Macquarie Perch – catchment survey, Snowy 2.0

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December 2022

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Institute
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Macquarie Perch – catchment survey, Snowy 2.0

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Caveat: This report was completed in December 2021 and consequently does not contain more recent information which may have become available.

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1 Introduction

Snowy Hydro Limited received approval in 2020 to construct a new large-scale pumped hydro-electric storage and generation scheme (Snowy 2.0), to increase hydro-electric capacity within the existing Snowy Mountains Hydro-electric Scheme. This will involve the connection of the existing Talbingo and Tantangara reservoirs via a series of underground pipes and an underground power generation station. Water will be transferred in both directions between the reservoirs, which are in separate river catchments.

The Arthur Rylah Institute for Environmental Research has been engaged by Snowy Hydro to provide specialist advice that can inform the selection of options and preparation of various aquatic Management Plans required as part of the NSW and Commonwealth approvals for the Snowy 2.0 project. This report details a catchment survey design for Macquarie Perch (*Macquaria australasica*). It sets out objectives and potential activities to be undertaken to identify additional sub-populations of Macquarie Perch, and identify potential translocation sites, and their status/suitability, an important conservation action for the species. As such, its value and relevance will extend beyond the Snowy 2.0 Management Plans.

We develop a catchment survey program adapted to the catchment of what is usually known as the upper Murrumbidgee River. This area has been divided into Upper (upstream of Tantangara Reservoir) and Mid (between Tantangara Reservoir and southern ACT border) zones in the Snowy 2.0 Environmental Impact Statement (Cardno 2019). This survey encompasses both reaches, though mainly the Mid reach. The catchment survey program is based on relevant literature, including results and knowledge gained from previous surveys for Macquarie Perch in the Murrumbidgee River catchment, unpublished ad hoc fish sampling in the catchment, and knowledge of the environmental requirements of Macquarie Perch (Lintermans 2016; 2019, 2020, 2021; unpublished data).

This program addresses the following areas:

- Catchment survey objectives.
- Catchment survey activities.
- Catchment survey task details.
- Options for habitat enhancement.
- Indicative effort.
- Considerations.

1.1 Relevance to priority conservation actions

Priority actions identified by NSW DPI (2015) that are relevant to this document include:

- Conduct targeted surveys to determine the current distribution and abundance of Macquarie Perch (medium priority).
- Monitor Macquarie Perch populations over time to assess trends in abundance and distribution and to identify emerging threatening processes (high priority).
- Identify potential candidate sites for possible future translocation of Macquarie Perch (low priority).

The following priority actions listed in the national recovery plan for Macquarie Perch (Commonwealth of Australia 2018) are also partly relevant to this document:

- Protect Macquarie Perch from competition with and predation by introduced fish species (Priority 1).
- Protect Macquarie Perch populations from outbreaks of disease and parasites (Priority 2).

2 Catchment survey objectives

The overarching objective of a catchment survey for Macquarie Perch within the Mid-Murrumbidgee catchment is to:

- Establish the geographic extent of the existing population(s) of Macquarie Perch in both the Murrumbidgee River mainstem and major tributaries.

Secondary objectives, which are detailed in section 3, are:

- Identify potential translocation sites.
- Identify opportunities for habitat enhancement.
- Verify the presence and distribution of target pest fish within the catchment (i.e. Redfin Perch, *Perca fluviatilis*).

The 'Catchment Survey' has close synergies with the Translocation Strategy and will potentially provide important data to inform future translocation activities. The results of the catchment survey will also inform the Macquarie Perch monitoring (see Lintermans et al. 2022). If Macquarie Perch are detected outside of the previously known areas, monitoring activities should be revised to include newly identified sub-populations for the following monitoring year.

3 Catchment survey activities

To meet catchment survey objectives, the following broad activities have been identified, with the new data collected to be analysed along with existing biological and ecological information. Note that tasks are not mutually exclusive, and many tasks or task components can be undertaken at the same locations during the survey.

3.1 Determine the current distribution and abundance of Macquarie Perch in the mid-Murrumbidgee catchment

This task will specifically:

- Confirm the current distribution and relative abundance of Macquarie Perch in different areas of the catchment where suitable habitat may exist, but historical sampling has not been sufficient to detect or detail the population.

- Identify areas where habitat exists but Macquarie Perch are absent or in lower than expected abundance.

- Identify locations with opportunities for habitat enhancement to improve conditions for Macquarie Perch.

- Improve knowledge of pest fish in the catchment.

Knowledge of the distribution, abundance, status, and population trajectory of threatened fish is essential to the management and ultimately the recovery of the species (Lintermans and Robinson 2018; Scheele et al. 2019). For Macquarie Perch, the broad distribution of the species is well understood (Commonwealth of Australia 2018) but fine-scale distributional knowledge is still lacking in many areas.

In the Mid-Murrumbidgee catchment (upstream of the ACT Border) knowledge of Macquarie Perch distribution is adequate for a large portion of the Murrumbidgee River mainstem between Yaouk and the Numeralla River junction (Lintermans 2016, 2020, 2021). This mainstem section has been the subject of numerous fish sampling events over the last two decades and is the core focus of the proposed monitoring (Lintermans et al. 2022). However, occasionally lowland sites can harbour small populations of Macquarie Perch where higher velocity flows can mitigate sediment accumulation (e.g. gorges such as Cooma Gorge between Mittagang Crossing and Murrells Crossing). Consequently, targeted assessments of Macquarie Perch occupancy within gorge habitats on the Murrumbidgee River mainstem is also warranted.

In contrast, contemporary fish surveys of the Murrumbidgee River between Tantangara Reservoir and Yaouk, and the major tributaries of the Murrumbidgee River downstream of Cooma, is patchy, with little to no data available from the past two decades using methods targeted at detecting Macquarie Perch (e.g. Lintermans 2016). Major tributaries with little available recent scientific knowledge of their fish fauna include the Big Badja, Kybean, Numeralla, Bredbo, Strike-A-Light rivers and the Goorudee Rivulet (Lintermans 2002). There also is little knowledge of the status of the species in the Queanbeyan River (just downstream of the Mid-Murrumbidgee catchment) where a Macquarie Perch population was known to exist until the mid-2000s (Lintermans 2006, 2013a).

Further, Macquarie Perch are susceptible to sedimentation, which fills deep pools, affects fish food supplies and diversity, and renders spawning sites unsuitable (Commonwealth of Australia 2018; Tonkin et al. 2022). Consequently lower-altitude tributary sites which have been heavily impacted by land clearing, forestry, grazing and water abstraction are considered less likely to contain undetected remnant populations than forested upland sites with intact riparian vegetation. However, Macquarie Perch is known to be able to persist as small, self-sustaining populations in short river sections of 10–25 km (Lintermans 2013a; Sharley and Tonkin 2019).

As such, the occupancy of Macquarie Perch in major tributaries of the Mid-Murrumbidgee River remains a key knowledge gap. Ascertaining new extant populations and confirming the distribution and abundance of the existing populations, in addition to identifying suitable sites for habitat enhancement and potential translocation, are key activities that will contribute important knowledge to enable actions to identify population trend and mitigate the risk of extinction for this endangered species.

The knowledge of pest fish presence and distribution will be gathered from locations sampled for Macquarie Perch.

3.2 Identify potential Macquarie Perch translocation or reintroduction sites

This task will specifically:

- Identify potential translocation/reintroduction sites by assessment of reaches for habitat suitability and possible restoration actions (such as riparian and instream repair, fishways, flow management and translocations) aimed at supporting new self-sustaining populations of Macquarie Perch or extending the range of existing populations.

The survey to identify remnant or unidentified Macquarie Perch populations (see above) should seek to prioritise river reaches that are still in good condition. Such sites which are unoccupied potentially represent good opportunities for future translocation/stocking, so serve a dual purpose. If new sub-populations are discovered, then further work is required to assess their long-term viability and genetic status prior to any subsequent decisions around translocations. Newly identified sub-populations should be added to the monitoring program in time for the following season (Lintermans et al. 2022). If Macquarie Perch are deemed to be absent from a survey site, the potential for the site to be considered as a future translocation site will need to be assessed against a range of criteria. While this will be covered in depth as part of the Stocking and Translocation Strategy, in brief these criteria could include:

- Presence/ongoing stocking of salmonids.

- Presence of other introduced fish species such as Carp (*Cyprinus carpio*), Redfin Perch, Eastern Gambusia (*Gambusia holbrooki*).

- Presence/ongoing stocking of other predatory native fish—Trout Cod (*Maccullochella macquariensis*), Murray Cod (*Maccullochella peelii*) and Golden Perch (*Macquaria ambigua*).

- Historical Macquarie Perch distribution.

- Access for both conservation actions and public access.

- Permission for access to privately owned sites.

- Existing threatening processes.

- Water security.

- Available length of stream.

- Habitat quality (current and potential) including the identification of opportunities for habitat enhancement activities.

- Existing in-stream barriers and/or the suitability of the site for augmentation/construction of an artificial barrier (that limit native fish dispersal and/or prevent alien fish invasion (e.g. Redfin Perch).

- Community support for threatened fish translocations.

3.3 Locate barriers to Macquarie Perch dispersal/colonisation or predator control barrier locations

This task will specifically:

- Identify existing fish passage barriers, locations that may be conducive to construction of artificial barriers or to the augmentation of existing barriers to improve barrier efficiency.

- Identify locations with opportunities for habitat enhancement.

Natural barriers preventing fish movement are often related to water volumes and levels, and flow volumes down the Murrumbidgee River are artificially reduced. Prior to Snowy Hydro corporatisation in 2002, Tantangara Reservoir removed approximately 99% of flow to the Murrumbidgee River downstream with the flow reduction still 73% at Yaouk (approximately 27 km downstream). (Pendlebury et al. 1997). Flow releases from Tantangara Reservoir now target an annual volume of 27 GL/year (30% of average natural flow (Water Administration Ministerial Corporation 2002), but the annual flows released from Tantangara are contingent on annual allocations to the Snowy and Montane Rivers. These allocations are based on the annual allocation in the Murray and Murrumbidgee River systems in the preceding year, with environmental flow releases from Tantangara recommended by the Snowy Advisory Committee. The maximum release capacity from Tantangara Reservoir is 1500 ML/day (Snowy Scientific Committee 2010) with actual releases

averaging 21.1 GL/year between 2011–12 and 2019–20 and in 33% of years did not exceed 10 GL/year (Snowy Hydro 2021).

Downstream of Yaouk is a self-sustaining population of Macquarie Perch (Lintermans 2016; 2020) and it is suspected that barriers to fish migration are preventing movement of Macquarie Perch to areas upstream of this location (M. Lintermans unpublished data). Investigation of location and characteristics of these barriers would inform barrier mitigation measures as suitable Macquarie Perch habitat is thought to exist and could be assessed as part of the catchment survey. Barrier characterisation will also inform reintroduction of the species to the river between Yaouk and Tantangara Reservoir (if barriers cannot be mitigated) (see Stocking and Translocation Strategy). LiDAR coverage is readily available for the area, so identification of existing barrier locations and characterisation is possible. Follow-up fine-scale barrier characterisation is now possible utilising drone technology (Westoby et al. 2012; Woodget et al. 2017; Allan and Lintermans 2021).

3.4 Priority survey sites

Twenty-two priority survey sites have been identified for assessment (Figure 1, Table 1). These include sites from each major tributary of the mid-Murrumbidgee River where Macquarie Perch is likely, or has the potential to, occur. Tributaries are an important consideration as they may not be impacted as quickly by Redfin Perch if this species establishes in the Murrumbidgee River mainstem. Sites are also included on the Murrumbidgee River mainstem where suitable habitat may exist, but sampling has been insufficient to date to reliably detect a permanent population. A site is defined as reach 400–1000 m in length, and incorporates a diversity of mesohabitat types (run, riffle, pool) that would be expected to meet the ecological requirements of Macquarie Perch (feeding, spawning, shelter) (Lintermans 2007; Tonkin et al. 2022).

For some sites where public access is readily available precise coordinates have been provided, but for other locations where private access and landholder permissions will be required, the centroid of a river reach only is given and further on-ground inspection and access negotiation will be required before the site may be used.

The Catchment survey sites in Figure 1 have been selected in:

- Poorly sampled tributaries where the species may still occur.
- Mid-Murrumbidgee River mainstem sites (upstream and downstream of the core reproducing range: see Lintermans et al. 2022) where localised conditions may have facilitated retention of small, recruiting sub-populations and/or where lack of sampling effort may have overlooked existing sub-populations.
- Upstream of Tantangara Reservoir where Macquarie Perch presence was historically reported.

While the mid-Murrumbidgee Catchment is the key focus of this current program, consideration could also be given to survey other locations for Macquarie Perch in other parts of its natural range, particularly where the return on investment (population increased per dollar spent) may be higher in areas outside the current project boundaries, e.g. the Queanbeyan River. This system is farther downstream, is known to contain suitable habitat and was known to contain a population of Macquarie Perch until the early-mid 2000s but has been poorly sampled. Consequently, as a minimum, it may provide value as a nearby translocation site.
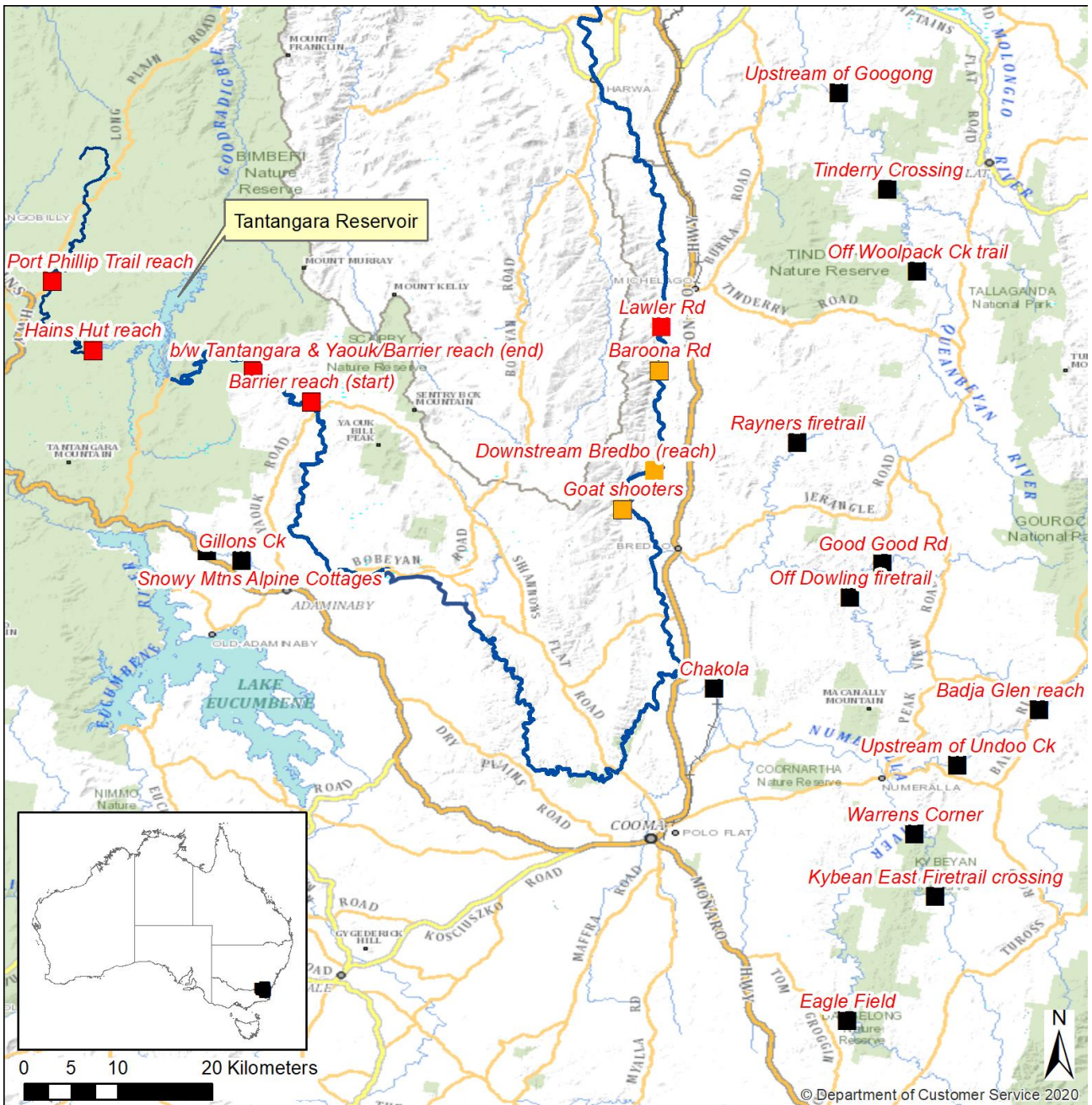
Figure 1. Mid- to upper Murrumbidgee River catchment with proposed catchment survey site locations for detection of Macquarie Perch and habitat assessment, and the barrier assessment reach.

Dark blue line – Murrumbidgee River mainstem; Yellow squares – gorge sites; Red squares – mainstem sites; Black squares – tributary sites.

Table 1. Catchment survey sites, Murrumbidgee subcatchment[1] location, access, and availability of previous fish survey data since 1998

[1] upper – upstream of Tantangara Reservoir; mid – below Tantangara Reservoir to southern ACT border; lower – downstream of southern ACT border; [A] Lintermans unpublished data; [B] data from Lintermans (2013a); [C] NSW DPI Boat electrofishing data (not directly comparable).

Waterbody	Site/Reach name	Subcatch-ment	Decimal Latitude, Longitude	Historic Presence?	Public or private access	Previous survey data available? (years)
Main stem						
Murrumbidgee River – below Cooma	Lawler Road	mid	–35.745756 149.133327	Yes	Public	Yes (2019, 2020, 2021)
	Baroona Road (Gorge)	mid	–35.787796 149.131900	unknown	Private	
	Downstream Bredbo (reach)	mid	–35.883118 149.126997	Yes	Private	Yes (2020, 2021)
	Goat Shooters (Gorge)	mid	–35.920010 149.096142	Yes	Public/Private?	
Murrumbidgee River – upstream of Yaouk (Barrier reach)	Barrier Reach (start)	mid	From: –35.817351 148.79828 Upstream to: –35.787356 148.743073°	unknown	Private	
Murrumbidgee River – below Tantangara Reservoir	Between Tantangara and Yaouk/Barrier reach (end)	mid	–35.787356 148.743073	angler report	Public/Private	
Murrumbidgee River – above Tantangara Reservoir	Hains Hut Reach	upper	–35.768538 148.589282	Yes	Public (National Park)	
	Port Phillip Trail reach	upper	–35.702074 148.550504	unknown	Public (National Park)	
Tributary streams						
Queanbeyan River	Upstream of Googong	lower	–35.522550 149.303272	Yes	Public (Nature Reserve)	[B] 1996–97, 2001, 2003–2006

Waterbody	Site/Reach name	Subcatch-ment	Decimal Latitude, Longitude	Historic Presence?	Public or private access	Previous survey data available? (years)
	Tinderry Crossing	lower	–35.614666 149.349697	unknown		[C] 2004, 2007, 2010, 2013, 2014, 2016, 2017, 2019
	Off Woolpack Creek Trail	lower	–35.692647 149.378625	unknown	Public (Nature Reserve)/private	
Strike-A-Light River	Rayners Firetrail	mid	–35.856642 149.263596	unknown	Private	
Bredbo River	Good Road	mid	–35.971772 149.345123	unknown	Private	
	Cowra Creek off Dowling Firetrail	mid	–36.004614 149.314134	unknown	Private	
Kybean River	Kybean East Firetrail crossing	mid	–36.290756 149.395372	unknown	Private?	
	Warrens Corner	mid	–36.230597 149.375522	unknown	Private	[A] 1998
Numeralla River	Chakola	mid	–36.091702 149.184032	Yes	Private	
	Eagle Field	mid	–36.408988 149.311316	unknown	Private	[C] 2010, 2020
Big Badja River	Badja Glen reach	mid	–36.111870 149.495039	Yes	Public/Private	[C] 2010, 2016
	Upstream of Undoo Creek	mid	–36.164952 149.417127	unknown	Private	
Goorudee Rivulet	Gillons Creek	mid	–35.969653 148.731462	unknown	Private	
	Snowy Mtns Alpine Cottages	mid	–35.960202 148.698525	unknown	Private	

4 Catchment survey tasks

Given the large spatial extent of the study area, coupled with high effort required to detect Macquarie Perch at a site using conventional survey techniques, we propose that the catchment survey will commence with a broad and rapid screen of all sites for Macquarie Perch and pest fish, while also undertaking habitat assessments to identify existing barriers and locations that many be conducive to barrier augmentation/construction, opportunities for habitat enhancement and potential translocation sites (Task 1). This will allow for the prioritisation of survey sites based on the presence of Macquarie Perch, or if absent, based on suitability as a translocation site (Figure 2). Sites where Macquarie Perch are detected, or considered to have value for translocations, will then be assessed in further detail using conventional survey techniques directly comparable to Macquarie Perch population monitoring methods (to assess relative abundance and size structure) and/or to confirm absence of pest fish (part of Task 2, Figure 2). Following this categorisation, Priority A sites where Macquarie Perch are detected are to be added to the monitoring program for the subsequent year, whilst investigations for potential translocations should continue at Priority B sites.

In addition, more detailed assessment may be required at fish sampling sites of existing potential predator barriers or barrier locations, potential movement barriers to Macquarie Perch. This is particularly required in the in the reach between Yaouk and Tantangara Reservoir (see Figure 1). Barrier assessments should be undertaken during physical sampling, where possible.

This can be summarised as:

1. Rapid eDNA screen of all 22 priority main-stem and tributary sites for Macquarie Perch and Redfin Perch, including habitat assessment.

2. Detailed assessments:
    A. Physical sampling of fish at:

    a. The two gorge sites on Murrumbidgee River main stem irrespective of the eDNA outcome — characterisation of these poorly-known sites where only adult Macquarie Perch have been found.

    b. The site assessed as having the most suitable habitat for Macquarie Perch in the identified tributary streams downstream from Tantangara Reservoir, irrespective of the eDNA result — to characterise the fish population with respect to the value of the site for future translocation.

    c. Any survey sites with a positive eDNA detection for Macquarie Perch – to characterise the Macquarie Perch population.

    B. Instream fish movement barrier and predator barrier assessments.
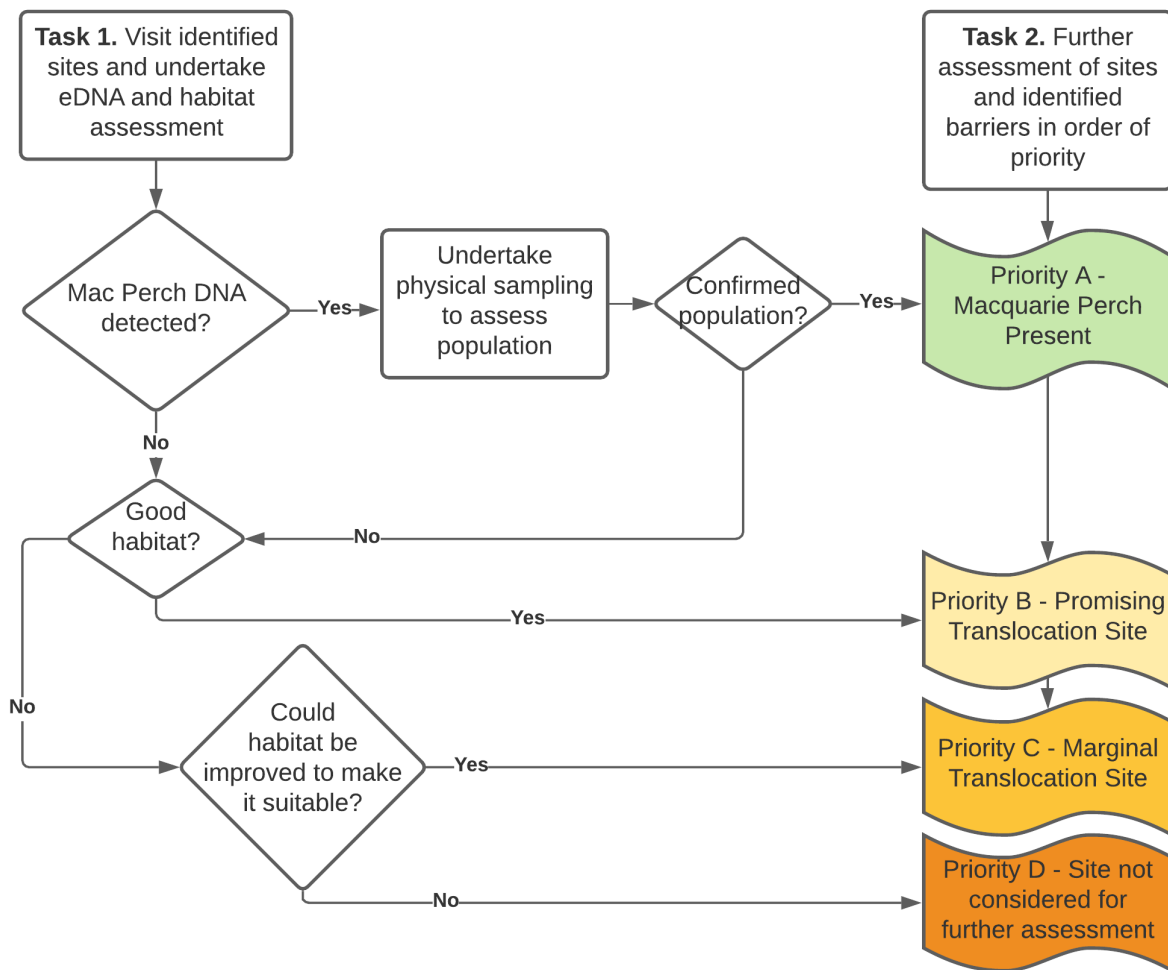
Figure 2. Flow chart of Macquarie Perch catchment survey tasks and summarised activities

4.1 Task 1. Rapid screen of survey sites

Initial site screening can be efficiently undertaken by the detection of the DNA of Macquarie Perch, and pest fish species (i.e. Redfin Perch) in water samples. This environmental DNA (eDNA) process is a widely used technique for detecting and quantifying a very small amount of target DNA in the environment (including water) (Taberlet et al. 2018). This would allow for more targeted physical sampling by eliminating sites without a positive detection. eDNA sampling has previously been used to identify fish faunal composition in a subset of sites in the upper Murrumbidgee catchment (Bylemans et al. 2018a).

eDNA detection is an evolving, relatively new technique and relies on the ability to detect short strands of DNA, unique to each target species, from a water sample (Wood et al. 2013; Taberlet et al. 2018). It is now increasingly used to detect rare or threatened animal species, including invasive species (Fukumoto et al. 2015; Janosik and Johnstone 2015; Bylemans et al. 2016; Hinlo et al 2018). However, many factors may influence the presence and amount of DNA in the water column and sample, and the ability to isolate and detect DNA in the sample, leading to potential false negatives (non-detection when present) or false positives (detection when absent) (Furlan and Gleeson, 2016, Hinlo et al. 2017, Taberlet et al. 2018, Stewart 2019). Bylemans et al. (2018b) showed that in the upper Murrumbidgee catchment optimal sampling eDNA strategies varied along altitudinal and biodiversity gradients, and species detection was also variable between mid-stream and near-bank samples.

An effective eDNA protocol should have high sensitivity to the DNA of target species, particularly at very low amounts, as well as specificity, to avoid positive detection of evolutionarily closely related species (i.e. similar DNA) (Furlan et al. 2016, Hinlo et al. 2018, Bylemans et al. 2019). A species-specific assay to detect Macquarie Perch DNA in environmental samples has already been developed (Piggott 2017; Piggott et al.

2020). Similarly, an eDNA probe to detect the pest species Redfin Perch has also been developed (Bylemans et al. 2016) which can be used to refine potential translocation sites given this species is a major threat to Macquarie Perch. A recent project has used eDNA successfully to target both species in the Abercrombie River (Bylemans et al. 2018b; Rojahn et al. 2021) and Murrumbidgee River (Weeks et al.2019).

In combination with the eDNA sampling, sites will also undergo assessment for factors which are important as habitat to support Macquarie Perch (i.e. instream and riparian habitat suitability, stream size and water permanency, predator barriers).

Any Macquarie Perch present are likely be in low abundance, or anecdotal reports would already exist. Therefore, detection power will increase if the survey is repeated. As such, for sites where the initial habitat assessment considers the location suitable for Macquarie Perch but none are detected, eDNA sampling should be repeated either in the consecutive year, or leaving a one or two-year gap between surveys. Any positive eDNA detection should be followed up with detailed sampling.

4.1.1 Methods

eDNA sampling

Replicate eDNA water samples will be collected during a site visit and either analysed nearby using a portable unit or sent to a laboratory. The time taken at a site for this task is expected to be approximately 1–2 hours.

eDNA water samples. Eight replicate eDNA samples of water should be taken across the channel at all sites. Samples should consist of 1 L of water per replicate, and filtered onsite using self-preserving filters, with used filters numbered and stored prior to laboratory analysis. Onsite filtering is rapid, allowing more sites to be sampled per day and does not require regular return of the sampling crew to the laboratory for filtration.

Site assessment

As the survey sites have been remotely selected without ground truthing, there is a likelihood that some sites will not contain Macquarie Perch and may also be unsuitable for any future translocation or stocking activities (Priority D sites, Figure 2). As such, important contextual information can be collected on site suitability for Macquarie Perch while the catchment survey is being undertaken. The following factors should be recorded during eDNA/fish surveys. The site assessment will be a rapid, objective, and qualitative appraisal of the following site attributes:

Instream and riparian habitat suitability. Initial rapid assessment of habitat suitability (both instream and riparian) for Macquarie Perch will be an important first step and will also assist in identifying opportunities for habitat enhancement. Specifically, characteristics to include are riparian vegetation, shading, substrate, instream structure (boulders, logs instream aquatic vegetation) and mesohabitat characteristics (presence of pool/riffle sequence).

Stream size and water permanency. This is to assess the potential permanency of adequate water at the location. This can be based on the observation of water depth, flow, and connectivity across the sampled reach, depth and substrate of pools, the presence and population structure of fish or crustacea, potential presence of instream aquatic vegetation which may indicate permanency if known (e.g. some species of bryophytes; Meagher and Fuhrer 2003), or active spring outflow (McCartney et al. 2013).

Predator barriers. An initial rapid qualitative site assessment will determine the potential presence of any effective, or partially effective, instream barriers possibly capable of preventing upstream movement of Redfin Perch. Further assessment can then be undertaken at a later stage, if required (e.g. as part of the Stocking/Translocation Strategy). The movement capacity of Macquarie Perch means that barriers need to be assessed at a larger (reach) scale. The assessment may be based on:

- The presence of one of more instream barriers such as waterfalls or cascade/waterfall series nearby (up to 20 km downstream).

- An absence of Redfin Perch (or other large alien species such as Carp). The presence of trout is not a 'stop-go' decision point as much of the Macquarie Perch distribution in south-eastern Australia overlaps with trout, and Rainbow Trout (*Oncorhynchus mykiss*) are still widely stocked in the upper Murrumbidgee catchment (NSW DPI 2021). The presence of trout may be an indicator of suitable Macquarie Perch habitat (spawning gravels, cooler water temperatures, water permanency, adequate food supplies to support large-bodied fish). However, if a site is selected for future translocation of Macquarie Perch, then stocking of Rainbow Trout and Brown Trout (*Salmo trutta*) should cease in that sub-catchment above the identified barrier.

The absence of Redfin Perch or Carp does not necessarily indicate that a barrier exists further downstream. Carp are still invading the upper Murrumbidgee system mainly via the illegal use of bait fish or illegal stocking of farm dams (Lintermans 2004b). LiDAR or GIS investigations should be used to identify the presence or likely location of such barriers.

4.2 Task 2 Detailed fish and barrier assessments

While the use of eDNA to identify the presence of rare fish species is becoming increasingly widespread, it remains limited in its capacity to quantify abundance (e.g. Hinlo et al. 2018), and cannot distinguish between life phases (juveniles, sub-adults, adults). As such, physical sampling to characterise aspects of the fish population will be required at sites where knowledge of fish (e.g. Macquarie Perch, Redfin Perch, or the fish community) is important.

We therefore propose that, following eDNA sampling and habitat assessment, conventional physical fish survey methods be undertaken at sites where specific fish assessments are required (see a–c on page 9). This data will also be useful to confirm the validity of the eDNA results.

In addition, more detailed assessment of fish movement barriers or predator barriers should be undertaken during fish assessments. In particular, fish barrier assessment is required in the Murrumbidgee River upstream of Yaouk as it will contribute to the assessment of sites for future translocation, and possibly to understanding the absence of Macquarie Perch in this reach over the last 20+ years.

4.2.1 Methods

Fish sampling

Conventional sampling methods will be used to verify and assess the status of any new sub-populations of Macquarie Perch detected from the eDNA surveys using the same survey technique as described in the broad population monitoring program (see Lintermans et al. 2022). This ensures that any detection of new Macquarie Perch sub-populations will have comparable data to be utilised as a potential baseline if the monitoring program is expanded to incorporate these new detections, or if the site is considered a priority for supplementary stocking (e.g. genetic rescue).

These methods will also be used to characterise the fish population (abundance, length range, etc.) at potential translocation sites, and at the two gorge sites on the mainstem of the Murrumbidgee River where there is a lack of information.

In summary, the methods used for conventional sampling will be:

Fyke nets. Twelve single-winged fyke nets (12 mm stretch-mesh) will be set at each site. Nets will be attached to the bank at the cod-end and then set at an angle to the bank facing downstream with a weight attached to the wing to hold the net securely. The single wing is attached to the centre of the front 'D' of the fyke net. Each fyke net has a 150 mm diameter polystyrene float inserted in the cod end to provide an airspace to prevent mortality of non-target animals such as Platypus. Nets will be set between 15:30 and 16:30 hours and left overnight. Nets will be retrieved between 07:30 and 08:30 hours the following morning, giving a 16-hour soak time.

The number and placement of nets at each site should be determined based on the operator expert judgement with details and co-ordinates taken so that similar levels of effort and location can be replicated if required.

Gill nets. Two braided monofilament gillnets, 50 meshes deep, stretch mesh size of 75 and 100 mm, 33 m length when strung on a float line will be set between 15:30 and 16:00 hrs and retrieved between 21:30 and 22:00 hours, giving a 6-hour soak time. The limited soak time will be employed to reduce stress or possible mortality of threatened fish species or non-target species such as Platypus and Eastern long-necked turtle (*Chelodina longicollis*). Previous research has demonstrated that the 6-hr soak time captured 79% of the number of Macquarie Perch captured using a 16-hr soak time, and that mortality of both target and non-target species was reduced (Lintermans 2013a). One end of each gill net will be attached to the bank and the other end attached to an anchor mid-stream.

Electrofishing. Backpack and boat electrofishing should follow the Sustainable Rivers Audit methodology (Davies et al. 2012) to facilitate comparisons with other long-term monitoring data. Boat electrofishing will only be deployed if a site has extensive pool and run habitats navigable by boat, and boat electrofishing is deemed necessary (as per the monitoring program). At each site deploy either 8 shots, each of 150 seconds (backpack) or 12 shots, each of 90 seconds (boat mounted) of accumulated power-on time. In portions of streams <10 m wetted channel width (as estimated by sampling teams), adopt zigzag coverage in wadeable habitats of sampled area (banks and riffle/runs). In streams >10 m wetted channel width (as estimated by sampling teams), adopt alternate shots alongside both banks in wadeable habitats (Banks and riffle/runs). In

deeper habitats use boat electrofishing shots of 90 seconds as per Murray–Darling Basin Fish Survey protocols (MDBFS 2015).

All fish species captured in the above methods will be identified, measured (Caudal Fork Length or Total Length, as appropriate). Weight of each Macquarie Perch captured should be recorded to 1 decimal place for small individuals and 0 decimal places for large individuals. All subadults and adult Macquarie Perch should be scanned for a PIT tag, and if a PIT tag is recorded, the code should be recorded in full. If no PIT tag is detected, a tag should be implanted as per standard procedures. All fish should be visually inspected for deformities, injuries (e.g. cormorant strike) and external parasites (e.g. *Lernaea cyprinacea*).

A small fin clip should be collected from the lower distal edge of the caudal fin of Macquarie Perch and preserved in 100% ethanol. Sampling should be conducted when detection probability for target fauna is maximised which coincides with lowest stream flows as efficiency is increased due to decreased water depth and width, reduced flow velocities and turbulence. We recommend March/April to undertake sampling which also allows an assessment for Macquarie Perch recruitment to be undertaken. Sampling will be undertaken in accordance with permits under the NSW Biodiversity Conservation Act 2016 and Fisheries Management Act 1994.

Barrier survey upstream of Yaouk

The Murrumbidgee River mainstem reach between Yaouk and sampling site 'Murrumbidgee R b/w Tantangara and Yaouk' (Figure 1) should be assessed for potential instream barriers to fish movement utilising topographic LiDAR (*Light Detection and Ranging).* LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the grounds surface. These light pulses, combined with concurrently collected GPS data, generates precise, three-dimensional information about the shape of landforms and their surface characteristics. LiDAR coverage, at 2 m pixel size from 2015, is currently publicly available for the upper Murrumbidgee catchment, and coverage at 1 m pixel resolution is also potentially available under commercial licence for some of the study zone. Vertical resolution is generally in the 'centimetre' range, and Lidar can differentiate broad terraces that might only be offset by 10 cm vertical (equivalent resolution to on-ground survey). This can generate long profiles of the river with adequate precision to identify potential fish barriers. Even in tight gorges vertical resolution is ≤ 50 cm (D. White pers. comm.). Once barriers have been identified, cross sectional analysis and mapping will coarsely characterise barriers.

Once priority barriers have been selected, on-site investigation utilising an unmanned aerial vehicle (UAV or drone) could be used to ground truth the LiDAR assessment. The UAV should incorporate a camera with a 20MP 1 inch CMOS sensor and mechanical shutter. Exposure values and flight centres are set automatically to lighting conditions and UAV speed using Map Pilot version 4.0.8. typical exposure settings are ISO 100, 8.8 mm focal length and between 1/160–1/500 second, and 4.6–5.6 aperture. Flight plans should be generated to enable 75% along and across track overlap at 50 m elevation above ground, with four passes along the stream. Photos are then processed into a 2 cm resolution orthoimage.

Photo locations can then be located within 3 cm relative accuracy and translated using ground control points surveyed to similar absolute accuracy using differential GPS (see Allan and Lintermans 2021).

5 Options for habitat enhancement

5.1 Summary of past and current habitat enhancements

Various habitat enhancement options have been deployed in the mid-Murrumbidgee catchment, both on the Murrumbidgee River mainstem and some tributaries. Most existing habitat enhancement options have been applied at small spatial scales, although some have been applied more broadly (Table 2). Interventions such as Carp 'fish-outs' are recognised for their importance in education and awareness raising but will have little impact on the overall Carp population (Norris et al. 2013). Similarly, other studies have shown that short-term Carp removal via boat electrofishing can remove significant numbers of Carp but have no significant long-term impacts on Carp density or biomass (Norris et al. 2011).

Table 2. Examples of existing and historic habitat works that have been undertaken in the mid-Murrumbidgee catchment

Key to organisation acronyms: LLS: Local Land Services; UMDR: Upper Murrumbidgee Demonstration Reach; UMLC: Upper Murrumbidgee Landcare Committee; ARRC: Australian River Restoration Centre (Rivers of Carbon); SMRC: Snowy Mountains Regional Council; BHA: Bush Heritage Australia.

Habitat works type	Current or past	By whom?	Spatial scale	Example locations
Willow control	Current and past	LLS, UMDR/ARRC, UMDR/ UMLC, Michelago Landcare, Bredbo Landcare	Landowner/site	Mittagang Xing- Murrells Crossing, Dromore, Bumbalong, Bredbo Gorge, Murrumbidgee/Bredbo River confluence, Colinton Gorge, Michelago Creek, Kissops Flat-Alum Creek
Instream woody habitat	past	UMDR/ARRC, UMDR/ Numeralla Fishing club, Numeralla Landcare	Sub-reach	Bumbalong, Scottsdale, Dromore, Murrells Crossing, Numeralla River
Erosion control	Current and past	UMDR/ARRC/GA, UMDR/BHA, LLS	site	Bumbalong, Gooroodee Rivulet, Kissops?
Riparian weed control (e.g. African lovegrass)	current	BHA	Sub-reach	Scottsdale
Riparian weed control (blackberry)	Current and past	UMDR/ARRC, UMDR/BHA, Bredbo Landcare/SMRC, Numeralla Landcare/SMRC	Sub-reach	Bumbalong, Murrumbidgee River and Bredbo River confluence, Badja and Numeralla Rivers
Carp control/fishout	Past and current	BHA, Bredbo and Numeralla fishing clubs, LLS (rangers)	site	Scottsdale, Numeralla River, Murrumbidgee River and Bredbo River at confluence, Murrells crossing
Riparian planting and fencing	Past and current	UMDR/ARRC, LLS/ARRC, BHA, Bredbo Landcare, LLS, Numeralla Landcare and Numeralla Fishing Club	Site/sub-reach	Scottsdale, Murrells Crossing, Bumbalong, Dromore, Gooroodee Rivulet, Murrumbidgee River and Bredbo River confluence, Numeralla River and Badja River
Fish Passage	Current and Past	NSW Fisheries/SMRC	site	Mittagang Crossing (this fish way is currently being upgrade)

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Deployment of large scale (financial as well as spatial) interventions directed specifically at fish habitat have largely been absent (with the exception of the landscape-scale African Lovegrass interventions by Bush Heritage Australia at Scottsdale).

For example the construction of infrastructure that has occurred in the ACT section of the Murrumbidgee River to deal with sand accumulation (instream groynes, and engineered log jams (Lintermans 2004a, 2005) has not occurred in the river upstream of the ACT. Instream impacts from the 2019–20 bushfires were locally severe, and there may be multiple opportunities for instream and riparian habitat rehabilitation in these areas.

5.2 Recommended habitat enhancement options

A variety of habitat interventions could be deployed to aid Macquarie Perch recovery in the study area. Firstly, sand accumulation and subsequent filling of refuge pools and spawning habitat is common across the mid-Murrumbidgee catchment. These accumulations are a result of historic factors such as land use change (vegetation clearing, grazing), pest animals (rabbits, goats) and flow reduction (Pendlebury et al.1997; Starr 1997; Starr et al. 1997; AWT and Fluvial Systems 1999; Lintermans 2004a). Sand accumulation and depth at a site/sub-reach scale is highly influenced by channel width and gradient, local features such as rock bars, and flow (AWT and Fluvial Systems 1999). Sub-reach physical interventions such as installation of groynes or other engineered structures could assist Macquarie Perch to move through such sediment impacted locations.

Fish passage interventions have been shown to improve fish distribution and abundance for a range of Australian native fish species (see review in Lintermans 2013b; Koehn and Crook 2013) including Macquarie Perch (Broadhurst et al. 2012, 2013). Fish passage interventions can involve multiple methods ranging from removal of anthropogenic barriers (e.g. dams, weirs, road crossings), construction of purpose-designed fishways (e.g. Ebner and Lintermans 2007; Barrett 2008; Lintermans 2013c), or provision of flow regimes to assist fish passage (e.g. environmental flows Broadhurst et al. 2016, 2020). In the mid-Murrumbidgee River, a single fish passage intervention has occurred (fishway at Mittagang Crossing at Cooma) utilising a rock ramp fishway design.

Severe flow reductions in the upper reaches of the mid-Murrumbidgee River (e.g. upstream of Yaouk) are thought to be potentially limiting Macquarie Perch movement to approximately 27 km of Murrumbidgee River mainstem further downstream, with the barriers likely consisting of instream rock bars or steep gradient sections that no longer drown out. Identification of the location and characteristics of these barriers (see Section 4.2) will facilitate assessment of management options to remediate them. Such remediation could encompass release of targeted drown-out flows, physical alteration to the barriers, or provision of small fishways. Identification of the barrier location could assist in identification and prioritisation of translocation sites in this area if a suitable barrier-free length of stream is present.

Small-scale (site/sub-reach) interventions such as willow and weed control, riparian planting and fencing, which have been successful and cumulatively over time, will make a significant contribution to improving habitat conditions for Macquarie Perch. A variety of existing organisations are present in the catchment (see Table 2) and are motivated to deliver such interventions.

A key recovery strategy of the National Macquarie Perch Recovery Plan is to 'Protect and restore Macquarie Perch habitat' (Commonwealth of Australia 2018). To identify priority habitat enhancement options and locations, and following the habitat characterisation conducted as part of this catchment survey, a scoping/consultation process with groups active in habitat enhancement activities in and adjacent to the mid-Murrumbidgee catchment should be conducted. Such a process would capture knowledge gained in previous habitat enhancement projects, and key Macquarie Perch populations or translocation sites identified via monitoring and investigations for stocking (Lintermans et al. 2022; Tonkin et al. 2022) The scoping process would also identify opportunities for co-investment.

6 Considerations

The following points have relevance to components of the catchment survey and may require further consideration.

Unknowns, adaptability, precautionary principle. This document details a process to complete a catchment-wide survey for currently unknown remnant Macquarie Perch populations or potentially suitable translocation sites. As the number of sites requiring conventional sampling following positive eDNA results is unknown, the amount of sampling effort is difficult to confidently define in advance.

Unexpected catchment or site conditions, access difficulties, weather conditions and/or a detection of Redfin Perch may mean modification to methods and priorities may be required during the survey to enable effective site assessment. The eventual degree of suitability of a site for Macquarie Perch translocation/stocking, may also not be known until further, more detailed site assessments are undertaken.

The success of a captive breeding program for the species, sourcing brood stock and disease considerations (EHN virus) all mean that the number of fish available for stocking or translocation is unknown, and consequently the number of translocation stocking sites required or able to be stocked is uncertain.

Consequently, a degree of adaptability is required throughout the catchment survey, and a precautionary principle should be followed: sampling many sites to **maximise** the discovery of suitable sites.

Environmental DNA. This has been highlighted earlier and remains an important issue. The technique has the potential to contribute from a presence/absence perspective for target species, but only once an appropriately rigorous and sensitive protocol/procedure has been developed, and which has also been field verified. This has been partially developed for Macquarie Perch but has not been deployed at a catchment scale.

Access. Some priority field sites may be close to public vehicular access, but many are on private land and access is dependent on landholder permissions and ongoing good will. Landholder access permissions can change rapidly.

Permits. Relevant permits to undertake the catchment survey will need to be organised well in advance. These are, but may not be restricted to, the following.

Scientific Collection Permit — authorises the taking and possession of fish (including threatened fish) for the purpose of research, under section 37 of the NSW *Fisheries Management Act 1994*. Available from the NSW Department of Primary Industries.

Scientific Licence — authorises research in the National Parks and Wildlife Service reserve system, authorised under section 132C of the NSW *National Parks and Wildlife Act 1974*. Available from the NSW Office of Environment & Heritage.

Animal ethics approval — for sampling of fish, and collection of voucher material (either NSW or institutional).

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