, B.A. (2012). *Genetic risk assessment for stocking Macquarie perch into Victorian waterways 2011*. Fisheries Victoria Internal Report Series no.45, August 2012, Victorian Department of Primary Industries, Alexandria, Victoria.

Hobday, A.J., & Lough, J.M. (2011). Projected climate change in Australian marine and freshwater environments. *Marine and Freshwater Research 62*, 1000 – 1014.

Horner, R.R. (2000). Introduction. In: Azous, A.L. & Horner, R.R. (eds.) (2000). *Wetlands and Urbanization Implications for the Future*. Lewis Publishers, Boca Raton. pp. 1 – 21.

Horwitz, P., Jasinska, E.J., Fairhurst, E., & Davis, J.A. (1998). *A review of knowledge on the effect of key disturbances on aquatic invertebrates and fish in the south-west forest region of Western Australia*. Report prepared for Environment Australia (Environment Forest Task force) and Western Australian Department of Conservation and Land Management.

Hunt, T.L., Douglas, J.W., Allen, M.S., Gwinn, D.C., Tonkin, Z., Lyon, J., & Pickworth, A. (2011). Evaluation of population decline and fishing sustainability of the endangered Australian freshwater fish *Macquaria australasica*. *Fisheries Management and Ecology 18(6)*, 513 – 520.

Ingram, B.A., & De Silva, S.S. (2007). Diet composition and preference of juvenile Murray cod, trout cod and Macquarie perch (Percichthyidae) reared in fertilised earthern ponds. *Aquaculture 271*, 260 – 270.

Ingram, B.A., Douglas, J.W., & Lintermans, M. (2000). Threatened fishes of the world: *Macquaria australasica* Cuvier, 1830 (*Percichthyidae*). *Environmental Biology of Fishes 59*, 68.

Ingram, B.A., Rimmer, M.A., & Rowland, S.J. (1994). Induced spawning trials with captive Macquarie perch, *Macquaria australasica* (*Percichthyidae*). *Proceedings of the Linnaean Society of New South Wales 114*, 109 – 116.

Jackson, P.D. (1981). Trout introduced into south-eastern Australia: their interaction with native fishes. *Victorian Naturalist 98*, 18 – 24.

Kabata, Z. (1979). *Parasitic Copepoda of the British Isles*. The British Museum, London.

Kearns, J. (2009). *Post wildfire translocation of Macquarie perch,* Macquaria australasica*, in King Parrot Creek, Victoria 2009*. Confidential Client Report prepared for the Victorian Department of Sustainability and Environment, Biodiversity and Ecosystem Services, Heidelberg, Victoria.

Kearns, J., Ayres, R., O'Mahony, J., Hackett, G., Liu, C., & Tonkin, Z. (2015). *Investigating movement and connectivity of Macquarie perch in King Parrot Creek, northern Victoria*. Unpublished Client Report for the Goulburn Broken Catchment Management Authority. Arthur Rylah Institute for Environmental Research, Victorian Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Kearns, J., Ayres, R., O'Mahony, J., & Lyon, J. (2012a). *Ongoing investigation of Macquarie perch and trout cod populations in the Goulburn-Broken Catchment*. Confidential Client Report for the Goulburn-Broken Catchment Management Authority. Victorian Department of Sustainability and Environment, Heidelberg, Victoria.

Kearns, J., Tonkin, Z., O'Mahony, J., & Lyon, J. (2012b). *Identification and protection of key spawning habitats for Macquarie Perch in King Parrot Creek: Black Saturday Victoria 2009 – Natural values fire recovery program*. Department of Sustainability and Environment, Heidelberg, Victoria.

Kearns, J., & Tonkin, Z. (2015). *A plan to address knowledge gaps for Macquarie perch in the Goulburn Broken Catchment*. Arthur Rylah Institute for Environmental Research. Unpublished Client Report for the Goulburn Broken Catchment Authority. Victorian Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Kingsford, R.T. (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology 25*, 109 – 127.

Knight, J.T. (2010). *The feasibility of excluding alien redfin perch from Macquarie perch habitat in the Hawkesbury-Nepean Catchment*. New South Wales Department of Primary Industries, Industry and Investment New South Wales.

Knight, J., & Bruce, A. (2010). Threatened Fish Profile: 'Eastern' Macquarie perch *Macquaria australasica* Cuvier, 1830. *Australian Society for Fish Biology Newsletter 40(2)*, 73 – 76.

Koehn, J. (2001). Ecological Impacts of Cold Water Releases on Fish and Ecosystem Processes. In: Phillips, B. (ed.) (2001). *Thermal Pollution of the Murray-Darling Basin Waterways: Workshop held at Lake Hume 18-19 June 2001*. World Wide Fund for Nature – Australia.

Koehn, J.D. (2005). Threats to Murray cod. In: Lintermans, M. & Phillips, B. (eds.) (2005). *Management of Murray cod in the Murray-Darling Basin – Canberra Workshop, June 2004*. Murray-Darling Basin Commission, Canberra, pp. 30 – 37.

Koehn, J., Brumley, A., & Gehrke, P. (2000). *Managing the Impacts of Carp*. Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Canberra.

Koehn, J.D., Doeg, T.J., Harrington, D.J., & Milledge, G.A. (1995). *The effects of Dartmouth Dam on the aquatic fauna of the Mitta Mitta River.* Department of Conservation and Natural Resources, Melbourne.

Koehn, J.D., & O'Connor, W.G. (1990a). *Biological Information for Management of Native Freshwater Fish in Victoria.* Department of Conservation and Environment, Freshwater Fish Management Branch, Arthur Rylah Institute for Environmental Research, Victoria.

Koehn, J.D., & O'Connor, W.G. (1990b). Threats to Victorian native freshwater fish. *Victorian Naturalist 107*, 5 – 12.

Koster, W.M., Dawson, D.R., Morrongiello, J.R., & Crook, D.A. (2014). Spawning season movements of Macquarie perch (*Macquaria australasica*) in the Yarra River, Victoria. *Australian Journal of Zoology 61(5)*, 386 – 394.

Lake, J.S. (1957). Trout populations and habitats in New South Wales. *Australian Journal of Marine and Freshwater Research 8*, 414 – 450.

Lake, J.S. (1959). *The freshwater fishes of New South Wales*. New South Wales State Fisheries Bulletin No. 5.

Lake, J.S. (1967a). *Freshwater fish of the Murray-Darling River system*. New South Wales State Fisheries Fisheries Research Bulletin No. 7, Chief Secretary's Deparment.

Lake, J.S. (1967b). Chapter 8 – Principal Fishes of the Murray-Darling River System. In: Weatherly, A.H. (ed.) (1967). *Australian Inland Waters and Their Fauna.* Australian National University Press, Canberra, pp. 192 – 213.

Lake, J.S. (1971). *Freshwater fishes and rivers of Australia*. Thomas Nelson, Sydney, Australia, 61 pp.

Lake, J.S (1978). *Australian Freshwater Fishes: and illustrated field guide*. Thomas Nelson Australia Pty Ltd, West Melbourne, Australia.

Langdon, J.S. (1989a). Prevention and control of fish diseases in the Murray-Darling Basin. *Proceedings of the workshop on native fish management*, *Canberra, 16–18 June 1988.*

Langdon, J.S. (1989b). Experimental transmission and pathogenicity of epizootic haematopoietic necrosis virus (EHNV) in Redfin Perch *Perca fluviatlis* L., and 11 other teleosts. *Journal of Fish Diseases 12(4)*, 295 – 310.

Langdon, J.S., & Humphrey, J.D. (1987). Epizootic haematopoietic necrosis, a new viral disease in redfin perch, *Perca fluviatilis* L., in Australia. *Journal of Fish Diseases 10(4)*, 289 – 297.

Langdon, J.S., Humphrey, J.D., Williams, L.D., Hyatt, A.D., & Westbury, H.A. (1986). First virus isolation from Australian fish: an iridovirus-like pathogen from redfin perch, *Perca fluviatilis* L. *Journal of Fish Diseases 9*, 263 – 268.

Lintermans, M. (1991a). The decline of native fish in the Canberra region: the effects of habitat modification. *Bogong 12(3)*, 4 – 7.

Lintermans, M. (1991b). The decline of native fish in the Canberra region: the impacts of introduced species. *Bogong 12(4)*, 18 – 22.

Lintermans, M. (2002). *Fish in the Upper Murrumbidgee Catchment: A Review of Current Knowledge*. Environment ACT, Canberra. 92 pp.

Lintermans, M. (2004). Human-assisted dispersal of alien freshwater fish in Australia. *New Zealand Journal of Marine and Freshwater Research 38(3)*, 481 – 501.

Lintermans, M. (2005). *Environmental Flows in the Cotter River, ACT, and the response of the threatened fish species* Macquaria australasica *and* Gadopsis bispinosus *in 2003 and 2004*. Consultancy report to ACTEW Corporation and ActewAGL. Environment ACT, Canberra, 33 pp.

Lintermans, M. (2006a). Threatened fish in mountain streams: out of sight, out of mind. *Proceedings of the May 2006 National Parks Association: Caring for Namadgi – Science and People*, pp. 41 – 54. National Parks Association of the ACT, Canberra.

Lintermans, M. (2006b). The re-establishment of the endangered Macquarie perch Macquaria australasica in the Queanbeyan River, New South Wales, with an examination of dietary overlap with alien trout. Technical report, CRC for Freshwater Ecology, Canberra. 34pp.

Lintermans, M. (2007). *Fishes of the Murray-Darling Basin: An introductory guide.* Murray-Darling Basin Commission Publication No. 10/07

Lintermans, M. (2008). *The Status of Macquarie Perch* Macquaria australasica *in the Mongarlowe River in 2007 and 2008*. Consultants report to the Friends of the Mongarlowe River Inc. 30 pp.

Lintermans, M. (2012). Managing potential impacts of reservoir enlargement on threatened *Macquaria australasica* and *Gadopsis bispinosus* in southeastern Australia. *Endangered Species Research 16*, 1 – 16.

Lintermans, M. (2013a). The rise and fall of a translocated population of the endangered Macquarie perch, *Macquaria australasica*, in south-eastern Australia. *Marine and Freshwater Research 64*, 838 – 850.

Lintermans, M. (ed) (2013b). *Using translocation to establish new populations of Macquarie perch, trout cod and two-spined blackfish in the Canberra region*. Final report to ACTEW Water. Institute for Applied Ecology, University of Canberra, Canberra.

Lintermans, M. (2013c). Chapter 12 – Conservation and Management. In: Humphries, P., & Walker, K. (eds.) (2013). *Ecology of Australian Freshwater Fishes*. CSIRO Publishing, Collingwood. pp. 283 – 316.

Lintermans, M. (2015). *Personal communication by email to the Department of the Environment, 28 May 2015*. Associate Professor Mark Lintermans, Institute for Applied Ecology, University of Canberra.

Lintermans, M. (2017). *Personal communication by email to the Department of the Environment and Energy, 31 August 2017*. Associate Professor Mark Lintermans, Institute for Applied Ecology, University of Canberra.

Lintermans, M., & Ebner, B. (2010). Threatened Fish Profile: 'Western' Macquarie perch *Macquaria australasica* Cuvier 1830. *Australian Society for Fish Biology Newsletter 40(2)*, 76 – 78.

Lintermans, M., Lyon, J.P., Hames, F., Hammer, M.P., Kearns, J., Raadik, T.A., & Hall, A. (2014). Managing fish species under threat: case studies from the Native Fish Strategy for the Murray-Darling Basin, Australia. *Ecological Management and Restoration 15*, 57 – 61.

Llewellyn, L.C. (1971). Breeding studies on freshwater forage fish of the Murray-Darling River System. *The Fisherman (NSW) 3(13)*, 1 – 12.

Lloyd, L.N., & Tomasov, J.F. (1985). Taxonomic Status of the Mosquitofish, *Gambusia affinis* (Poeciliidae), in Australia. *Australian Journal of Marine and Freshwater Research 36*, 447 – 451.

Long, W. (2017). Macquarie perch feared lost in NSW Murray found for first time since 2009. Posted 31 May 2017. Australian Broadcasting Commission (ABC).
Viewed: 9 October 2017
Available on the Internet at:
http://www.abc.net.au/news/rural/2017-05-31/nrn-macq-perch-found/8572968

Lugg, A. (1999). *Eternal winter in our rivers: addressing the issue of cold water pollution*. NSW Fisheries, Nowra New South Walkes, 17 pp.

Lugg, A., & Copeland, C. (2014). Review of cold water pollution in the Murray Darling Basin and impacts upon fish communities. *Ecological Management and Restoration 15*, 71 – 79.

Lyon, J., Lennie, R., Ryan, T., & Todd, C. (2002). Physical and Biological Impacts of Cold Water Dam Releases (Abstract). *Proceedings of the Annual Conference of the Australian Society for Fish Biology*, Cairns, Queensland, 14-17 August 2002.

Lyon, J.P., & O'Connor, J.P. (2008). Smoke on the water: can riverine fish populations recover following a catastrophic fire-related sediment slug? *Austral Ecology 33*, 794 – 806.

Lyon, J.P., Bird, T., Nicol, S., Kearns, J., O'Mahony, J., Todd, C.R., Cowx, I.G., & Bradshaw, C.J.A. (2014). Efficiency of electrofishing in turbid lowland rivers: implications for measuring temporal change in fish populations. *Canadian Journal of Fisheries and Aquatic Sciences 71*, 878 – 886.

MacDonald, A.J., Young, M.J., Lintermans, M., & Sarre, S.D. (2014). Primers for detection of Macquarie perch from environmental and trace DNA samples. *Conservation Genetics Resources 6*, 551 – 553.

Magilligan, F.J., Nislow, K.H., & Graber, B.E. (2003). Scale-independent assessment of discharge reduction and riparian disconnectivity following flow regulation by dams. *Geology 31(7)*, 569 – 572.

Mallen-Cooper, M., & Brand, D.A. (2007). Non-salmonids in a salmonid fishway: what do 50 years of data tell us about past and future fish passage? *Fisheries Management and Ecology 14(5)*, 319 – 332.

McKeown, K.C. (1934). Notes on the food of trout and Macquarie perch in Australia. *Records of the Australian Museum 19(2)*, 141 – 152.

Meyer, G.A., & Pierce, J.L. (2003). Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho: a long-term perspective. *Forest Ecology and Management 178*, 89 – 104.

Milton, D.A., & Arthington, A.H. (1983). Reproduction and Growth of *Craterocephalus marjoriae* and *C. stercusmuscarum* (Pisces: *Atherinidae*) in south-eastern Queensland, Australia. *Freshwater Biology 13(6)*, 589 – 597.

Milton, D.A., & Arthington A.H. (1984). Reproductive Strategy and Growth of the Crimson-spotted rainbowfish, *Melanotaenia splendida fluviatilis* (Castelnau) (Pisces: *Melanotaeniidae*) in south-eastern Queensland. *Marine and Freshwater Research 35*, 75 – 83.

Milton, D.A., & Arthington, A.H. (1985). Reproductive Strategy and Growth of the Australian smelt, *Retropinna semoni* (Weber) (Pices: *Retropinnidae*), and the Olive perchlet, *Ambassis nigripinnis* (De Vis) (Pisces: *Ambassidae*) in Brisbane, south-eastern Queensland. *Marine and Freshwater Research 36(3)*, 329 – 347.

Mol, J.H., & Ouboter, P.E. (2004). Downstream Effects of Erosion from Small-Scale Gold Mining on the Instream Habitat and Fish Community of a Small Neotropical Rainforest Stream. *Conservation Biology 18(1)*, 201 – 214.

Morrongiello, J.R., Beatty, S.J., Bennett, J.C., Crook, D.A., Ikedife, D.N.E.N., Kennard, M.J., Kerezsy, A., Lintermans, M., McNeil, D.G., Pusey, B.J., & Rayner, T. (2011). Climate change and its implications for Australia's freshwater fish. *Marine and Freshwater Research 62*, 1082 – 1098.

Murray-Darling Basin Authority (MDBA) (2017). *Sustainable Rivers Audit Fish and Macro 2004 to 2015*. Murray-Darling Basin Authority, Canberra.
Viewed: 11 October 2017
Available on the Internet at:
http://data.gov.au/dataset/fishmacro2004to2015

Murray-Darling Basin Commission (MDBC) (2003). *Murray-Darling Native Fish Strategy – Audit of Water Quality Problems*. Murray-Darling Basin Commission, Canberra.

Murray-Darling Basin Commission (MDBC) (2004). *Native Fish Strategy for the Murray-Darling Basin 2003–2013.* Murray-Darling Basin Commission, Canberra.

National Land and Water Resources Audit (NLWRA) (2001). *Australian Agriculture Assessment 2001.* Commonwealth of Australia, Canberra.

National Murray Cod Recovery Team (NMCRT) (2010). National Recovery Plan for the Murray Cod *Maccullochella peelii peelii*. Department of Sustainability and Environment, Melbourne.

Native Fish Australia (NFA) (2017). *Personal communication by email to the Department of the Environment and Energy, 31 August 2017*. Native Fish Australia (Victoria), Doncaster.

New South Wales Department of Planning (NSW DoP) (2008). *Impacts of underground coal mining on natural features in the Southern Coalfield: strategic review*. State of New South Wales through the NSW Department of Planning, Sydney.

New South Wales Department of Primary Industries (NSW DPI) (2005). *Threatened species in NSW: Macquarie perch:* Macquaria australasica. Primefact 9. DPI Threatened Species Unity, NSW Department of Primary Industries, Port Stephens.

New South Wales Department of Primary Industries (NSW DPI) (2010). *Narrandera's world first: breeding breakthrough for Macquarie perch*.
Viewed: 2 June 2015
Available on the Internet at:
http://www.dpi.nsw.gov.au/archive/news-releases/fishing-and-aquaculture/2010/world-first-breeding-breakthrough

New South Wales Department of Primary Industries (NSW DPI) (2013a). *Fisheries NSW Policy and Guidelines for Fish Habitat Conservation and Managemnt (2013 update).* Fisheries NSW, New South Wales Department of Primary Industries, a part of the Department of Trade and Investment, Regional Infrastructure and Services.

New South Wales Department of Primary Industries (NSW DPI) (2013b). *Brighter future for endangered Macquarie Perch*. Posted 17 December 2013, New South Wales Government, Department of Primary Industries.
Viewed: 13 August 2015.
Available on the Internet at:
http://www.dpi.nsw.gov.au/aboutus/news/all/2013/brighter-future-endangered-perch

New South Wales Department of Primary Industries (NSW DPI) (2016). *Personal communication by email to the Department of the Environment, 10 August 2016*. Fisheries NSW, Threatened Species. Department of Primary Industries.

New South Wales Department of Primary Industries (NSW DPI) (2017). *Personal communication by to the Minister for the Environment and Environment, 27 October 2017.* Department of Primary Industries – Fisheries.

New South Wales Department of Primary Industries (NSW DPI) (2017). *Redfin perch*. New South Wales Government, Department of Primary Industries.
Viewed: 16 October 2017
Available on the Internet at:
http://www.dpi.nsw.gov.au/fishing/pests-diseases/freshwater-pests/species/redfin-perch

New South Wales Fisheries Scientific Committee (NSW FSC) (2002). Final determination – Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams as a Key Threatening Process. 2002, Ref. No. FR 21, File No. FSC 01/06.New South Wales Department of Primary Industries.

New South Wales Fisheries Scientific Committee (NSW FSC) (2008). *Final determination* – Macqauria australasica – *Macquarie perch.* January 2008, Ref. No. FD 37. File No. FSC 99/20. New South Wales Department of Primary Industries.

Nguyen, T.T.T., Ingram, B.A., Lyon, J. & Guthridge, K. (2012). *Genetic diversity of populations of Macquarie perch,* Macquaria australasica. Fisheries Victoria Internal Report No 40, Victorian Department of Primary Industries, Queenscliff, Victoria, Australia, 23 pp.

Nicols, A. (1882). *The Acclimatisation of the Salmonidae at the Antipodes: Its History and Results*. Low, Marston, Searle and Rivington (Publishers), London.

Norris, R.H., Wright, D.W., Lintermans, M., Bourke D.F., & Harrison, E.T. (2012). *Food resources for Macquarie perch in Cotter Reservoir*. Final Report to the Bulk Water Alliance. Institute for Applied Ecology, University of Canberra, Canberra.

O'Connor, N.A. (1991). The effect of habitat complexity on the macroinvertebrates colonising wood substrates in a lowland stream. *Oecologia 85(4)*, 504 – 512.

Pait, A.S., & Nelson, J.O. (2002). *Endocrine Disruption in Fish: An Assessment of Recent Research and Results*. Center for Coastal Monitoring and Assessment, National Oceanic and Atmospheric Administration, Silver Sprin, Maryland, United States of America, 55 pp.

Pavlova, A. (2017). *Personal communication by email to the Department of the Environment and Energy, 11 August 2017*. School of Biological Sciences, Monash University, Melbourne.

Pavlova, A., Beheregaray, L.B., Coleman, R., Gilligan, D., Harrisson, K.A., Ingram, B.A., Kearns, J., Lamb, A.M., Lintermans, M., Lyon, J., Nguyen, T.T.T., Sasaki, M., Tonkin, Z., Yen, J.D.L., & Sunnucks, P. (2017a) Severe consequences of habitat fragmentation on genetic diversity of an endangered Australian freshwater fish: a call for assisted gene flow. *Evolutionary Applications 10*, 531 – 550.

Pavlova, A., Gan, H.M., Lee, Y.P., Austin, C.M., Gilligan, D.M., Lintermans, M., & Sunnucks, P. (2017b). Purifying selection and genetic drift shaped Pleistocene evolution of the mitochondrial genome in an endangered Australian freshwater fish. *Heredity 118*, 466 – 476.

Pearce, L. (2013). *Macquarie Perch Refuge Project – Final Report for Lachlan CMA*. NSW Trade & Investment, Department of Primary Industries.

Pearce, L., Gilligan, D., McLellan, M., Asmus, M., & Daly, T. (2017). A retreat for Maccas: Recreational angler-driven Macquarie perch recovery. *Proceedings of the Murray-Darling Basin Native Fish Forum 2017*, 39 – 42.

Petts, G.E. (1984). *Impounded rivers: Perspectives for ecological management*. John Wiley, Chichester, 326 pp.

Phillips, B. (ed.) (2001). Thermal Pollution of the Murray-Darling Basin Waterways: Statement, Recommendations and Supporting Papers. *Proceedings of a workshop held at Lake Hume, 18–19 June 2001*. Inland Rivers Network and WWF Australia. 89 pp.

Pittock, J., & Finlayson, C.M. (2011). Australia's Murray-Darling Basin: freshwater ecosystem conservation options in an era of climate change. *Marine and Freshwater Research 62*, 232 – 243.

Power, M.E. (1984). The importance of sediment in the grazing ecology and size class interactions of an armored catfish, *Ancistrus spinosus*. *Environmental Biology of Fishes 10(3)*, 173 – 181.

Preece, R. (2004). *Cold Water Pollution Below Dams in New South Wales: a desktop assessment*. Water Management Division, New South Wales Department of Infrastructure, Planning and Natural Resources, Sydney.

Pusey, B.J., & Arthington, A.H. (2003). Importance of the riparian zone to the conservation and management of freshwater fish: a review. *Marine and Freshwater Research 54*, 1 – 16.

Raymond, S., Lyon, J., & Hames F (2008). *Hollands Creek Demonstration Reach: 2007/08. Summary document*. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria.

Raymond, S., & Ryall, J. (2017a). *Hollands Creek Demonstration Reach fish survey (2008–2017)*. Arthur Rylah Institute for Environmental Research. Unpublished Client Report for the Goulburn Broken Catchment Management Authority, Victorian Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Raymond, S., & Ryall, J. (2017b). The effect of water temperature on larval Macquarie perch. Arthur Rylan Institute for Environmental Research. Unpublished Client Report for the Goulburn Broken Catchment Management Authority, Victorian Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Rhodes, J.O. (1999). *Heads and tales: recollections of a fisheries and wildlife officer*. The Australian Deer Research Foundation. Melbourne, Victoria.

Richards, C., & Bacon, K.L. (1994). Influence of fine sediment on macro-invertebrate colonization of surface and hyporheic stream substrates. *Great Basin Naturalist 54(2)*, 106 – 113.

Rimmer, A.E., Becker, J.A., Tweedie, A., Lintermans, M., Landos, M., Stephens, F.J., & Whittington, R.J. (2015). Prevalence and distribution of dwarf gourami iridovirus (Infectious spleen and kidney necrosis virus) in populations of ornamental fish prior to and after importation into Australia, with the first evidence of infection in domestically farmed Platy (*Xiphphorus maculatus*). *Preventative Veterinary Medicine 122*, 181 – 194.

Rimmer, A.E., Whittington, R.J., Tweedie, A., & Becker, J.A. (2016). Susceptibility of a number of Australian freshwater fishes to dwarf gourami iridovirus (Infectious spleen and kidney necrosis virus). *Journal of Fish Diseases doi:10.1111/jfd.12510*, 1 – 18.

Roberts, J., Chick, A., Oswald, L., & Thompson, P. (1995). Effects of carp, *Cyprinus carpio*, an exotic benthivorous fish, on aquatic plants and water quality in experimental ponds. *Marine and Freshwater Research 46,* 1171 – 1180.

Roberts, J., & Sainty, G. (1996). *Listening to the Lachlan*. Geoff Sainty and Associates, Potts Point, NSW.

Robertson M., Nichols, P., Horwitz, P., Bradby, K., & MacKintosh, D. (2000). Environmental narratives and the need for multiple perspectives to restore degraded landscapes in Australia. *Ecosystem Health 6(2)*, 119 – 133.

Rowland, S.J. (1983). Spawning of the Australian freshwater fish Murray cod, *Maccullochella peelii* (Mitchell), in earthen ponds. *Journal of Fish Biology 23*, 525 – 534.

Rowland, S.J., & Ingram, B.A. (1991). *Diseases of Australian native freshwater fishes with particular emphasis on the ectoparasitic and fungal diseases of Murray cod (*Maccullochella peeli*), golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*).* NSW Fisheries, Sydney, NSW, Australia.

Rowland, S.J., & Tully, P. (2004). *Hatchery Quality Assurance Program for Murray cod (*Maccullochella peelii peelii*), golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*)*. NSW Department of Primary Industries, September 2004.

Ryan, P.A. (1991). Environmental effects of sediment on New Zealand streams: a review. *New Zealand Journal of Marine and Freshwater Research 25(2)*, 207 – 221.

Ryan, T., Webb, A., Lennie, R., & Lyon, J. (2001). *Status of cold water releases from Victorian dams.* Department of Natural Resources and Environment, Arthur Rylah Institute, State Government of Victoria.

Schälchli, U. (1992). The clogging of coarse gravel river beds by fine sediment. *Hydrobiologia 235*, 189 – 197.

Schetzer, A. (2017). *Re-diversifying our waterways, a garden stake at a time.* First published on 9 July 2017. Pursuit by the University of Melbourne, Victoria.
Viewed: 20 September 2017
Available on the Internet at:
https://pursuit.unimelb.edu.au/articles/re-diversifying-our-waterways-a-garden-stake-at-a-time

Scott, A. (2001). *Water erosion in the Murray-Darling Basin: Learning from the past*. Technical Report No. 43/01, November 2001, CSIRO Land and Water, Canberra.

Shearer, K.D., & Mulley, J.C. (1978). The introduction and distribution of the carp, *Cyprinus carpio* Linnaeus, in Australia. *Australian Journal of Marine and Freshwater Research 29*, 551 – 563.

Sherman, B., Todd, C.R., Koehn, J.D., & Ryan, T. (2007). Modelling the impact and potential mitigation of cold water pollution on Murray cod populations downstream of Hume Dam, Australia. *River Research and Applications 23(4)*, 377 – 389.

Smith, H.G., Sheridan, G.J., Lane, P.N.J., Nyman, P., & Haydon, S. (2011). Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology 396*, 170 – 192.

Starrs, D., Ebner, B.C., Lintermans, M., & Fulton, C.J. (2011). Using sprint swimming performance to predict upstream passage of the endangered Macquarie perch in a highly regulated river. *Fisheries and Management Ecology 18*, 360 – 374.

State Fisheries Department (SFD) (1914). *Annual Report on the Fisheries of New South Wales for the Year 1914*. Printed under No. 6 Report from Printing Committee, 12 August 1915.

State Fisheries Department (SFD) (1923). *Annual Report on the Fisheries of New South Wales for the Year 1923*. Printed under No. 14 Report from Printing Committee, 23 October 1924.

Stead, D.G. (1913). An account of some experiments on the acclimatisation of two species of Australian freshwater perch. *Report of the Australasian Association for the Advancement of Science 14*, 279 – 288.

Stoessel, D. (2009). *An investigation into the status of Trout Cod (*Maccullochella macquariensis*) and Macquarie Perch (*Macquaria australasica*) in selected reaches of Seven Creek*. A consultants report for the Goulburn- Broken Catchment Management Authority. Freshwater Ecology Section, Department of Sustainability and Environment, Victoria.

Stone, M., & Droppo, I.G. (1994). In-channel surficial fine-grained sediment laminae. Part II: Chemical characteristics and implications for contaminant transport in fluvial systems. *Hydrological Processes 8(2)*, 113 – 124.

Thiem, J.D., Broadhurst, B.T., Lintermans, M., Ebner, B.C., Clear, R.C., & Wright, D. (2013). Seasonal differences in the diel movements of Macquarie perch (*Macquaria australasica*) in an upland reservoir. *Ecology of Freshwater Fish 22*, 145 – 156.

Thorncraft, G., & Harris, J.H. (2000). *Fish Passage and Fishways in New South Wales: A Status Report*. Technical Report 1/2000, Cooperative Research Centre for Freshwater Ecology, Canberra.

Todd, C.R., & Lintermans, M. (2015). Who do you move: a stochastic population model to guide translocation strategies for an endangered freshwater fish in southeastern Australia. *Ecological Modelling 311*, 63 – 72.

Tonkin, Z.D., Humphries, P., & Pridmore, P.A. (2006). Ontogeny of feeding in two native and one alien fish species from the Murray-Darling Basin, Australia. *Environmental Biology of Fishes 76*, 303 – 315.

Tonkin, Z., Kearns, J., Fanson, B., Mahoney, J., Ayres, R., Raymond, S., Todd, C., & O'Mahony, J. (2017a). *An assessment of Macquarie perch population dynamics in the Yarra River*. Unpublished Client Report for Melbourne Water, June 2017. Arthur Rylah Institute for Environmental Research, Victorian Department of Environment, Land, Water and Planning, Heidelberg.

Tonkin, Z., Kearns, J., Lyon, J., Balcombe, S.R., King, A.J., & Bond, N.R. (2017b). Regional-scale extremes in river discharge and localised spawning stock abundance influence recruitment dynamics of a threatened freshwater fish. *Ecohydrology 2017, e1842*.

Tonkin, Z., Kearns, J., O'Mahony, J., & Mahoney, J. (2016a) Spatio-temporal spawning patterns of two riverine populations of the threatened Macquarie perch (*Macquaria australasica*). *Marine and Freshwater Research 67*, 1762 – 1770.

Tonkin, Z., Kitchingham, A., Ayres, R.M., Lyon, J., Rutherford, I.D., Stout, J.C., & Wilson, P. (2016b). Assessing the distribution and changes of instream woody habitat in south-eastern Australian rivers. *River Research and Applications 32*, 1576 – 1586.

Tonkin, Z., Kitchingman, A., Fanson, B., O'Mahony, J., Hackett, G., Ayres, R., Kearns, J., & Lyon, J. (2016c). *Enhancing fish populations using instream woody habitat restoration: II. Quantifying environmental outcomes*. Arthur Rylah Institute for Environmental Research Unpublished Client Report for the Water and Catchments Group Division, Victorian Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Tonkin, Z., Lyon, J., & Pickworth, A. (2009). *An assessment of spawning stocks, reproductive behaviour and habitat use of Macquarie Perch Macquaria australasica in Lake Dartmouth, Victoria*. Arthur Rylah Institute for Environmental Research. Technical report series No. 188. Department of Sustainability and Environment, Heidelberg, Victoria.

Tonkin, Z., Lyon, J., & Pickworth, A. (2010). Spawning behaviour of the endangered Macquarie perch *Macquaria australasica* in an upland Australian river. *Ecological Management & Restoration 11(3)*, 223 – 226.

Tonkin, Z., Lyon, J., Ramsey, D.S., Bond, N.R., Hackett, G., Krusic-Golub, K., Ingram, B., & Balcombe, S.R. (2014). Reservoir refilling enhances growth and recruitment of an endangered remnant riverine fish. *Canadian Journal of Fisheries and Aquatic Sciences 71(12)*, 1888 – 1899.

Tonkin, Z., Macdonald, J., Kaus, A., Ramsey, D., Hames, F., Crook, D., & King, A. (2011). A field based assessment of native fish responses following eastern gambusia removal: putting theory into practice. In: Jackson, P. & Bamford, H. (eds) (2011). *Gambusia Forum 2011: Small fish…big problem*, 1–2 June 2011, Crown Plaza Hotel, Melbourne, Victoria, Australia.

Treadwell, S., Koehn, J., & Bunn, S. (1999). Large woody debris and other aquatic habitat. In: Price, P., & Lovett, S. (eds.) (1999). *Riparian Land Management Technical Guidelines, Volume 1: Principles of Sound Management*. Land and Water Resources Research and Development Corporation, Canberra.

Trimble, S.W. (1981). Changes in Sediment Storage in the Coon Creek Basin, Driftless Area, Wisconsin, 1853 to 1975. *Science 214*, 181 – 183.

Trueman, W.T. (2007). *A review of attempts at the artificial propagation of the Macquarie perch* Macquaria australasica *with recommendations for future action*. Native Fish Australia Technical Report #2. Native Fish Australia (Victoria), Doncaster.

Trueman, W.T. (2011). *True Tales of the Trout Cod. River Histories of the Murray-Darling Basin*. Murray-Darling Basin Authority Publication No. 215/11. Murray-Darling Basin Authority, Canberra.

Van Der Walt, B., Faragher, R.A., & Lowry, M.B. (2005). Hooking mortality of released silver perch (*Bidyanus bidyanus*) after capture by hook-and-line fishing in New South Wales, Australia. *Asian Fisheries Science 18*, 205 – 216.

Van Nieuwenhuyse, E.E., & LaPerriere, J.D. (1986). Effects of placer gold mining on primary production in subarctic streams of Alaska. *Water Resources Bulletin 22*, 91 – 99.

Victoria Department of Environment and Primary Industries (Vic DEPI) (2014a). Re-establishing Macquarie perch in the Ovens River: A multi-agency and community approach to restoring threatened native fish populations. Fact sheet published by the State of Victoria Department of Environment and Primary Industries, Melbourne 2014.
Viewed: 11 August 2015
Available on the Internet at:
http://www.depi.vic.gov.au/__data/assets/pdf_file/0007/256876/Ovens-River-fact-sheet_establishing-Macquaire-Perch-2014.pdf

Victoria Department of Environment and Primary Industries (Vic DEPI) (2014b). *Macquarie perch releases to rebuild wild stocks*. Last updated on 5 June 2014. State of Victoria, Department of Environment and Primary Industries.
Viewed: 13 August 2015
Available on the Internet at:

http://www.depi.vic.gov.au/about-us/media-centre/media-releases/macquarie-perch-releases-to-rebuild-wild-stocks

Victoria Department of Environment, Land, Water & Planning (Vic DELWP) (2015). *Personal communication by email to the Department of the Environment, 5 May 2015*. Ecology Policy Branch. Land, Fire and Environment. Victoria Department of Environment, Land, Water & Planning, East Melbourne, Victoria State Goernment.

Victoria Department of Environment, Land, Water & Planning (Vic DELWP) (2017). *Personal communication by email to the Department of the Environment and Energy, 29 August 2017*. Victoria Department of Environment, Land, Water & Planning, East Melbourne, Victoria State Government.

Victoria Department of Economic Development, Jobs, Transport & Resources (DEDJTR) (2015a). *Macquarie perch* | *Fish Species* | *Education* | *Fisheries* | *Agriculture*. Last updated on 29 July 2015. State of Victoria, Department of Economic Development, Jobs, Transport & Resources.
Viewed: 13 August 2015
Available on the Internet at:
http://agriculture.vic.gov.au/fisheries/education/fish-species/macquarie-perch

Victoria Department of Economic Development, Jobs, Transport & Resources (DEDJTR) (2015b). *Fish Stocking Reporting* | *Fish Stocking* | *Recreational Fishing* | *Fisheries* | *Agriculture*. Last updated on 31 July 2015. State of Victoria, Department of Economic Development, Jobs, Transport & Resources.
Viewed: 13 August 2015
Available on the Internet at:
http://agriculture.vic.gov.au/fisheries/recreational-fishing/fish-stocking/fish-stocking-reporting

Victoria Department of Economic Development, Jobs, Transport & Resources (DEDJTR) (2015c). *Macquarie perch* | *Freshwater Scale Fish* | *Catch Limits and Closed Seasons* | *Recreational Fishing Guide* | *Recreational fishing*. Last updated on 31 July 2015. State of Victoria, Department of Economic Development, Jobs, Transport and Resources.
Viewed: 17 August 2015
Available on the Internet at:
http://agriculture.vic.gov.au/fisheries/recreational-fishing/recreational-fishing-guide/catch-limits-and-closed-seasons/freshwater-scale-fish/macquarie-perch

Victoria Department of Economic Development, Jobs, Transport & Resources (DEDJTR) (2015d). *Broken – Angling Waters* | *Broken* | *Inland Angling Guide* | *Fishing Locations* | *Recreational Fishing* | *Fisheries* | *Agriculture*. Last updated on 29 July 2015. State of Victoria, Department of Economic Development, Jobs, Transport & Resources.
Viewed: 24 August 2015
Available on the Internet at:
http://agriculture.vic.gov.au/fisheries/recreational-fishing/fishing-locations/inland-angling-guide/broken/broken-angling-waters

Victoria Department of Economic Development, Jobs, Transport & Resources (Vic DEDJTR) (2016). *Macquarie perch | Freshwater Scale Fish | Catch Limits and Closed Seasons | Recreational Fishing Guide | Recreational Fishing*. Last updated on 7 December 2015. State of Victoria, Department of Economic Development, Jobs, Transport & Resources. Viewed: 7 April 2016
Available on the Internet at:
http://agriculture.vic.gov.au/fisheries/recreational-fishing/recreational-fishing-guide/catch-limits-and-closed-seasons/freshwater-scale-fish/macquarie-perch

Victorian Fisheries Authority (VFA) (2017). *Fish Stocking Reporting*. Last updated on 28 June 2017. The State of Victoria.
Viewed: 29 August 2017
Available on the Internet at:
https://vfa.vic.gov.au/recreational-fishing/fish-stocking/fish-stocking-reporting

Vilizzi, L., Thwaites, L.A., Smith, B.B., Nicol, J.M., & Madden, C.P. (2014). Ecological effects of common carp (*Cyprinus carpio*) in a semi-arid floodplain wetland. *Marine and Freshwater Research 65*, 802 – 817.

Vinyard, G.L., & O'Brien, W.J. (1976). Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). *Journal of the Fisheries Research Board of Canada 33(12)*, 2845 – 2849.

Walker, K.F. (1985). A Review of the Ecological Effects of River Regulation in Australia. *Hydrobiologia 125*, 111 – 129.

Walker, J., Raison, R.J., & Khanna, P.K. (1986). Fire. In: Russell, J.S. & Isbell, R.F. (eds.) (1986). *Australian Soils–the Human Impact*. Australian Society of Soil Science, University of Queensland Press, St Lucia, pp. 185 – 214.

Waters, T.F. (1995). Sediment in Streams: Sources, Biological Effects and Control. *American Fisheries Society Monograph 7*. American Fisheries Society, Bethesda, Maryland.

Weatherley, A.H. (1963a). Thermal stress and interrenal tissue in the perch *Perca fluviatilis* (Linnaeus). *Proceedings of the Zoological Society of London 141*, 527 – 555.

Weatherley, A.H. (1963b). Zoogeography of *Perca fluviatilis* (Linnaeus) and *Perca flavescens* (Mitchill) with special reference to the effects of high temperature. *Proceedings of the Zoological Society of London 141*, 557 – 576.

Weatherley, A.H. (1977). *Perca fluviatilis* in Australia: zoogeographical expression of a life cycle in relation to environment. *Journal of the Fisheries Research Board of Canada 34*, 1464 – 1466.

Wharton, J.C. (1968). Spawning areas of Macquarie perch *Macquaria australasica* above the Eildon Lake (Victoria). *Australian Society for Limnology Newsletter 6(1)*, 11 – 13.

Wharton, J.C.F. (1973). Spawning, induction, artificial fertilization and pond culture of the Macquarie perch (*Macquaria australasica* [Cuvier, 1830]). *Australian Society of Limnology Bulletin 5*, 43 – 65.

Whittington, R.J., Becker, J.A., & Dennis, M.M. (2010). Iridovirus infections in finfish: critical review with emphasis on ranaviruses. *Journal of Fish Diseases 33*, 95 – 122.

Whittington, R., Becker, J., Tweedie, A. & Gilligan, D. (2007). Susceptibility of previously untested fish species to EHN Virus, and the epidemiology of EHN Virus in the Murray-Darling Basin. *Proceedings of the Murray-Darling Basin Commission Native Fish Strategy Forum, Mildura, 29th-30th August 2007*. Murray-Darling Basin Commission, Canberra.

Whittington, R., Becker, J., Tweedie, A., Gilligand, D., & Asmus, M. (2011). *Susceptibility of previously untested basin fish species to Epizootic Haematopoietic Necrosis Virus (EHNV) and its epidemiology in the wild*. Final Report to Murray-Darling Basin Authority Project No. MD743, University of Sydney and NSW Government, Industry and Investment.

Whittington, R.J., & Hyatt, A.D. (1998). Contingency planning for control of Epizootic Haematopoietic Necrosis Disease. *Singapore Veterinary Journal 20*, 79 – 87.

Whittington, R.J., Kearns, C., Hyatt, A.D., Hengstberger, S., & Rutzou, T. (1996). Spread of epizootic haematopoietic necrosis virus (EHNV) in redfin perch (*Perca fluviatilis*) in southern Australia. *Australian Veterinary Journal 73(3)*, 112 – 114.

Whittington, R.J., Philbey, A., Reddacliff, G.L., & MacGown, A.R. (1994). Epidemiology of epizootic haematopoietic necrosis virus (EHNV) infection in farmed rainbow trout, *Oncorhynchus mykiss* (Walbaum): findings based on virus isolation, antigen capture ELISA and serology. *Journal of Fish Diseases 17*, 205 – 218.

Whittington, R.J., Reddacliff, L.A., Marsh, I., Kearns, C., Zupanovic, Z., & Callinan, R.B. (1999). Further observations on the epidemiology and spread of epizootic haematopoietic necrosis virus (EHNV) in farmed rainbow trout Oncorhynchus mykiss in southeastern Australia and a recommended sampling strategy for surveillance. *Diseases of Aquatic Organisms 35*, 125 – 130.

Wilson, E. (1857). On the Murray River Cod, with particulars of experiments instituted for introducing this fish into the River Yarra-Yarra. *Transactions of the Philosophical Institute of Victoria 2*, 23 – 34.

Wilson, S. (1879). *Salmon at the Antipodes: being an account of the successful introduction of salmon and trout into Australian waters*. Edward Stanford (publishing), London.

Wood, P.J., & Armitage, P.D. (1997). Biological effects of fine sediment in the lotic environment. *Environmental Management 21(2)*, 203 – 217.