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School of Life Sciences

MERI for Fish of the Melbourne Water region: A Discussion Paper

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Traditional Owner acknowledgement

The Centre for Freshwater Ecosystems, Albury–Wodonga is located on the land of the Latje Latje and Wiradjuri peoples. We undertake work throughout the Murray–Darling Basin and acknowledge the traditional owners of this land and water. We pay respect to Elders past, present and future.

Contents

Introduction

Melbourne Water (MW) has established a monitoring, evaluation, reporting and improvement (MERI) framework across the greater Melbourne region as part of the Healthy Waterways Strategy (HWS). The MERI framework is a structured, iterative process enabling MW to:

i) conduct status reporting on key values and conditions,

ii) measure and track progress (direction, magnitude/rate) towards objective/target achievement,

iii) evaluate and understand management effectiveness, knowledge gaps and uncertainties, and

iv) undertake adaptive improvement of decision-making that draws on what is learnt to update methods, models, practices and activities.

Fish occupy a diverse range of habitat types across the greater Melbourne region, and are influenced by environmental conditions such as hydroclimatic variability and disturbances to their habitat or catchment surroundings. Fish populations are currently being impacted by a range of anthropogenic threats in the region such as flow regime change, fish passage barriers, urbanisation, habitat modification and loss (instream and riparian), floodplain isolation, climate change and introduced species. Fish are of high cultural, social and biodiversity value, and are therefore a key value and important indicator of overall waterway health. Hence, it is important to measure and track fish population status throughout the region, and determine which management targets have been achieved, and where suitable management restoration efforts should be applied or whether they have been successful.

Over the last few decades, considerable sampling effort of fish assemblages has occurred for a variety of monitoring and research objectives in the greater Melbourne region (Figure 1). Fish survey data for the region has most commonly been collected on an *ad hoc* basis (e.g., one-off aquatic biota assessments (e.g. Raadik and Lieschke (1999); as part of discrete research projects of limited duration; or as systematic sampling methodologies over several years (e.g., King et al. (2011),Tonkin et al. (2014), Tonkin et al. (2016)). The most comprehensive surveillance-type assessment of fish in the MW region to date was the Southern Basins (SB) monitoring program from 2004–2011 (Lieschke et al. 2013). The SB program was funded by the Victorian Department of Environment and Primary Industries using methodologies based on the Sustainable Rivers Audit (SRA) (Davies et al. 2010). The study was designed to report on the health of fish assemblages at the river basin scale using a series of metrics (Fish health, Expectedness, Nativeness) to evaluate the health of fish populations across Victoria. Further discussion of these metrics is provided below. Within the Melbourne Water jurisdiction, SB program sampling was undertaken at sites in the Yarra, Maribyrnong, Bunyip and Werribee rivers. While MW has invested substantially in fish monitoring over many years, to date there has not been a sustained long-term program of surveillance monitoring of fish assemblages across the MW region.

MW is committed to establishing a robust, cost-effective surveillance monitoring program for fish in rivers, wetlands and estuaries of the greater Melbourne region, to enable reporting on the status and trajectory of fish populations consistent with the objectives of the HWS MERI framework. MW is also committed to optimising investment in intervention monitoring activities designed to evaluate the effectiveness of specific management interventions and to develop better understanding of the physical and ecological requirements of native fish populations.

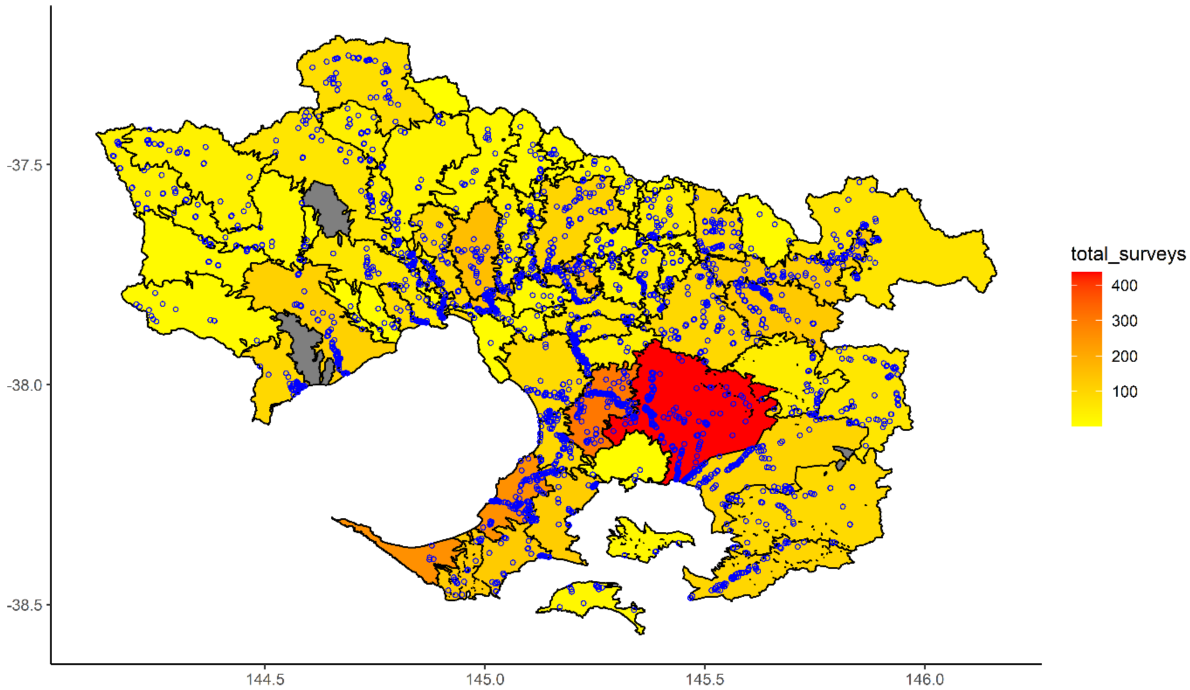


Figure 1: Distribution of fish survey sites from 1990-2017 (source: Melbourne Water fish database).

What this discussion paper does

This discussion paper provides the project team's guidance on considerations for the development of a surveillance monitoring program across three broad habitat types (rivers, wetlands and estuaries) in the MW region. We also provide a brief discussion of broad approaches to intervention monitoring and describe ancillary data and areas of research and development that are required to adequately assess changes in stream processes and function to support fish populations.

This paper has been drafted concurrently with similar discussion papers prepared for MW MERI on streams of the Melbourne Water Region and platypus populations, and will provide information to support the development of Monitoring Evaluation Plans (MEPs). We note that while there is considerable overlap between these discussion papers, there are also important differences in their justification, aims and proposed monitoring designs. For example, the streams paper aims to provide a framework for assessing overall stream health (Yung and Chee 2019), whereas the platypus and fish discussion papers aim to assess the status and trajectory of species of high priority and, in the case of fish, species assemblages.

Overview of past survey efforts

As mentioned above, a large number of fish surveys has been conducted in the MW jurisdiction over many years, including studies supported directly and indirectly by MW, as well as by other agencies, universities and consultants. Data from some of these surveys have been collated into MW's fish database, which was provided to the project team for the purposes of this paper (see Appendix 1). The fish database spans as far back as the 1930s and up until 2017 and includes many types of observations, including systematic surveys, targeted research surveys, translocation and stocking records and anecdotal observations.

While the MW fish data base contains a large number of fish records, it has become clear during the current study that some sources of fish data in the MW jurisdiction are missing from the database. We have used data from the MW database to broadly examine the distribution of sampling effort and species distributions across the region. However, it is important to note that our analyses are based on an incomplete data set. Given the importance of accurate data for informing monitoring design and as a basis for the development of the HSMs for fish, we strongly recommend a review and update of the MW fish database to ensure that the full range of data on fish distributions is captured. Such a review is not within the scope of this discussion paper.

As the purpose of the paper is to provide an evaluation of monitoring requirements (as opposed to a detailed description of current species distributions), we used data from 1990-2017 to provide information on the number of previous fish surveys for each habitat type and the number of species recorded from each habitat for each sub-catchment in the MW jurisdiction.

For the purposes of this analysis, the data were pre-processed in the following ways:

- Non-fish species were removed.
- Only the years between 1990 and 2017 were used. The year 1990 was used as a minimum as this corresponds with the minimum date used to compose the Melbourne Water Fish Habitat Suitability Models.
- Survey methods that were unlikely to have been used in formal surveys were omitted, i.e. those coded as ANGLING, OBS, STOCKING, STOPNET, FISHWAYTRAP, TRANSLOCATION, Observed, Observation. However, those without survey methods given were retained as they made up a large portion of the data (751 records).
- Data without geographic coordinates, or with coordinates that did not overlap polygons of the GIS layer MWregion_subcs_260117, were omitted. While the original dataset contained references to subcs these were reassigned by intersecting data coordinates with the subc layer. In some cases, mostly in estuary mouths, data had to be manually assigned subcs as they fell just outside the polygon layer. This increased the number of data points with matched to subcs from 7289 to 7899. Data points that could not be match to subcs included 13 which had no geographic reference provided and 44 which either fell outside the Melbourne Water region or were incorrectly attributed.

Rivers and streams

Surveys have occurred at over 2,000 locations within the freshwater sections of rivers since 1990. All sub-catchments have had at least some survey effort. However, survey site density is greatest within the central/north east regions and the greatest survey effort has occurred in the catchments of the Cardinia and Eumemmerring Creeks. Electrofishing activities have been carried out in most sub-catchments, with electrofishing surveys having taken place at 1,191 unique locations across the region. Notable exceptions where there were no survey sites include the Lollypop Creek and Kororoit Creek upper sub-catchments, and where surveys have been few are the Boyd Creek, Dalmore outfalls and Steels and Paul's Creek sub-catchments.

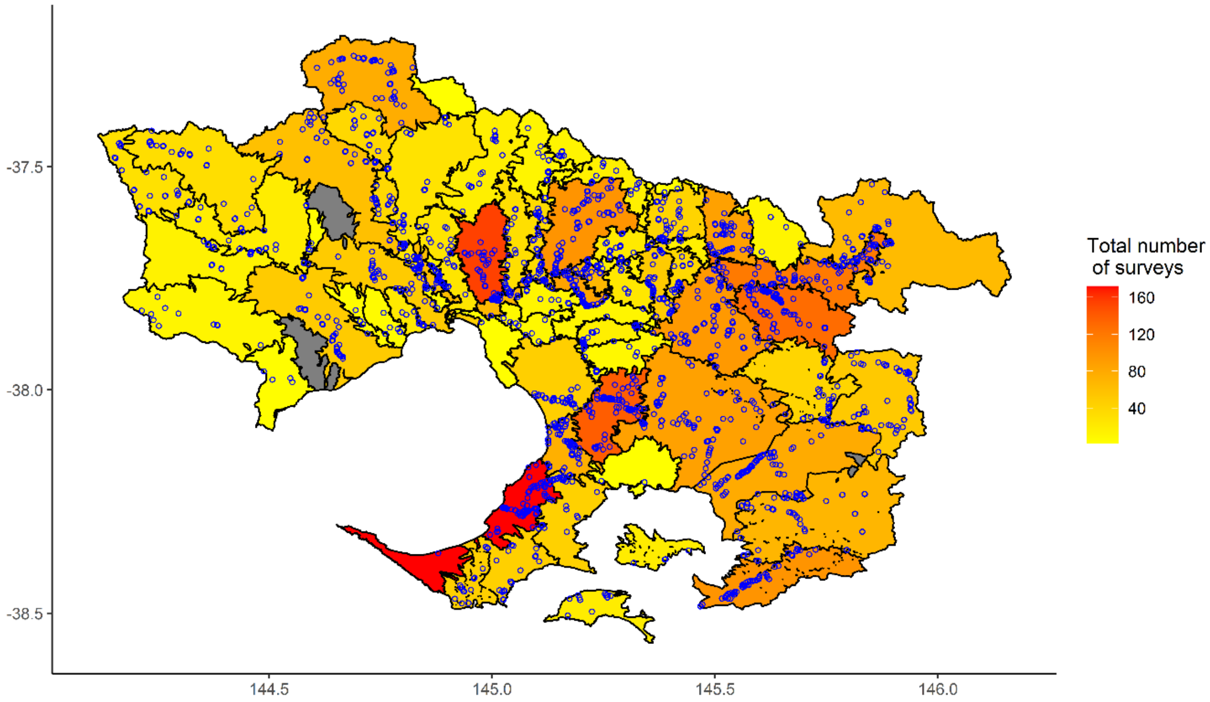


Figure 2: Distribution of river and stream survey sites since the year 1990 with colour of polygons indicating the number of surveys undertaken in each sub-catchment (grey polygons are sub-catchments where no surveys have taken place). Points indicate survey sites with larger blue points indicating sites at which electrofishing has taken place.

Thirty-seven species of fish have been recorded in rivers and streams since 1990. Of these, 27 are native and 10 are introduced species. Distributions and frequencies of occurrences of native fish species across sub-catchments are illustrated in Figure 3; however, it should be noted that these data may be skewed by survey effort. The greatest number of native and priority species occur in the east of the region, notably in the sub-catchments of the Yarra River and Lang Lang River.

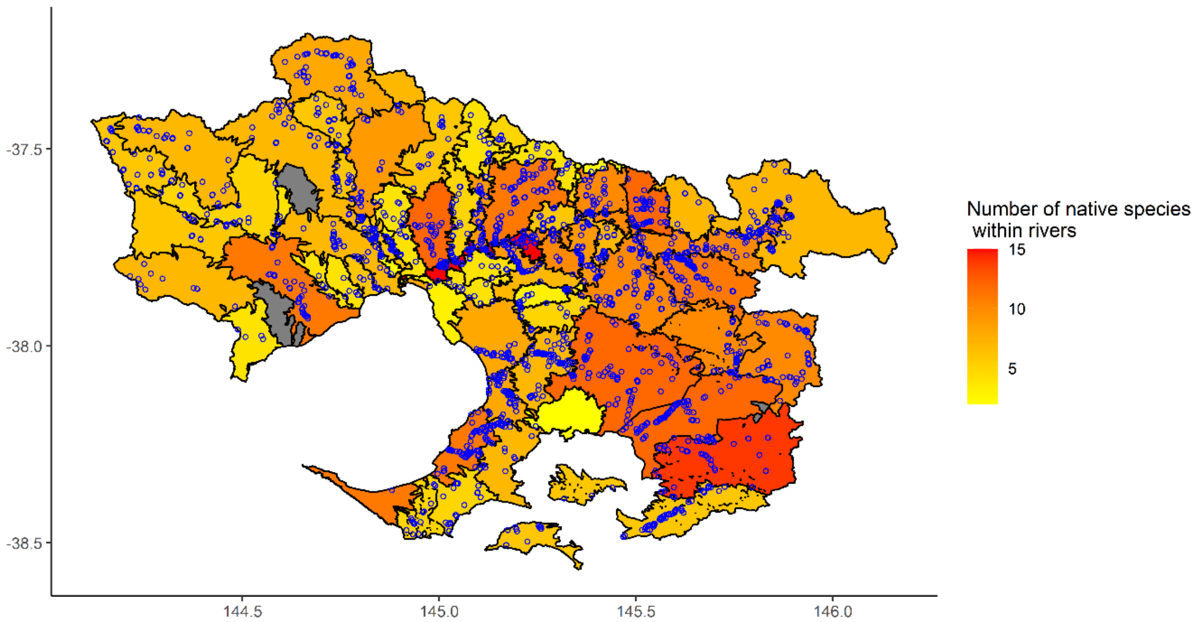


Figure 3: Number of fish species recorded from rivers and streams in each sub-catchment.

Wetlands

Three hundred and fifty-two locations within wetlands have been surveyed for fish since 1990, with some wetlands having multiple survey points (Figure 4). The majority of wetlands surveyed for fish are in the eastern catchments draining into Port Phillip Bay. Clusters of surveyed wetlands occur in the Cardinia, Dandenong and Kananook creek catchments. The largest survey effort has occurred in the catchment of the Cardinia, Toomuc, Deep and Ararat Creeks. Electrofishing surveys have been conducted at 65 locations. The Melbourne Water 'MWregion_Waterbodies_v1.0' layer records over 69,000 waterbodies in the Greater Melbourne region. Considering this, and the lack of surveys conducted in many sub-catchments, it is clear that data on wetland fish assemblages in the MW jurisdiction is very sparse. This scarcity of data needs to be considered in the following assessment, as numbers of species are likely to be heavily affected by low survey effort.

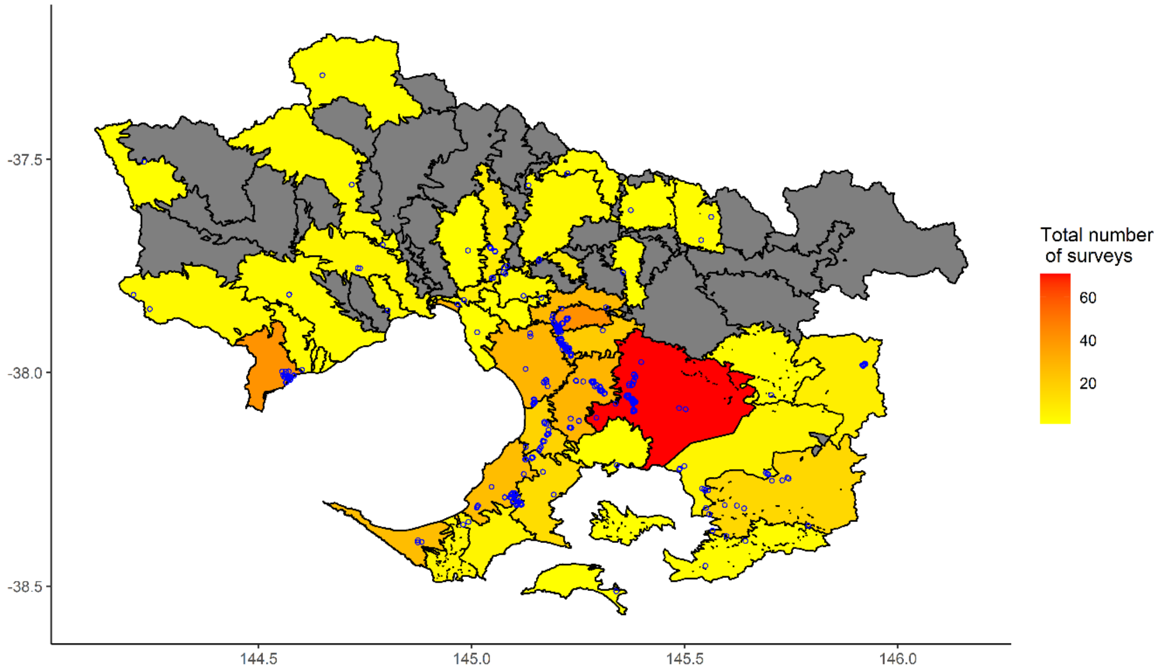


Figure 4: Distribution of wetlands surveyed since the year 1990. Colour of polygons indicates the number of wetlands within catchments. All wetlands have been surveyed once during the time period. Points indicate survey sites with larger blue points indicating sites at which electrofishing has taken place.

There have been 23 fish species recorded in wetlands since 1990, including 14 native species and nine introduced species. The greatest number of native species are recorded from the Blind Creek and Mornington Peninsula Western Creeks catchments (Figure 5). The majority of records for individual wetland surveys contained only one native species (n = 201), 62 records contained two native species, 22 contained three and only 2 contained four native species.

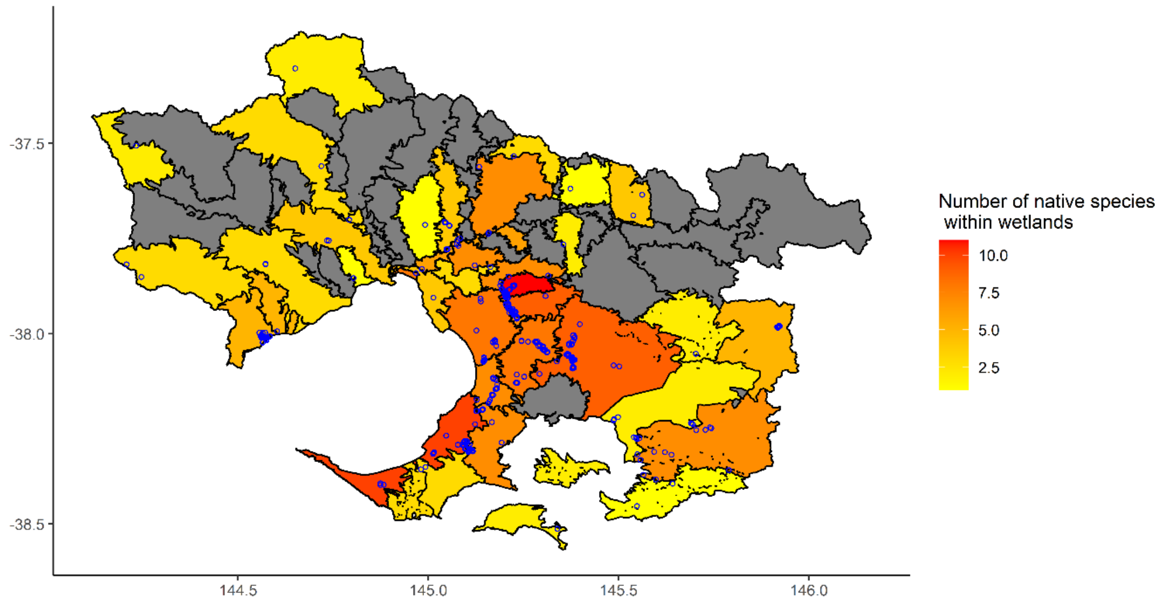


Figure 5: Numbers of native species recorded in wetlands for each sub-catchment in the Melbourne Water region.

Estuaries

Twenty-three estuaries were surveyed between 1990 and 2017 with 381 surveys taking place at 377 sampling locations. Most coastal sub-catchments have had surveys in estuarine reaches; however, no surveys are recorded since the year 1990 for estuaries in the Laverton Creek and French and Phillip Islands sub-catchments (Figure 6).

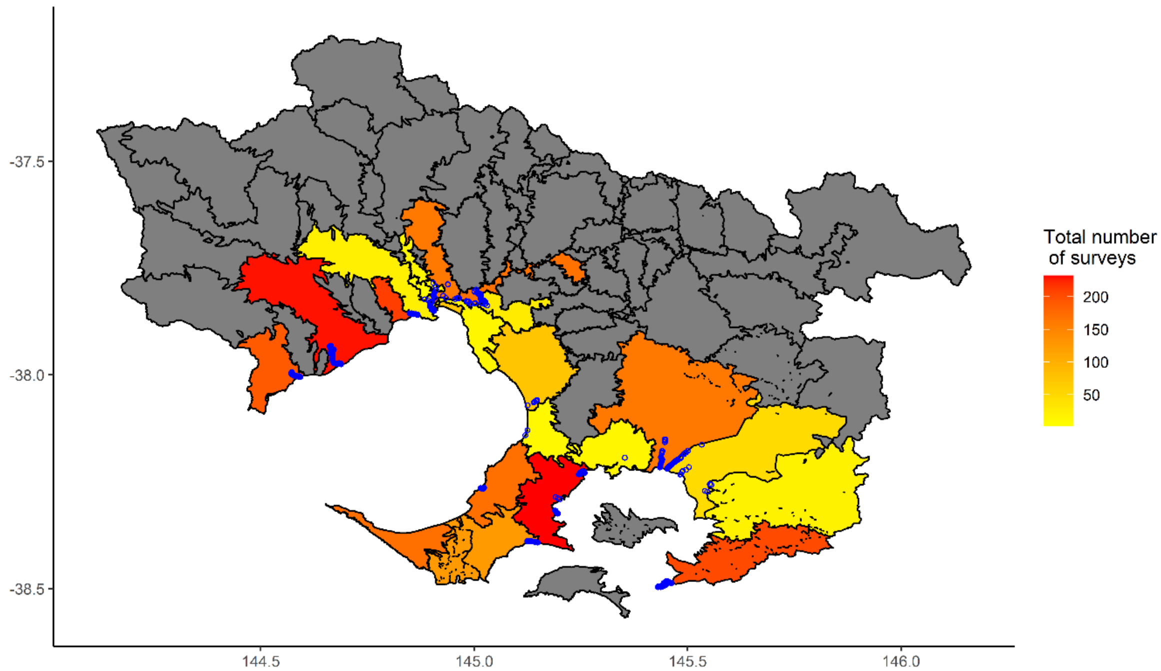


Figure 6: Sub-catchments where surveys have been conducted in estuarine reaches. Polygon colour represents number of surveys. Points are survey sites with blue points representing sites where electrofishing has occurred.

Ninety eight species have been recorded in estuarine reaches, including a mixture of species recognised as predominantly inhabiting marine, estuarine and freshwater environments (Figure).

The majority of species (n = 88) were native. Highest diversity is seen in the Bass River, Moonee Ponds Creek, and Werribee sub-catchments. The catchments of Stony Creek, Maribyrnong River, Lang Lang River and Dalmore Outfalls had less than 10 species.

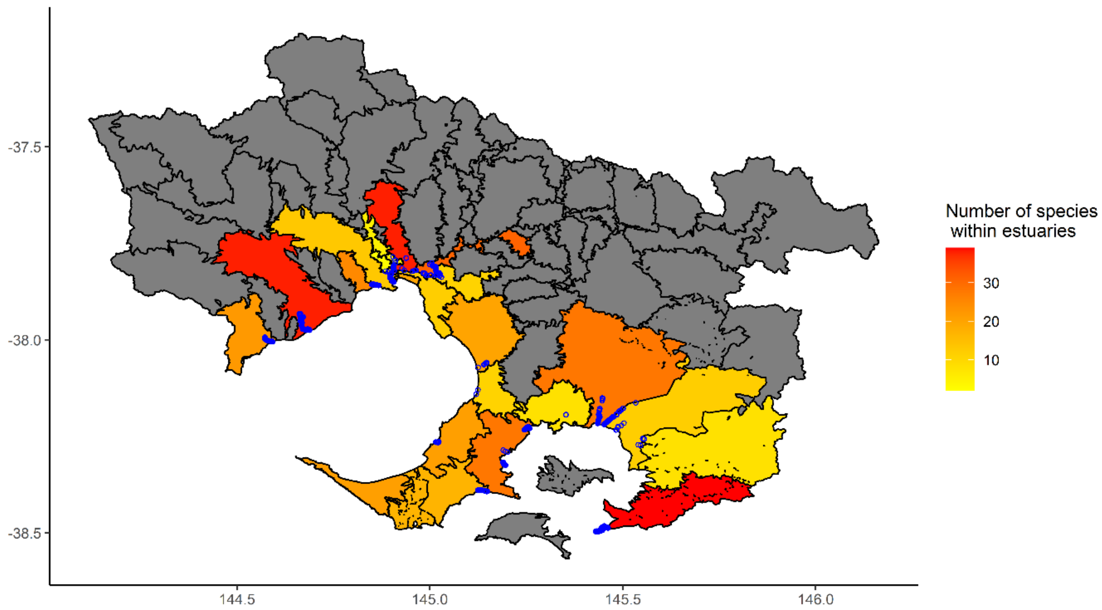


Figure 7: Number of native species recorded in estuarine reaches within sub-catchments

Identifying priority species

Data on the distributions and relative abundance of all fish species sampled at a survey site are important considerations for surveillance monitoring, as they allow for the derivation of assemblage-level metrics, such as species richness and observed/expected ratios (discussed in more detail below) or population assessments where required. However, given the limitations imposed by available resources and logistics, it is necessary to prioritise sampling locations to ensure that species of high importance are adequately represented in the surveillance monitoring program. This approach to sample site selection contrasts with the Southern Basins Sustainable Rivers Audit (Lieschke et al. 2013), which used a randomised site selection process to sample a representative selection of sites without regard to species' distributions, and focusses on assessment of fish assemblage condition. Whilst randomised site selection may reduce potential biases in the distribution and physical characteristics of sampling sites, surveillance monitoring is focussed on assessing condition and trends over time, incorporating species richness targets, in this context a randomised site selection approach may lead to an under-representation of high-priority species and inefficient allocation of resources with respect to the MERI objectives.
Prioritisation of freshwater fish species for monitoring and management intervention in the MW jurisdiction has been conducted on several previous occasions, including the Fish Habitat Management Strategy (Heron et al. 2003) and the MW EWR monitoring design report (Robinson and Dickson 2019) (Table 1: Freshwater fish species previously identified as priorities in the Fish Habitat Management Strategy (FHMS) (Heron et al. 2003) and Environmental Water Resources (EWR) monitoring design report (Robinson and Dickson 2019). Tick denotes species identified as high priority.). Heron et al. (2003) identified priority species on the basis of their formal conservation status, the legal requirements of the SEPP for the Yarra and Western Port catchments (EPA, 1999; 2000) and additional assessments of the importance of the species from a regional or statewide perspective (Table 1). Robinson and Dickson (2019) identified priority fish species in the Yarra, Tarago/Bunyip, Werribee and Maribyrnong catchments based on whether they are migratory or if there are environmental flow recommendations targetted towards their conservation.

Table 1: Freshwater fish species previously identified as priorities in the Fish Habitat Management Strategy (FHMS) (Heron et al. 2003) and Environmental Water Resources (EWR) monitoring design report (Robinson and Dickson 2019). Tick denotes species identified as high priority.

Common name	Scientific name	Current conservation status	FHMS	Justification in FHMS	EWR Yarra	EWR Tarago /Bunyip	EWR Werri -bee	EWR Mariby-rnong
Australian grayling	*Prototroctes maraena*	IUCN: Vulnerable, decreasing EPBC: Vulnerable FFG: Threatened	✓	• Listed as threatened species in Australia • Listed under the FFG Act • Listed as Threatened fauna in Victoria • Used as SEPP indicator species	✓	✓		
Australian mudfish	*Neochanna cleaveri*	IUCN: Endangered, unknown FFG: Threatened	✓	• Listed under the FFG Act • Listed as Threatened fauna in Victoria		✓		
Australian smelt	*Retropinna semoni*	IUCN: Not listed			✓		✓	✓
Broad-finned galaxias	*Galaxias brevipinnis*	IUCN: Least concern, unknown		• Considered regionally significant in the Yarra Basin	✓	✓		
Common galaxias	*Galaxias maculatus*	IUCN: Least concern, unknown		• Used as SEPP indicator species for Yarra	✓	✓	✓	
Dwarf galaxias	*Galaxiella pusilla*	IUCN: Endangered, decreasing FFG: Threatened	✓	• Threatened species in Australia • Listed under the FFG Act • Listed as Threatened		✓		
Flat-headed gudgeon	*Philypnodon grandiceps*	IUCN: Least concern, stable					✓	✓
Mountain galaxias	*Galaxias olidus*	IUCN: Least concern, decreasing					✓	
Ornate galaxias	*Galaxias ornatus*	IUCN: Least concern, decreasing			✓	✓		✓
Pouched lamprey	*Geotria australis*	IUCN: Data deficient, unknown			✓		✓	
River blackfish	*Gadopsis marmoratus*	IUCN: Least concern, decreasing		• Used as SEPP indicator species for Yarra • Regional significance due to declining populations and range	✓	✓		
Short-finned eel	*Anguilla australis*	IUCN: Near threatened, unknown			✓	✓	✓	✓
Short-headed lamprey	*Mordacia mordax*	IUCN: Near threatened, stable			✓	✓		
Southern pygmy perch	*Nannoperca australis*	IUCN: Near threatened, decreasing				✓		✓
Spotted galaxias	*Galaxias truttaceus*	IUCN: Least concern, stable		• Used as SEPP indicator species for Yarra	✓	✓		
Tupong	*Pseudaphritis urvillii*	IUCN: Least concern, stable		• Used as SEPP indicator species for Yarra	✓	✓	✓	
Macquarie perch	*Macquaria australasica*	IUCN: Endangered, decreasing EPBC: Endangered	✓	• Listed under the FFG Act • Listed as Threatened • Significant population in Victoria	✓			
Murray cod	*Maccullochella*	IUCN: Least	✓	• Threatened in their natural	✓			

Common name	Scientific name	Current conservation status	FHMS	Justification in FHMS	EWR Yarra	EWR Tarago /Bunyip	EWR Werri -bee	EWR Mariby-rnong
	peelii	concern, increasing EPBC: Vulnerable		environment				
Yarra pygmy perch	*Nannoperca obscura*	IUCN: Endangered, decreasing EPBC: Vulnerable FFG: Threatened	✓	• Threatened species in Australia • Listed under the FFG Act				

Although previous assessments of priority species can inform the MERI, effective prioritisation of species for future surveillance monitoring is highly dependent on the current and emerging policy and management drivers within the MW jurisdiction, and will thus require significant input from relevant MW staff. As a starting point, we have developed a preliminary list of 15 fish species across the three habitat types (rivers and streams, wetlands, estuaries) for consideration as priority species to guide the selection of sites for the MERI (Table 2). These priority species have been selected using four criteria:

- local, regional and national conservation significance (listed by IUCN, EPBC, FFG);
- not threatened currently, but considered at risk over the medium to long term;
- of high cultural, recreational or commercial significance;
- common species that can be used as indicators for life history guilds that are vulnerable to specific threats (e.g., fish with diadromous life histories are especially affected by instream barriers; non-migratory species may be more affected by localised habitat degradation).

Table 2: *Preliminary list of priority fish species for surveillance monitoring in the MW jurisdiction. Tick denotes habitat types where priority species should be targeted for monitoring; * denotes habitats where the species occurs, but targeted monitoring for that species is not prioritised; and – denotes habitats where the species rarely occurs or is absent.*

Common name	Scientific name	River	Wetland	Estuary	Rationale
Australian grayling	*Prototroctes maraena*	✓	*	*	Threatened species.
Australian mudfish	*Neochanna cleaveri*	✓	✓	*	Threatened species.
Dwarf galaxias	*Gallaxiella pusilla*	*	✓	-	Threatened species.
Common galaxias	*Galaxias maculatus*	✓	✓	✓	Representative of catadromous life history.
River blackfish	*Gadopsis marmoratus*	✓	-	-	Representative of non-migratory riverine life history. Risk of climate change impact.
Short-finned eel	*Anguilla australis*	✓	✓	✓	Representative of catadromous life history. Global decline of eels, anecdotal evidence of decline in Australia. High cultural and commercial value.
Short-headed lamprey	*Mordacia mordax*	✓	✓	✓	Representative of anadromous life history. Anecdotal evidence of decline in lamprey numbers in Australia.
Yarra pygmy perch	*Nannoperca obscura*	*	✓	-	Threatened species.
Southern pygmy perch	*Nannoperca australis*	*	✓	-	Representative of non-migratory wetland life history.
Macquarie perch	*Macquaria australasica*	✓	✓	✓	Threatened species. Not native to MW region, but Yarra populations are nationally significant.
Tupong	*Pseudaphritis urvillii*	✓	*	✓	Representative of catadromous and estuarine life histories.
Black bream	*Acanthopagrus*	*	-	✓	Representative of estuarine life history.

Common name	Scientific name	River	Wetland	Estuary	Rationale
	butcheri				High cultural, recreational and commercial value.
Estuary perch	*Percalates colonorum*	-	-	✓	Representative of estuarine life history. High cultural, recreational and commercial value.
Pale mangrove goby	*Mugilogobius platynotus*	-	✓	✓	Threatened species.
Blue spot goby	*Pseudogobius olorum*	-	✓	✓	Representative of estuarine life history; also found in low-lying estuarine and freshwater wetlands.

Distribution of priority species

A good understanding of the distributions of high-priority species is critical to ensuring that these species are adequately represented in the surveillance monitoring program. Habitat Suitability Models have been developed for fish species in riverine environments within the Greater Melbourne region (Chee et al. 2020). These HSMs generated for the HWS provide predictions of species' occurrence based on a range of reach-level physical parameters regardless of whether survey data exists for the reach. The lack of reliance on existing survey data allows for projections across the entire MW jurisdiction, although it should be noted that the HSMs represent statistical predictions only and not actual occurrences. In the absence of HSMs for particular species, distribution maps can also be prepared based on existing survey data (potentially using expert opinion to fill in gaps in the recorded distributions of species).

Here, we use river and stream habitat as an example of how HSMs (or other data sources) can be used to identify the locations of sampling sites to ensure that high-priority species are adequately represented in the fish MERI. Figure 8 presents maps of predicted occurrences for eight priority species for which HSMs are available. These models produce a probability of occurrence ranging from 0 - 1. However, for illustrative purposes, we have highlighted only those stream segments for which the probability of occurrence was equal to or greater than the natural prevalence of the species. The threshold for which species are predicted varies depending on an individual species' prevalence. For instance, the prevalence of *Anguilla australis*, as calculated from the data from which the models were derived is 0.653. Thus, stream segments that have a predicted occurrence rate of 0.653 or above for *Anguilla australis* are coloured red, while those below are coloured blue. It is possible to adjust the threshold values used in this approach to suit the specific context during development of the MERI. For example, relaxing the threshold at which a species of very high-priority and limited distribution is predicted to be present would reduce the chance of missing sites where species may be infrequently present.

To determine "hotspots" of high-priority species diversity, the number of high-priority species predicted to be present in an area can be calculated. This has been done for each stream reach using the models generated for the eight selected priority species (Figure 9). This analysis reveals that:

1. High-priority species are not predicted to occur in the majority of stream reaches
2. A large number of reaches where these species are predicted to occur contain only a single high-priority species.
3. The maximum number of co-occurring species is five, but this occurs in only two reaches.

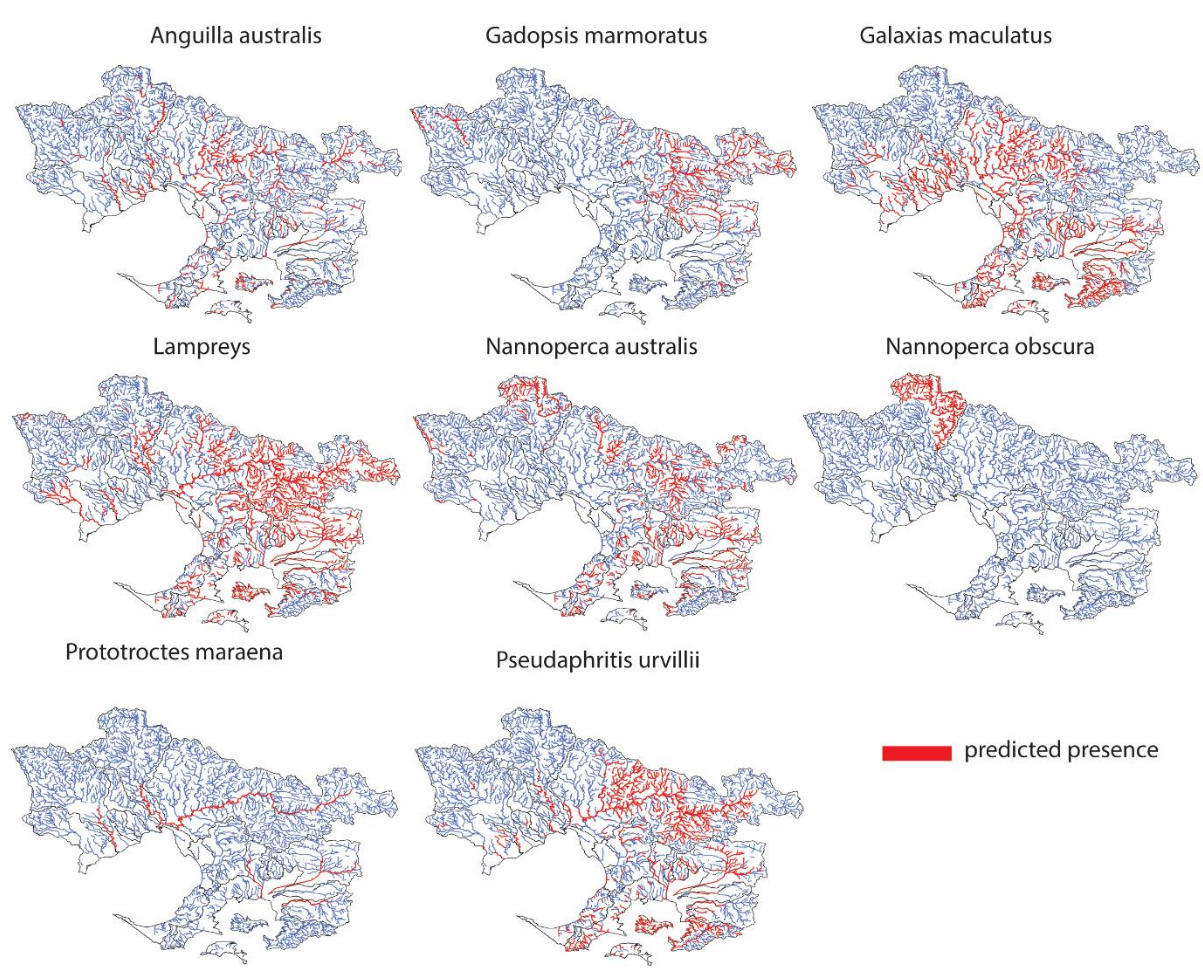


Figure 8: Maps of the Melbourne Water region river systems species indicating regions where selected priority species are predicted to be present

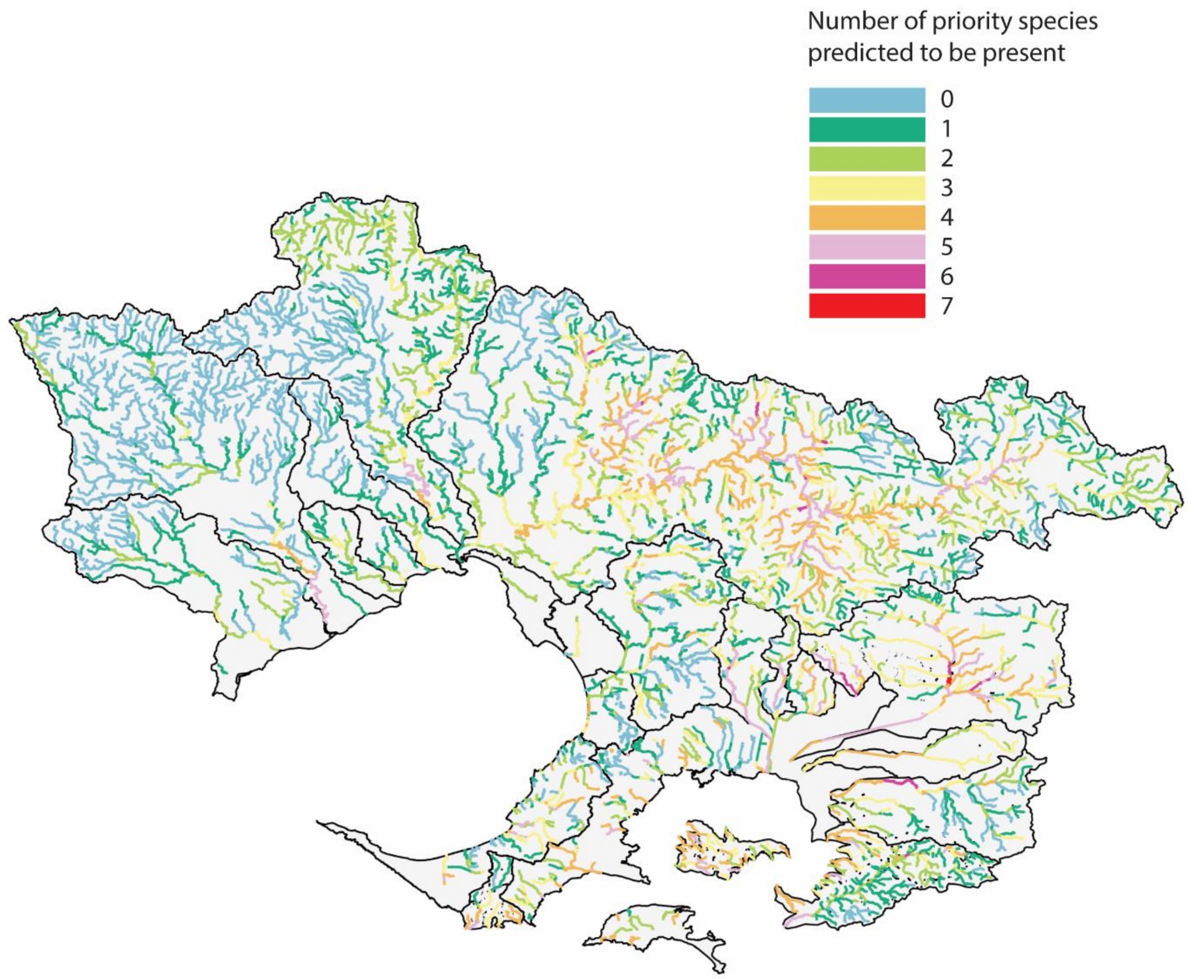


Figure 9: Map of the Melbourne Water region river systems indicating the number of selected priority species predicted to occur in each stream segment.

Measuring the status of fish populations

Healthy Waterways Strategy (HWS) metrics

A series of fish-related metrics were used during the development of the HWS as measures of the status of fish as a key value within each habitat type and MW region. Here, we provide a brief appraisal of the metrics for each habitat type and discuss additional considerations for the development of fish-related metrics in the context of a broad-scale surveillance monitoring program for the MW region.

The HWS fish metric for rivers and streams (Figure 10) is based on presence-absence information using predicted distributions from the HSM or survey data. The metric is derived by comparing the number of species recorded or predicted to occur in a particular reporting period against the total number of fish species historically recorded in the catchment. Because this metric is based on presence-absence information and is aggregated across the whole catchment for HWS reporting, it does not facilitate detection of trends in the abundance and distribution of species over time. A change in the value of this metric would only occur if a species became absent from all sites within the catchment over the relevant reporting period. The metric is also sensitive to the total number of fish species historically recorded from a catchment which, in turn, is influenced by the cumulative survey effort. As relationships between species detection and sampling effort are strongly non-linear (Gwinn and Beesley 2013), catchments with low survey effort are likely to have a relatively low number of recorded species comprised mainly of common and widespread species, and an under-representation of rare and spatially restricted species. As a consequence, surveillance data collected from catchments with historically poor survey effort may produce consistently higher metric scores (observed versus recorded) than catchments with more extensive survey effort.

Fish

Based on habitat suitability models for native freshwater species and survey data	Very High	All or almost all native freshwater species recorded in the catchment likely to be present
	High	Most native freshwater species recorded in the catchment likely to be present
	Moderate	About half the native freshwater species recorded in the catchment likely to be present
	Low	Few freshwater native species recorded in the catchment likely to be present
	Very Low	Very few or no native freshwater species recorded in the catchment likely to be present

Figure 10: HWS fish metric – rivers and streams.

The fish metric for wetlands (Figure 11) was not fully developed in the HWS. Assessments of the condition wetland fish for the Yarra, Dandenong and Westernport and Mornington Peninsula catchments in the HWS were based primarily on the presence of nationally listed and otherwise significant species (Table 3). The Werribee and Maribyrnong were not assessed due to a lack of available data.

Fish

Wetland fish metric will be developed through the Strategy implementation. Significant fish = 5	Very High	Significant fish species (5)
	High	To be developed
	Moderate	To be developed
	Low	To be developed
	Very Low	To be developed

Figure 11: HWS fish metric – wetlands.

The HWS fish metric for estuaries (Figure 12) is based on records of conservation listed or estuarine dependent species. Similar to the metric for rivers and streams, the estuary metric is based on presence information and does not facilitate the detection of trends in the abundance and distribution of species over time. The emphasis on records of listed species also does not provide a good indication of the condition of estuarine fishes, as very few estuarine resident species are listed. This has the practical effect of rendering this metric insensitive to variation in the condition of estuarine resident fishes. To illustrate, the condition of the Yarra River estuary was rated as “very high” in the HWS because the threatened Australian Grayling use the estuary during their migration between the sea and freshwater (Table 3). In effect, this means that any catchment with records of Australian grayling in the freshwater reaches should be given a “very high” estuary condition rating, irrespective of the condition of the estuary itself.

Fish

Incorporates significant fish, drought refuge and the Estuary Entrance Management Support System for Fish As-set Score	Very High	Records include listed fish species
	High	Records include estuarine dependent (Seasonal faculta-tive and Seasonal obligate) species
	Moderate	Records of only non-estuarine dependent fish (marine or freshwater) species
	Low	Not applicable
	Very Low	No records of fish

Figure 12: HWS fish metric – estuaries.

Table 3: Current condition and target summaries for fish for the five MW regions / catchments as articulated in the HWS 2018. Condition and targets represent an average across the catchment for that habitat type. NA = Not available.

MW Region / catchment	Habitat	Current summary state	Current summary trajectory	Summary long-term target and trajectory	Explanation
Werribee	Rivers	Low	Low, maintained	Moderate, improve	- Fish score is currently low overall but can be improved to moderate through improved instream connectivity, stormwater management, provision of adequate stream flows and streamside revegetation.
	Wetlands	NA	NA	NA	- Very little data exist for wetland fish and a metric for wetland fish in this region will be developed through the Strategy implementation.
	Estuaries	High	Moderate, decline	High, maintained	- Fish score for estuaries is high with a current trajectory of moderate. Changes to the estuarine water regime as a result of urbanisation and climate change may impact fish communities. A good diversity of estuarine dependent species inhabit the estuaries and are likely to remain. The target is to maintain at high.
Maribyrnong (incl. Moonee Ponds Creek)	Rivers	Low	Low, maintained	Moderate, improve	- Fish score is low overall, with 13 native and nine exotic freshwater species recorded. These include the threatened freshwater species Australian grayling, Yarra pygmy perch and Tasmanian mudfish. Fish score is considered likely to improve over time. The target is to improve from low to moderate.
	Wetlands	NA	NA	NA	- Very little data exists for wetland fish and a metric for wetland fish in this region will be developed through the Strategy implementation.
	Estuaries	High	High, maintained	High, maintained	- Fish score for estuaries is high and is predicted to remain high in the long term. A good diversity of estuarine dependent species inhabits the estuaries and are likely to remain. There are also several estuarine species, including black bream, yellow-eye mullet and mulloway.
Yarra	Rivers	Low	Moderate, improve	High, improve	- Fish scores are currently low overall, however the main stem of the Yarra is very important for native fish – with 14 indigenous freshwater species, including the nationally significant Australian grayling, Tasmanian mudfish, and several estuarine species such as black bream, yellow eye mullet and mulloway. The fish score is considered likely to improve over time. The target is to improve the overall score from low to high.
	Wetlands	Low	High, improve	High, improve	- Fish score is currently low overall. However, environmental watering of key billabongs and re-engagement of floodplain wetlands in the long term is predicted to significantly improve the fish score up to high.
	Estuaries	Very high,	Very high, maintained	Very high, maintained	- Fish score is currently very high, with significant species such as the Australian Grayling using the estuary as part of its migration path between the sea and fresh waters. A good diversity of estuarine dependent fish species also inhabit the estuary. The target is to maintain at very high.
Dandenong	Rivers	Low	Moderate, improve	Moderate, improve	- Fish score is currently low overall, but can be improved to moderate through improved instream connectivity, streamside revegetation,

MW Region / catchment	Habitat	Current summary state	Current summary trajectory	Summary long-term target and trajectory	Explanation
					stormwater management and provision of suitable stream flows. There are 12 freshwater species (including the nationally threatened dwarf galaxias), nine exotic species and several estuarine species (including black bream and yellow-eye mullet). The target is to improve from low to moderate.
	Wetlands	Very high	Very high, maintained	Very high, maintained	- Very little data exists for wetland fish, and a metric for wetland fish in this region will be developed through the Strategy implementation. A number of wetlands in the Dandenong Catchment support the nationally listed dwarf galaxias and more recently reintroduced Yarra pygmy perch. These wetlands will retain a fish status of very high due to the ongoing presence of these species.
	Estuaries	High	High, maintained	High, maintained	- Fish value score for estuaries in the Dandenong Catchment is high and predicted to remain high in the long term. A good diversity of estuarine dependent species inhabit the estuaries and are likely to remain. The target is to maintain as high.
Westernport and Mornington Peninsula	Rivers	Low	High, improve	High, improve	- Fish score is currently low overall for rivers, with 18 native freshwater species and eight exotic species recorded in the catchment; includes nationally significant species dwarf galaxias, Australian grayling, Tasmanian mudfish and pale mangrove goby. Target is to improve to high for rivers.
	Wetlands	High	Low, decline	Very high, improve	- Fish score for wetlands is high, with a currently trajectory of low. However, a number of wetlands in the Westernport catchment support the nationally listed dwarf galaxias and other significant species. Work to re-engage floodplain wetlands will further improve the fish status to protect these species in additional wetlands. Target is to improve from high to very high for wetlands.
	Estuaries	High	High, maintained	High, maintained	- Fish score for estuaries is high and is predicted to remain high in the long term. A good diversity of estuarine dependent species inhabit the estuaries and are likely to remain. Target is to maintain at high for estuaries.

MERI objectives for fish

The examination of the fish metrics developed for the HWS shows a strong focus on reporting on the presence of native freshwater fish. While metrics derived from presence/absence data are useful for assessing the presence of fish populations and represent an important component of a comprehensive surveillance monitoring program, they should be complemented by targeted additional monitoring of high value populations to allow for proactive identification of emerging issues that may be impacted fish populations.

The development and implementation of additional metrics from surveillance monitoring data has the potential to add considerable value to:

- Allow Insight into the trajectory of populations' abundance
- Provide an early indicator of any future trajectory change (e.g., continued failed recruitment as an indicator of future population decline or extinction)
- Allow better insights into the cause of population stresses and potential mechanisms, such that management response could be significantly delayed or would be too late for recovery.

A hypothetical example of where a presence only monitoring approach would be less useful than a population dynamics approach is provided in Figure 13. Here a hypothetical population of a declining species (actual population indicated as black line in figure), declines eventually to extinction at 2035-2040. By monitoring the population structure (length-frequency of the population in the samples) we can see that recruits decline early and rapidly, and are not present post 2025 (green line). This would be an early warning from the monitoring that without future recruitment occurring, the population will most likely become extinct when the adults die. The presence of mature fish in the population declines early, but continues in very low abundances for some time (yellow line). Both the decline in recruits and adult abundance provides an early indication of declining population health, and enables management to attempt restoration efforts before the population becomes extinct. By contrast, metrics based on species presence only (red line) will continue to record the presence of the population in the catchment up until a sharp decline in distribution followed by sudden disappearance. With only this monitoring approach, management actions will only be able to be used close to extinction, when it may be too late.

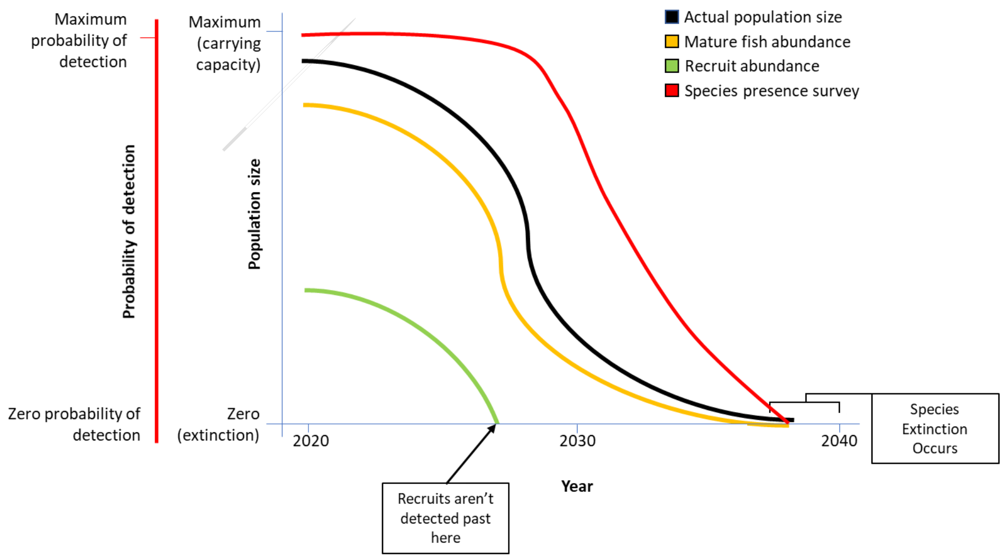


Figure 13: Idealised model of a hypothetical fish population approaching decline.

With this in mind, we suggest that fish monitoring undertaken as part of the HWS has several key aims. The first is to provide MW and the broader community with ongoing information regarding the distribution and status of key fish populations across the region. Over time this will allow the detection and reporting of current status and trajectory of metrics (both improvements and declines). Such information can help determine where more targeted monitoring and/or research may be required to understand and manage threats to fish in particular catchments. The data will also provide the ability to test and refine the HSMs that are being used to guide investment to address existing threats to stream health. Finally, the ongoing collection of empirical data on fish assemblages provides a valuable information base to assist with future research efforts.

We therefore propose the MERI objectives for fish are:

1) To understand the trajectory of the distribution and status of fish populations over the medium and long term
2) To utilise this information for reporting, targeted monitoring, testing and refining HSMs, to guide future research, and to inform adaptive management/fish conservation actions.

MERI structure

We propose that two complementary fish monitoring programs are required to meet the MERI fish objectives:

1. Broad scale, presence/absence monitoring
2. Focussed monitoring of high-priority species and populations/assemblages.

The **broad scale monitoring program** would provide an indication of the presence or absence of fish species across the MW jurisdiction. This program provides information on species occurrence at regular intervals but does not provide information on population status or trajectory and provides only limited ecological information for use in management decisions. The **focused program** aims to provide an indicator of the status and trajectory of priority species' populations or assemblages within targeted regions. A key aspect of this monitoring program is that it is tailored to monitor priority species, or regions or places of interest. This program would include targeted monitoring of priority species, sites of particular significance (e.g. Ramsar-listed wetlands, recreationally or culturally important species), and regions likely to be impacted by future threats (e.g. urban growth, sea level rise). Unlike the broad scale approach, this monitoring program includes more intensive sampling of fish abundance and population measures, such as population structure and evidence of regular recruitment.

This detailed monitoring is critical for early warning signals of population and ecosystem change where such changes would be of greatest concern. For example, information on population structure can provide critical information on population status and trajectory (increasing or decreasing numbers), and measures of population structure (such as recruitment strength) (e.g., Koster et al. 2020). This could provide an early warning of potential longer-term trends before populations reach levels that are both undesirable and/or difficult to reverse. Understanding fish population structure can help inform our understanding of ecological processes and functionalities that are difficult to derive from other taxonomic groups, such as macroinvertebrates. For instance, connectivity of aquatic environments is critical for maintaining healthy populations of many species. Examples of connectivity that are important to consider include in-stream connectivity in the absence of barriers, lateral connectivity between streams and their associated floodplains, and the periodicity of estuaries connecting with marine environments. Population studies on diadromous fish are particularly well suited for assessing how well-connected environments are.

The underlying logic of the two-tiered approach provided here can be applied across habitat types, i.e. river, wetland or estuary; although considerations regarding detailed sampling designs and methods will be required for surveying at the different habitat types. These considerations are discussed further below.

Carefully selected monitoring sites based on the distributions of high-priority species and threats enables evaluation at larger scales, such as major catchments. Figure 14 provides a schematic diagram of how the various monitoring methods can be integrated to provide spatially and temporally comprehensive monitoring information. We believe that combining the two approaches outlined here will optimise data gathering, will be informative over multiple spatial scales (i.e., site, catchment, Greater Melbourne region) and will be sensitive enough to detect impacts at time scales that are relevant for management.

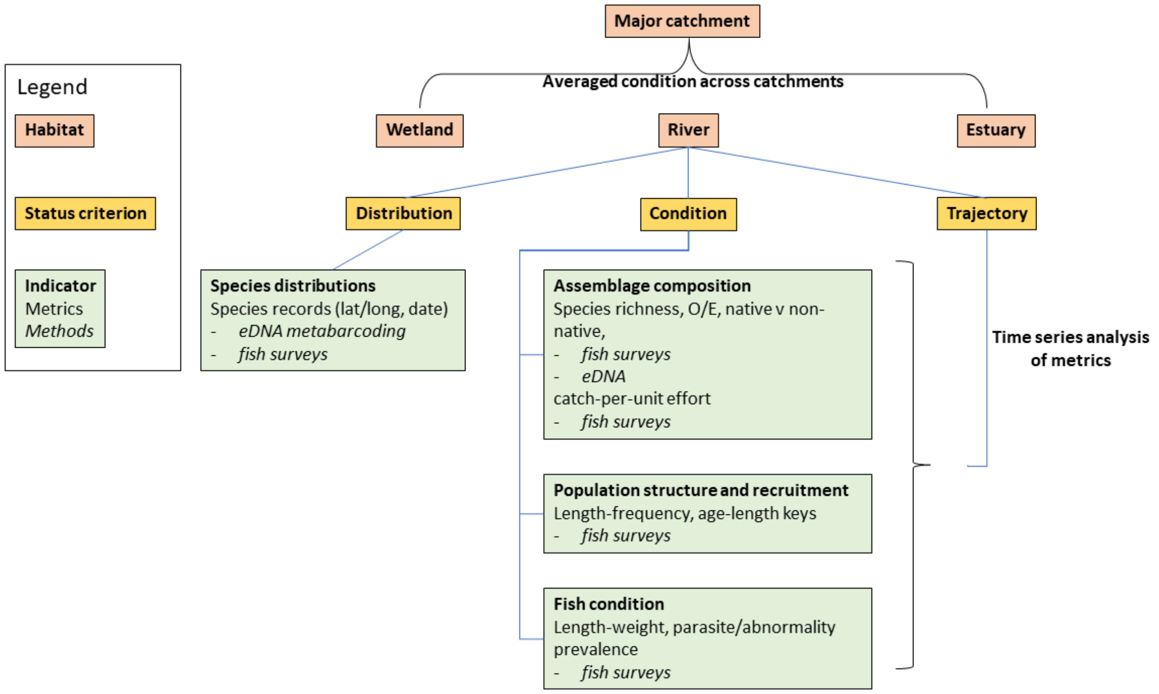


Figure 14: Schematic diagram of how different survey methods and metrics are applied across different waterbody types and at different spatial and temporal scales. Here we have expanded the indicators and methods for rivers, but these are applicable across each habitat type

Program 1: Broad scale, presence/absence monitoring

Monitoring the presence/absence of species over large spatial scales and over time will provide an indication of species distributions and changes in distribution over time. It will also facilitate testing and refinement of the HSMs developed for fish species in the MW region. These HSMs are an important component of reporting and analysis for program 1 as they can be used to inform the basis by which expected to observed patterns of presence and absence are assessed. However, in addition to HSMs we recommend employing an intensive, scientifically based sampling approach that attempts to determine the occurrence and distribution of all potential fish species in the MW region on a regular basis. Additional complimentary data on species distributions can also be sourced from a variety of other programs such as citizen scientist projects, research or monitoring programs, intervention monitoring programs, other concurrent survey efforts. While such data may be very useful for informing understanding of the status of fish species, *ad hoc* data collected outside of the surveillance monitoring program are not comparable over time and their inclusion in quantitative metrics of fish condition should generally be avoided. There is certainly scope, however, to design and implement citizen science and other types of projects that collect data with sufficient consistency to include in metrics for fish condition reporting in the MERI.

A cost-effective way to monitor species occurrence over a large sampling region (such as the MW region) is to employ the use of environmental DNA (eDNA). The eDNA technique is a rapidly developing monitoring tool, where sampling occurs of the environment and then tested for traces of DNA that are left behind by organisms in the form of sloughed cells, faeces and extra cellular fragments (Jerde et al. 2011). eDNA has been applied to water (Ficetola et al. 2008, Doi et al. 2017), soil (Fahner et al. 2016, Shackleton et al. 2019) and air (Ruppert et al. 2019) samples for detecting organisms. To date, its utility has been demonstrated for fish (Furlan and Gleeson 2016, Bylemans et al. 2018), amphibians (Pilliod et al. 2014), and mammals (Lugg et al. 2018).

MW are actively investing in eDNA bio-monitoring, having recently undertaken a large scale eDNA monitoring case study program encompassing ~340 sites in the MW region. Our recommendations stem from our understanding that MW plan to undertake future eDNA monitoring specifically for MERI objectives at ~1200 sites, but whereby a subset of sites are sampled each year and each site is sampled every 4-5 years. The distribution of proposed eDNA monitoring sites (Figure 15) covers a large portion of the region and includes an extensive spatial representation of wetlands, rivers and estuaries.

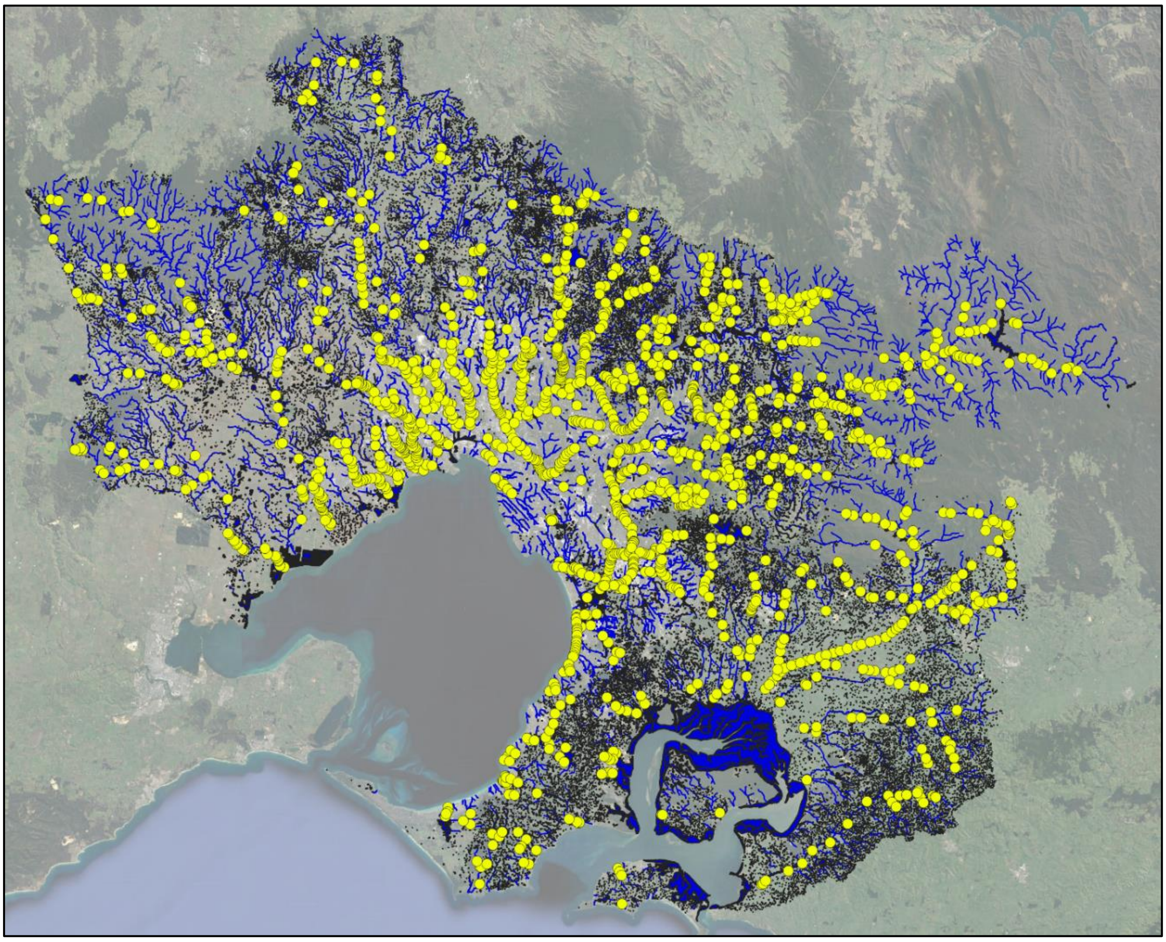


Figure 15: Distribution of currently proposed MERI eDNA monitoring sites.

The extensive spatial coverage of the planned eDNA monitoring program (Figure 15) appears sufficient for informing the MERI on current status and trends the distributions of fish species across the MW jurisdiction. Mapping of the distributions of the putative high-priority species against proposed locations of eDNA samples shows that the range of most species is well covered (Figure 16). However, there is a risk that species with very limited distributions (e.g., Yarra pygmy perch, Australian mudfish) will only be sampled every 5 years in this design; increasing the likelihood that they are not detected when present. A way to minimise this risk, is that if an expected species is not detected at the catchment level, that more targeted sampling (either eDNA or traditional methods) be undertaken to investigate the status of the species.

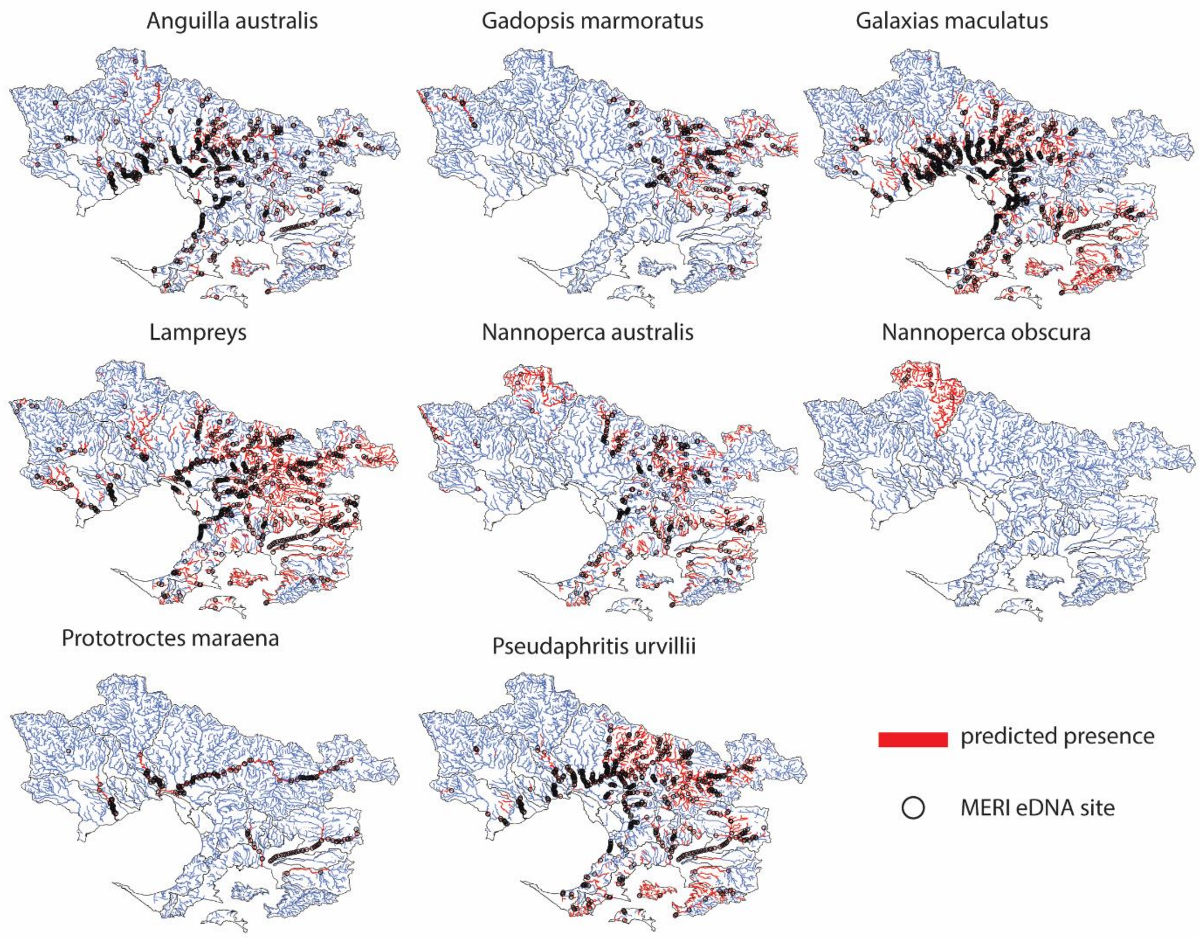


Figure 16: Distribution of proposed eDNA sites within 500m of locations where priority species have been recorded.

Program 2: Focused fish monitoring

Sampling design: A program focusing on sampling the size structure or population dynamics of key fish species or fish assemblages at locations of specific interest, will provide information on the trajectories of fish populations and assemblages that cannot be obtained using presence/absence approaches. Although Program 2 will result in the collection of data on the full range of fish species collected, the primary focus is to provide information on priority species and locations of specific interest.

Size structure analysis is one of the most frequently used fish assessment tools, providing an insight into population size, recruitment, growth and mortality (Neumann and Allen 2007). Metrics derived from this type of direct field data have been widely used in the past in many monitoring programs in Australia (e.g. SRA and SB program, Long Term Intervention Monitoring of Environmental Water), and are sensitive indicators of population change and responsive to environmental change and disturbance.

Monitoring in this program should be conducted during Autumn, when spring/summer recruitment of diadromous and non-diadromous fishes has occurred, population abundance is relatively stable and water levels and turbidity are likely to be lower. Annual sampling is preferable for understanding population size structure changes through time, and how those are being influenced by environmental conditions, including catchment and hydrologic influences. This would provide the capacity for ongoing assessment of the status and resilience of fish populations and assemblages to support adaptive management and restoration efforts (see Walsh and Chee (2019). We recognise, however, that resource limitations may preclude this level of sampling effort. A sampling frequency of every 2 years would provide the capacity to effectively monitor the trajectory of fish metrics for priority species, although there is a concomitant reduction in the level of detail available from the data as the temporal resolution of sampling is reduced.

The focus of survey efforts will largely depend on the reason for monitoring. For instance, if monitoring is undertaken to track the overall fish condition of important areas, such as Ramsar-listed wetlands (where assemblage composition is often considered important), then monitoring would focus on gathering data on fish assemblages. However, if the reason for monitoring is to track the population size and characteristics of key species (e.g. threatened or recreationally important species) then monitoring would largely focus on gathering population data of those key species. Data gathered in Program 2 would also feed directly into the presence/absence records for Program 1.

To capture Melbourne-wide effects as well as effects within species regions and sub-catchments, we propose that survey effort and site selection be distributed in such a way as to target priority species (see for example figure 8), but to also ensure spatial representativeness across the MW region. A wide geographic spread of monitoring effort is important to ensure that spatial variation in factors including hydrology, local climate and geology, instream and riparian habitat, urbanisation and fish species distributions is represented in the sampling design.

Within each catchment, we suggest prioritising sampling locations based on the following criteria:

- Presence of high priority species
- Spatial representation across the catchment
- Significant locations, such as those of conservation significance (e.g. Ramsar sites and MW Sites of Biodiversity Significance (SoBS) or areas of high species diversity)
- Regions of identified current or future threats (e.g. within the urban growth boundary where downstream effects might be anticipated, and can be identified in time for suitable restoration or protection measures to be implemented)
- Sites of known good condition that may serve as comparisons with sites impacted by threats
- Availability of previous data to allow for long-term analyses and value-add.
- Areas identified as important in the E-Water MERI

The question of how many sites to sample and how often they should be sampled is difficult to answer definitively because it is reliant upon a range of factors, including the available resources, logistical considerations, the level of required precision and accuracy, the nature of the objectives being measured against, catchability of the species, the analytical methods applied to the data and the site characteristics.

With these considerations in mind, a suitable surveillance monitoring program for rivers and streams could consist of 10 sites in each of the five MW catchment regions, with five sites each in low and high elevation reaches (Figure 17). The methodologies outlined in the Southern Basins SRA (Lieschke et al. 2013) provides an appropriate sampling approach for each site and a sampling frequency of once every two years (2 catchments one year, 3 catchments the next) is considered sufficient to allow for an ongoing appraisal of the trajectories of fish species within each catchment.

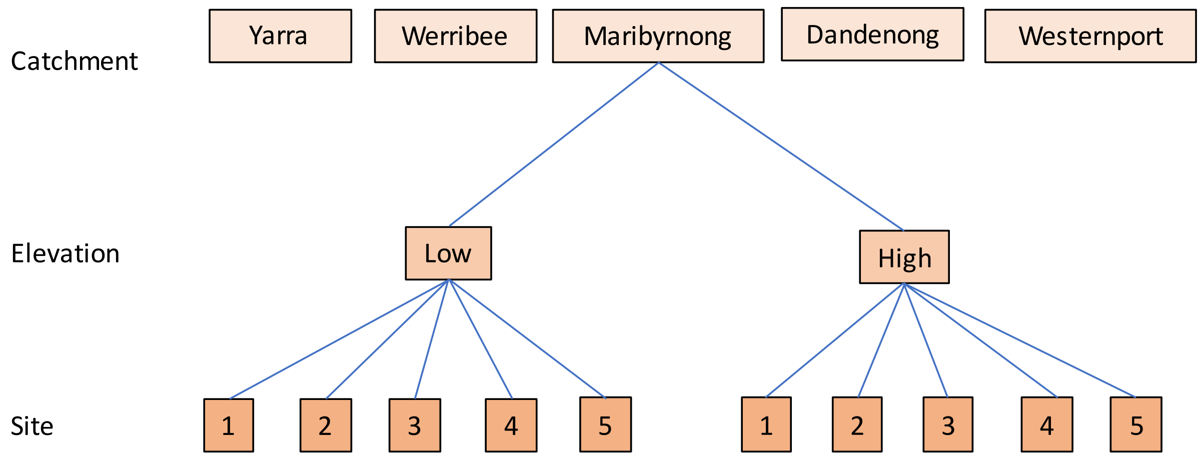


Figure 17: example of a potential fish sampling regime for rivers and streams.

For wetlands, the distinction between low and high elevation is considered less important as a determinant of fish species composition than in longitudinally connected rivers and streams. An example of a suitable surveillance monitoring program for wetlands could therefore consist of 10 sites per catchment (Figure 18). As wetlands are highly variable in their physical form, it is likely that different methodologies will be required to adequately sample the selected wetlands. One approach to addressing this issue is to first select wetland sites based on their priority (as discussed above), and then develop a customised, repeatable sampling protocol for each wetland based on the considerations presented in Table 4.

While the use of different methods in different wetlands may preclude direct comparisons between wetlands, customised sampling to suit the conditions would improve sampling efficiency and, thus, optimise the ability to track trajectories in fish condition over time. Direct comparisons between wetlands of variable physical form (e.g. billabongs to shallow basin depressions, to upland stream wetlands) are problematic regardless of whether standardised methods are used, due to issues of variable catchability and capture efficiency under different conditions, so the use of customised sampling protocols for each wetland is not considered a major disadvantage in the context of the MERI. A sampling frequency of once every two years (2 catchments one year, 3 catchments the next) is considered sufficient to allow for an ongoing appraisal of the trajectories of fish species within each catchment.

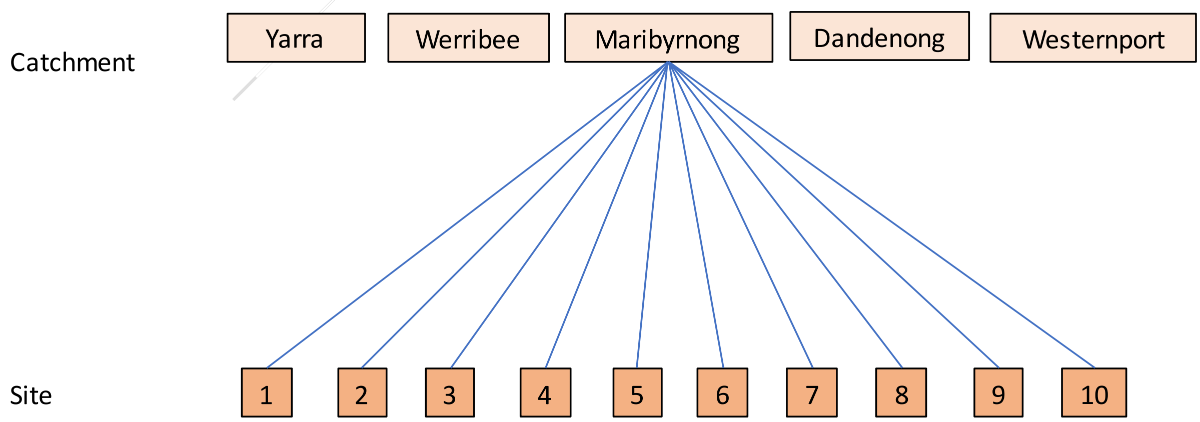


Figure 18: example of a potential fish sampling regime for wetlands.

The structure of a monitoring program for estuaries requires different considerations to rivers, streams and wetlands. Large river basins contain many kilometres of stream and river length and numerous wetland complexes that are spatially arranged via connected drainage networks. In contrast, estuaries represent the single outlet of each river basin to the sea. The HWS recognises ~30 estuaries across the MW jurisdiction. Given the much more discrete distribution of estuarine habitats, a lower number of estuarine sites is required to provide sufficient coverage for the MERI. Estuaries are also temporally and spatially complex environments that undergo rapid shifts in physico-chemical characteristics (e.g., salinity, water levels an inundation patterns due to tides) over very short time frames. To properly characterise the fish assemblages associated with the different conditions that occur within an estuary it is necessary to sample from locations across the marine-freshwater gradient. An example of a suitable surveillance monitoring program for estuaries could therefore consist of 3 estuaries per catchment, with estuaries selected to target priority species/locations and to ensure spatial representativeness (Figure 19). Within each estuary, we recommend at least three sites across the salinity gradient be sampled. The development of a detailed estuary sampling protocol for the MERI should consider the information on sampling methods presented in Table 4 and existing information on appropriate sampling protocols for condition assessment in estuaries (Hallett and Tweedley 2015; Hallett et al. 2019). Development of the estuarine component of the MERI should also be closely aligned with developments in the DELWP's Index of Estuarine Condition program.

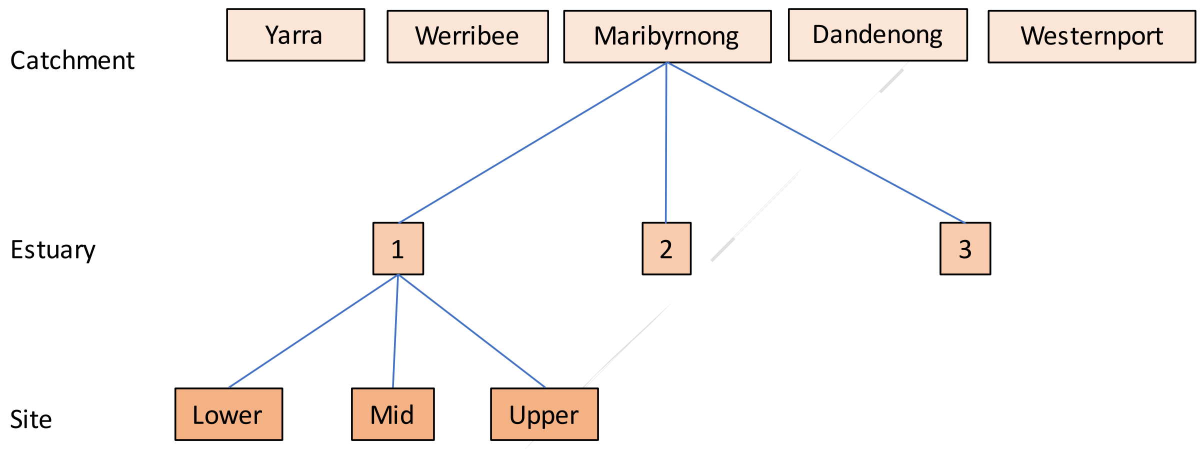


Figure 19: example of a potential fish sampling regime for estuaries.

Sampling methods: A wide variety of methods is available to sample fish in rivers, wetlands and estuaries. Each of these methods has inherent advantages, disadvantages and biases with regards to taxa, body size, environmental conditions and sample timing (Murphy and Willis 1996). Table 4 below outlines recommended survey methods and other sampling considerations for monitoring fishes in MW region.

Whilst issues of capture efficiency for the various methods are important considerations for the interpretation fish survey data, especially with regards to estimates of species abundance (Gwinn and Beesley 2013), a range of useful metrics can be derived from fish survey data to inform adaptive management in the absence of quantitative capture efficiency information. These metrics are discussed in more detail below.

Table 4: Recommended survey methods and sampling considerations for rivers, wetlands and estuaries for Program 2 Monitoring design. Primary – method is preferred as it collects a diversity of species and life stages, secondary – are aimed at species that are not susceptible to primary method, and can be used to augment sampling efforts.

	Electrofishing	**Fyke netting**	**Gill netting**	**Seine netting**	**Bait traps**	**Dip netting**
River, streams	Y (primary)	Y (secondary)	N	N	Y (secondary)	Y (secondary)
Wetlands	Y (primary where appropriate)	Y (primary where appropriate)	N	Y (primary where appropriate)	Y (secondary)	Y (secondary)
Estuaries	N	Y (primary)	Y (secondary)	Y (primary where appropriate)	Y (secondary)	Y (secondary)
Sampling considerations	- active sampling method - no delay in obtaining data - type of electrofishing unit (boat, bank, backpack) deployed dependent on depth, conductivity and site access - commonly used to sample freshwater fish - samples a wide size range of fishes - other considerations include boat ramp access, length of stream accessible from site - estuarine electrofishing is possible but equipment not widely available - highly specialised gear with limited operators available	- passive sampling method - targets mobile fishes - requires soak time for gear efficiency - needs to be monitored for entrapment of non-target biota - could be considered additional technique for juvenile Macquarie perch and eels	- passive sampling method - requires appropriate mesh sizes for target species (e.g. large mesh applicable for larger bodied species only) - boat access generally required - targets mobile fishes - requires soak time for gear efficiency - needs to be constantly monitored for entrapment of non-target biota - may be associated with sampling mortality of fish	- active sampling method - requires appropriate mesh sizes for target species (e.g. large mesh applicable for larger bodied species only) - not useful in highly complex habitat (e.g. woody debris, emergent vegetation) - may be associated with sampling mortality of fish	- passive sampling method - useful for sampling small-bodied fish, particularly cryptic species - can be with or without baits depending on target species - requires soak time for gear efficiency	- active sampling method - useful for sampling small-bodied fishes in dense aquatic vegetation - particularly useful for targeting dwarf galaxias and Yarra pygmy perch

Fish sampling methods can be broadly categorised as passive or active. Passive methods include mesh nets and traps which rely on fish encountering the sampling gear by moving into the net or trap. This reliance on active movement by fish to encounter the sampling gear makes passive gears much more susceptible to sampling biases because the movement behaviours and activity rates of fish are strongly dependent on fish size and species, time of day and season, and environmental conditions (e.g. flow). Passive gears must also be left in place to allow sufficient time for fish to encounter the gear and is efficiency is limited when fish have limited movements. The time required for effective setting of passive gear usually ranges from several hours to overnight. The requirement for staff to remain onsite for extended periods whilst passive gear is deployed adds considerably to the costs associated with this type of survey approach. The setting of passive gears for extended period also increases the chances of interactions with non-target species, including platypus and water rats, and the time spent by target species entangled in nets or traps can result in elevated mortality rates.

Active sampling techniques are those in which the gear is actively moved in order to encounter the fish. The main types of active methods commonly used for fish surveys include electrofishing (boat, bank, backpack), seine nets and sweep nets. Whilst active methods have some biases associated with their use, they tend to provide more representative samples of fish assemblages than passive gears. Further, because active methods do not need to be deployed for extended periods, the staffing costs, chances of encounters with bycatch species and mortality of fish tend to be greatly reduced. Extensive comparisons of different active and passive fish sampling methodologies have been conducted previously in the NSW Rivers Survey (Harris and Gehrke 1997) and the MDBA Sustainable Rivers Audit (Davies et al. 2010). Based on these studies, it was concluded that electrofishing is the most effective fish sampling technique available for fish population status monitoring, both in terms of cost and sample representativeness. Electrofishing is often combined with small traps that specifically target small-bodied species that are not well represented in electrofishing samples (SRA, Southern Basins Program).

Given the overwhelming advantages of electrofishing as a survey technique for fish in Australian freshwaters, we recommend that this method be used as the basis for the targeted surveillance monitoring program in the Melbourne Water region. Guidelines for the use of electrofishing for fish assemblage monitoring are available and should be used as a basis for detailed implementation plan. The Southern Basins Program methodology provides an example of a suitable sampling regime. Aside from optimising the sampling protocol, use of standardised approaches has the important advantage of ensuring that data from previous surveys is comparable to the data collected in future, thus providing opportunities for increased inference regarding the status and trajectory of fish populations. Electrofishing is used globally as a fish monitoring tool and an Australian Code of Practice has been developed to guide safe usage of the technique. All operators conducted electrofishing should be adequately qualified and conduct their activities in alignment with the code of practice and appropriate risk management frameworks.

Although electrofishing is a highly effective method for sampling fish, its use is not possible in all circumstances. For example, in saline wetlands and estuaries electrofishing using widely available units is not possible. In such cases, it will be necessary to employ passive gears such as fyke nets, seine nets and bait traps. The use of passive gears – and interpretation of sample results – requires careful consideration regarding the behaviour and susceptibility to capture of different species, the environmental conditions at the time of sampling (moon phase, tide, river discharge), staffing costs and potential for collection of non-target species. As for electrofishing, detailed protocols for sampling estuaries and wetlands can be applied using guidelines from existing programs as a basis (Index of Estuarine Condition, WETMAP). The Arthur Rylah Institute (ARI) also operates an electrofishing boat that can operate under high salinity and may be of use for sampling saline wetlands and estuaries (Warry et al. 2013). Use of this equipment should be considered in relevant areas, recognising, however, that ARI is currently the only operator of such equipment.

Water quality parameters (dissolved oxygen, turbidity, temperature, conductivity, pH) should also be measured at each site to allow for assessment of the physical conditions that may affect sampling efficiency and fish condition at each site. Electrofishing time for each shot and power and duty cycle settings should be recorded as per the Southern Basins Program protocol as metadata to allow for catch-per-unit-effort (CPUE) adjustments to the data if required. Where passive gears are set, net soak times should be recorded to allow calculation of CPUE.

Fish sampling metrics: Annual fish population abundance and size structure data lends itself to a number of useful fish metrics (Table 5) and analyses that can be used to assess population trajectory change. Presence metrics can be used for simple report card style reporting and generally require just visual inspection of length frequency plots. All other metrics can be analysed using simple linear modelling approaches with sites and time as factors.

Table 5: Potential fish metrics used in population size structure reporting

Metric	Data used	Description and use
Relative abundance	Catch per Unit Effort	Tracking population change through time.
Presence of recruits	Abundance per length class	Inspection of length frequency plots for presence of recruits (length varies for each species) each year and through time
Proportion or number of recruits	Abundance per length class	Proportion or abundance of recruits relative to the number of individuals collected each year through time.
Presence of multiple size classes	Abundance per length class	Inspection of length frequency plots for presence of all relevant age classes (length varies for each species) each year and through time
Proportion of mature fish	Abundance per length class	Proportion or abundance of mature fish relative to the number of individuals collected each year through time.
Body condition	Length and weight	Calculate standard body condition indices L:W of individual and calculate residual for individual (ie is above or below average body condition for entire sample)

The rationale for including targeted sampling in the MERI is to allow for assessment of the abundance of native and introduced species, annual recruitment, population size structure and fish condition (if needed). Such assessments should use the fish measurements described in Table 6 on individual fishes (up to 50 fish per species per site).

Table 6: Highly desirable and useful individual fish measurements to be recorded for each fish collected.

Fish measurement	Unit measurement (unit)	Justification
Highly desirable		
Species	Genus species resolution	Species richness counts
Length	Standard length (mm)	Easily recorded when fish is captured Critical data for population structure assessment, e.g. presence of recruits, mature individuals
Weight	Wet weight (g)	Easily recorded when fish is captured Useful for measuring body condition changes (indicator of stress) Analysed relative to length
Useful		
Sex	Male or female	Easily assessed in some species (e.g. *Gambusia holbrooki*) Possible to assess sex ratio change in the future
Disease and/or parasites	Number and type if known	Easily assessed externally High incidence indicates stress
Abnormalities	Number and type	Easily assessed externally High incidence indicates stress

Reporting and Analysis

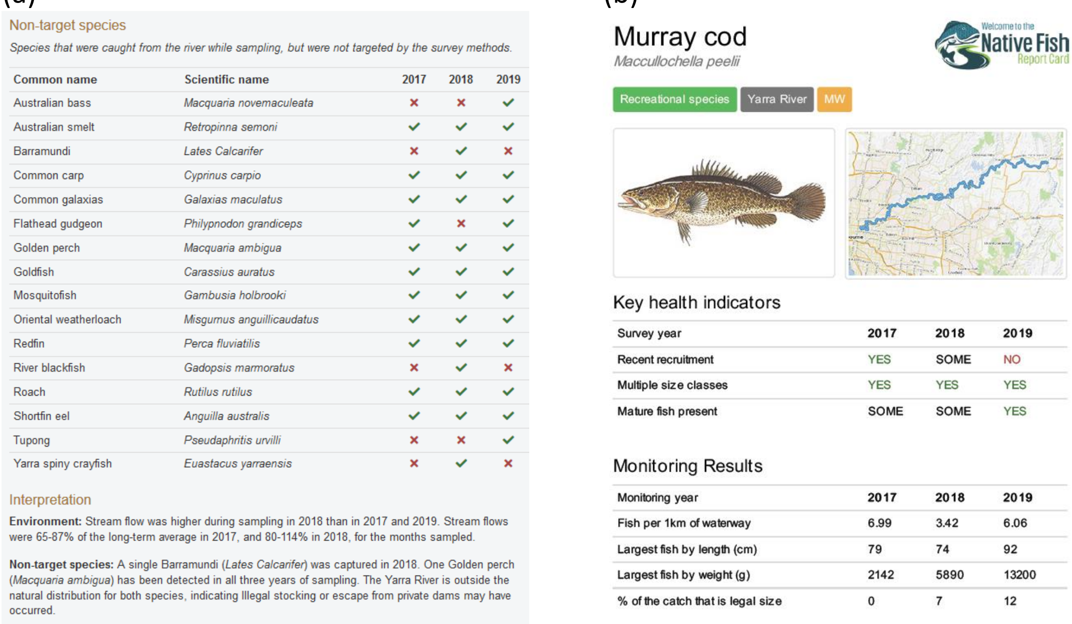
We recommend that as data are collected each year, a simple analysis and reporting be undertaken based on data from both monitoring programs, but that every four years more in-depth analysis are performed to assess trajectories over time. Analysis of the data is a critical component of any monitoring program. Analysis and reporting can be as time consuming as the field components of projects and at times can be under-prescribed in project planning. We believe that investing more heavily in later years, when more temporal data are available, is the best option for optimising the production of usable outputs and investment in analyses. If early reporting of trajectory is desirable, we recommend conducting quantitative analysis of existing datasets at key locations or species of interest.

There must also be careful quality assurance and quality control of data as it is collected and entered into MW databases. This includes articulating a clear set of data standards – such as naming conventions, measurement units, the nature of surveys (e.g. whether specific species were being targeted), gear type and effort. We would recommend the generation of a standardised set of summary information – such as survey-site lists, species lists, size-range, species abundances, survey effort by site, to allow those responsible for data collection to quickly check the validity of the data they have provided. Ensuring the quality, accuracy and precision of the data being collected is an important component of all monitoring programs. Construction of specialised database inputs (templates for data entry) and database management systems is recommended.

Yearly reporting of species occurrence data and an overview of focused monitoring activities can be conducted with little investment. It can be largely descriptive, providing a snap-shot of the status of species or populations, and possibly highlighting areas of concern. The current Victorian Native Fish Report Card (which includes the Yarra River catchment) is a useful example of an easily understood report-card style output which uses simple metrics of both overall fish community diversity (presence or absence in sampling) and population health status indicators (recent recruitment, multiple age classes and mature fish present; see Figure 20). Comparison to previous data could be made but with an aim to provide a broad picture of the MW region, rather than fine-detail analyses that are likely to be more time consuming, have insufficient power to elucidate effects, and yield fewer usable outputs when data cover only short time-periods.

Yearly reporting may include:

- Descriptive statistics (e.g. species richness, species lists)
- Maps of species' extents
- Graphs of population structure (i.e. length-age classes)
- Basic comparisons current and previous surveys.


(a)

Non-target species

Species that were caught from the river while sampling, but were not targeted by the survey methods.

Common name	Scientific name	2017	2018	2019
Australian bass	*Macquaria novemaculeata*	✗	✗	✓
Australian smelt	*Retropinna semoni*	✓	✓	✓
Barramundi	*Lates Calcarifer*	✗	✓	✗
Common carp	*Cyprinus carpio*	✓	✓	✓
Common galaxias	*Galaxias maculatus*	✓	✓	✓
Flathead gudgeon	*Philypnodon grandiceps*	✓	✗	✓
Golden perch	*Macquaria ambigua*	✓	✓	✓
Goldfish	*Carassius auratus*	✓	✓	✓
Mosquitofish	*Gambusia holbrooki*	✓	✓	✓
Oriental weatherloach	*Misgurnus anguillicaudatus*	✓	✓	✓
Redfin	*Perca fluviatilis*	✓	✓	✓
River blackfish	*Gadopsis marmoratus*	✗	✓	✗
Roach	*Rutilus rutilus*	✓	✓	✓
Shortfin eel	*Anguilla australis*	✓	✓	✓
Tupong	*Pseudaphritis urvilli*	✗	✗	✓
Yarra spiny crayfish	*Euastacus yarraensis*	✗	✓	✗

Interpretation

Environment: Stream flow was higher during sampling in 2018 than in 2017 and 2019. Stream flows were 65-87% of the long-term average in 2017, and 80-114% in 2018, for the months sampled.

Non-target species: A single Barramundi (*Lates Calcarifer*) was captured in 2018. One Golden perch (*Macquaria ambigua*) has been detected in all three years of sampling. The Yarra River is outside the natural distribution for both species, indicating Illegal stocking or escape from private dams may have occurred.

(b)

Murray cod

Maccullochella peelii

Key health indicators

Survey year	2017	2018	2019
Recent recruitment	YES	SOME	NO
Multiple size classes	YES	YES	YES
Mature fish present	SOME	SOME	YES

Monitoring Results

Monitoring year	2017	2018	2019
Fish per 1km of waterway	6.99	3.42	6.06
Largest fish by length (cm)	79	74	92
Largest fish by weight (g)	2142	5890	13200
% of the catch that is legal size	0	7	12

Figure 20: Example of yearly reporting for (a) presence data for fish and (b) population metric report card for Murray cod in the Yarra catchment from the Native Fish report card (https://www.nativefishreportcard.org.au/portal.php) .

Every four years, investment could be made into a more thorough analysis and reporting, including quantitative evaluation of the condition and trajectories of species and populations. These analyses may focus more on local or catchment scale trajectories, highlighting potential issues within populations and their likely causes. Responses to intervention actions would be analysed at this time.

Four yearly reporting may include:

- Assessment of trajectories in fish condition metrics
- Evaluation of impacts such as barriers, and remedial works such as barrier removal
- Investigation into local/catchment and species-level trajectories.

Fish status assessment

The primary aim of the surveillance monitoring in the fish MERI is to provide a platform for assessing the condition and trajectory of fish populations and reporting against the performance objectives outlined in the HWS. Examples of performance criteria associated with different categories of condition at the assemblage level (Program 1) and species level (Program 2) are presented in Table 7 This type of information can be converted into prescriptive rubrics to allow for a consolidated assessment of condition and examination of changes in condition over time. Potential rubrics based on the proposed fish metrics (see Table 8) are presented below.

Table 7: Performance criteria for condition different levels at the assemblage level (Program 1) and species level (Program 2).

Condition	Performance criteria or evidence for Program 1: broad scale monitoring	Performance criteria or evidence for Program 2: Priority species (could be one or many species)
Very high	- All expected native freshwater species are recorded - occurs at an increasing or stable number of sampling sites	- Priority species population's abundance is maintained or increasing - Evidence of strong recruit and mature age classes in population over multiple years - population occurs at all expected sites and samples or is increasing in occurrence - body condition index improving or stable from previous years - very low incidence of disease, parasites or abnormalities noted in surveys.
High	- Most expected native freshwater species are recorded - Population occurs at an increasing or stable number of sampling sites	- Priority species population's abundance is maintaining or increasing - Evidence of variable recruit input and mature age classes in population over multiple years - population occurs at all expected sites and samples or is increasing in occurrence - body condition index stable from previous years - low incidence of disease, parasites or abnormalities noted in surveys.
Moderate	Half of expected native freshwater species are recorded - Population occurs at a stable number of sampling sites	- Priority species population's abundance is maintained - Occurrence of recruit and mature age classes in population has declined over multiple years - population occurs in the majority of expected sites and samples - body condition index has declined from previous years - high incidence of disease, parasites or abnormalities noted in surveys.
Low	Few of expected native freshwater species are recorded - Population occurs at a declining number of sampling sites	- Priority species population's abundance is declining - Occurrence of recruit and mature age classes in population has declined over multiple years - species occurrence is declining compared to number of expected sites and sample frequency - body condition index has declined from previous years - high incidence of disease, parasites or abnormalities noted in surveys.
Very low	Very few of expected native freshwater species are recorded - Population occurs at a declining number of sampling sites	- Priority species population's abundance is declining - Occurrence of recruit and mature age classes in population has declined over multiple years - species occurrence is declining compared to number of expected sites and sample frequency - body condition index has declined from previous years - very high incidence of disease, parasites or abnormalities noted in surveys.

Assemblage-level rubric

Data from Programs 1 and 2 provide information on the composition of fish assemblages that can be used to generate key metrics of fish assemblage condition at the catchment level (Table 8). The suggested metrics for the fish MERI are similar to those used in the Southern Basins SRA and AVIRA framework. The metrics would be calculated for each survey period and based on the median metric score across all sites within a catchment. The metrics would incorporate species presence data from the broad-scale eDNA sampling (Program 1) and the targeted collection surveys (Program 2). A combined fish assemblage condition score could be generated for each catchment by combining the values across the four metrics into a single value; for example, by assigning values of 1-5 (1 = very low, 5 = very high) to each metric and calculating the overall median score).

Table 8: Potential rubric for classifying fish assemblage status at the catchment scale.

Metric	Very high	High	Moderate	Low	Very low
Observed/expected	>90% of expected species	70-89% of expected species	50-69% of expected species	30-49% of expected species	<30% of expected species
Species richness	>8 native species	7-8 native species	4-6 native species	2-3 native species	<2 native species
Nativeness (species)	>90% native species	70-89% native species	50-69% native species	30-49% native species	<30% native species
Nativeness (biomass) Program 2 surveys only	>90% native biomass	70-89% native biomass	50-69% native biomass	30-49% native biomass	<30% native biomass

Comparisons among consecutive surveys can be conducted to assess whether the trajectory of catchment condition is 'on track' to meet the relevant HWS objectives (Table 9). For example, if the objective for fish in a catchment is to ***maintain*** the current status, then all yellow boxes or a combination of yellow and green boxes can be considered as 'on track' (catchments A and B in Table 9). If the objective is to ***improve*** fish condition in the catchment, then all green boxes or a combination of yellow and green boxes may be considered as 'on track' (catchment A only). A catchment whose condition for any particular metric is decreasing (i.e., red boxes) would be considered as not 'on track'. This type of basic comparison can be conducted for the individual metrics, as well as the combined fish assemblage condition score for each catchment. Basic comparisons could be included in the yearly reporting schedule (e.g., report card style comparisons), and more comprehensive quantitative analyses examining overall trends across all surveys conducted every four years.

Table 9: Report card style comparisons among consecutive surveys from theoretical catchments with different fish condition metric trajectories.

Catchment A

Metric	Survey 1	Survey 2	Condition
Observed/expected	Moderate	High	Increasing
Species richness	Moderate	Moderate	Stable
Nativeness species	Low	Low	Stable
Nativeness biomass	High	High	Stable

Catchment B

Metric	Survey 1	Survey 2	Condition
Observed/expected	Moderate	Moderate	Stable
Species richness	Moderate	Moderate	Stable
Nativeness species	Very high	Very high	Stable
Nativeness biomass	High	High	Stable

Catchment C

Metric	Survey 1	Survey 2	Condition
Observed/expected	Moderate	High	Increasing
Species richness	Low	Low	Stable
Nativeness species	Moderate	Low	Decreasing
Nativeness biomass	Moderate	Low	Decreasing

Species status assessment

As previously discussed, information on species presence is a coarse measure of fish population condition that does not allow for the identification of declines in abundance and condition. The primary aim of the targeted collection surveys is to provide an ongoing appraisal of the status of key native fish species to allow for timely identification of changes to populations and assemblages. At the species level, therefore, the emphasis is on understanding species' trajectories.

We suggest the use of six key metrics for the species-level assessment (Table 10). Similar to the basic comparisons mentioned above for the fish assemblage condition assessment, among-survey (yearly or every two years) comparisons could be made for all species using the average or median value for each metric across all sites in the catchment (Table 11). As for the assemblage level assessments described above, comparisons among consecutive surveys can be conducted at the species level to assess whether the trajectory of key species is 'on track' to meet relevant target status and more detailed analyses conducted each four years to examine overall trends (Table 12). It should be noted that decreasing values in metrics between consecutive surveys (i.e., red boxes) would be expected due to natural variation in population dynamics; however, a pattern of decreasing metric values over multiple surveys periods provides an indication of species declines and can identify species that require management intervention. It may be possible to incorporate threshold of change criteria into these assessments based on analyses of variation in the data (e.g., <10% change in metric value considered as 'stable').

*Table 10: Six key metrics for the species-level assessment for each catchment. * incorporates eDNA and survey data.*

Metric
Sites present (%)*
Abundance (CPUE)
Juvenile recruitment (young-of-year CPUE)
Mature fish abundance (mature fish CPUE)
Disease/parasite/abnormality prevalence (%)
Body condition (mean length-weight residuals)

Table 11: Example of how key metrics could be used to assess trajectory of key species.

Metric	Survey 1	Survey 2	Trajectory
Sites present (%)	50%	60%	Increasing
Average Abundance (CPUE)	10/hr	15/hr	Increasing
Juvenile recruitment (young-of-year CPUE)	5/hr	3/hr	Decreasing
Mature fish abundance (mature fish CPUE)	5/hr	10/hr	Increasing
Disease/parasite/abnormality prevalence (%)	15%	20%	Decreasing
Body condition (length-weight residuals)	-1	-1	Stable

Table 12: Example of how key metric trajectories could be used to identify and report on fish species that are declining but remain present within the catchment. In this case, there is repeated failure of juvenile recruitment into the population, leading to a decline in overall abundance.

Metric	Survey 2	Survey 3	Survey 4
Sites present (%)	Stable	Stable	Stable
Abundance (CPUE)	Stable	Decreasing	Decreasing
Juvenile recruitment (young-of-year CPUE)	Decreasing	Decreasing	Decreasing
Mature fish abundance (mature fish CPUE)	Increasing	Stable	Decreasing
Disease/parasite/abnormality prevalence (%)	Stable	Increasing	Stable
Body condition (length-weight residuals)	Stable	Stable	Stable

What other data/tools are needed?

There are several ancillary data sets or tools that will be needed to comprehensively analyse the fish data derived from each of the two programs. Importantly, a number of these datasets are inputs to the HSMs that have been developed for fish, and so changes in those attributes over time will need to be included in any updates to these predictions. Some of these datasets have already been developed, some are under construction and some will need updating at regular intervals.

In-stream barriers

Connectivity among fish populations can be severely impacted by low water levels, estuary mouth closure and in-stream barriers. Therefore, information on these structures is critical for MERI reporting as they can have a significant effect on fish population dynamics. A database of partial and full in-stream barriers within the Melbourne Water region has been compiled (Coleman and Chee 2017). This database contains temporal information for tracking the removal or construction of instream barriers over time. Targets have been set in the HWS for removing/improving existing fish passage barriers. Ensuring that the barriers database is updated regularly is a relatively simple but important process. For estuary sites, the status of mouth as being open or closed during and prior to surveying needs to be known and incorporated into analysis and interpretation of fish metrics. Physico-chemical data for some estuaries, including mouth status, are available from programs such as estuary watch (http://www.estuarywatch.org.au/).

Extent of current and projected urbanisation

Fish populations respond to changes in landscape type, especially to urbanisation and its associated changes to runoff patterns. A geo-spatial layer has been developed that includes current and future urban development (Chee and Walsh, unpublished). This layer will be important for tracking responses of fish populations to urbanisation. Moreover, assessing responses as urbanisation encroaches on new areas will require regularly updating this layer.

Vegetation cover (and quality)

Vegetation cover (and continuity) upstream of survey sites is included as a predictor variable in the fish HSMs as ‘attenuated forest’. This metric considers the characteristics of vegetation within a 20m buffer on both sides of a reach (see Walsh and Chee, 2019 for more details). It is anticipated that the existing riparian tree cover spatial dataset will need to be updated using similar methods for reporting at the desired future timepoints (e.g. 4 and 8 years from HWS implementation). It is In updating these datasets it will be important to capture both improvements and declines in vegetation cover and quality.

Flow modification

Flow modification is an obvious driver of changes in fish populations, but is currently not incorporated into any of the strategy’s instream HSMs. This in part reflects a data deficiency – many of the features that impact on downstream flow have previously not been well mapped. This is in part being dealt with through the development of a high resolution waterbodies layer, which will permit development of course flow modification metrics based on farm-dam, reservoir and major diversion weir impacts. A library of temporal changes in such effects will enable tracking of flow modification. It is however important to note that downstream hydrologic impacts arising from extractions and diversions can vary significantly depending on local settings. There will likely be greater potential to infer flow-regime impacts from the more comprehensive datasets being collected under Program 2 due to the more detailed information regarding recruitment and other population processes, which may be sensitive to interannual variability in hydrologic metrics.

Wetland inundation regime

Information on the hydrology of wetlands will be critical for analysing wetland fish communities. To date, data on wetland inundation is sparse both spatially and temporally. This lack of data will impede our ability to forecast species population responses over the Melbourne Water region and through time. Working alongside Geosciences Australia, we are currently rectifying this situation through developing and testing ways to extract hydrological data from satellite imagery. The final product will be a tool that predicts the likelihood of water in any given 30 x 30 m area (1 pixel of a satellite image). Using this tool will be as simple as accessing and analysing satellite images for desired periods. Because these images are collated and orthorectified by Geosciences Australia, there will be little ongoing maintenance to be done.

Habitat suitability models

Habitat suitability models have already been produced for all fish species in the Melbourne Water region (Chee et al. unpublished). These are currently used to inform Melbourne Water's Healthy Waterways Strategy (HWS) and form a critical component of the HWS reporting. Models are based on environmental parameters that fish species respond to and these parameters may change over time, for instance as barriers are constructed or removed. Therefore, the habitat suitability models will need to be updated on a regular basis. We would not recommend this be done annually, but should be considered (for example) every 4-5 years as part of a larger analysis designed to align with the broader MERI program.

Intervention monitoring

As well as the surveillance monitoring programs designed to assess general trends in fish populations across the region, it will also be important for MW to invest in intervention monitoring activities designed to evaluate the effectiveness of specific interventions, and to test specific hypotheses from conceptual models.

Intervention monitoring is differentiated from surveillance monitoring both in its purpose and approach. For example, intervention monitoring typically adopts a more structured 'experimental' approach, in which the effects of an intervention (e.g. a fishway) are monitored in such a way as to provide very clear evidence as to what changes have occurred, and what factors are responsible for those changes (Downes et al. 2002). To this end, development of clear *a priori* hypotheses or questions is an essential component of intervention monitoring. Additionally, intervention monitoring will often involve some form of control (or reference), against which the intervention is tested. There are various design options available, that each differ in their inferential strength. The classic design, with good inferential power is the 'Before-After Control-Impact (BACI)' design, which includes a control sample and samples collected before and after the intervention. For example, to test the effectiveness of fishway construction, ideally surveys would include samples collected both before and after the fishway was constructed, as well as a control stream, in which a fish passage interruption still persists. Additional samples may also be collected from streams with no fishway as a reference (a BACRI) design (Downes et al. 2002).

We have not attempted to spell out the specific requirements of any single form of intervention monitoring, as the opportunities for implementing specific experimental designs (and their associated costs and benefits) can vary considerably. For example, it has been widely acknowledged that intervention monitoring to test the effects of environmental flows is typically constrained by the fact that few (if any) 'control' or 'reference' rivers exist, against which the effects of a particular flow release can be compared. One option in such cases is to use a modelled 'reference' – i.e. to use the outputs (for example from a habitat suitability or population model) to generate predictions of what would have happened under the flow-regime expected without the environmental flow. Such an approach provides counterfactual evidence and has gained some attention in recent years in environmental research.

The Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) is currently in Stage 6. This agreed monitoring of environmental flows focusses on specific mechanisms where environmental flows are likely to result in an outcome promoting immigration, dispersal and recruitment of diadromous fish in Victorian coastal rivers (DELWP 2017a, b). Table 13 outlines the rivers included in VEFMAP for fish and the design and indicators being used in the program.

Table 13: Design of VEFMAP in MW regions, from DELWP (2017b).

Key Evaluation Question	Rivers in MW region included in VEFMAP	Sampling method and design	Indicator
Do environmental flows promote immigration by diadromous fishes in southern Victorian coastal rivers?	Barwon River, Werribee River, Bunyip/Tarago River, Cardinia Creek	Fyke netting and fishway trapping. In each river weekly during spring and summer. No indication of sites.	Diadromous fish presence and abundance (Abundance of juvenile diadromous fish)
Do environmental flows enhance dispersal, distribution and recruitment of diadromous fishes in southern Victorian coastal rivers?	Werribee River, Bunyip River, Moorabool River	Event based netting and end-of-season electrofishing. Netting at up to 9 sites over 3 nights prior and during spring/summer environmental flow release. End-of-season electrofishing in Feb/March. No sites indicated.	Diadromous fish presence and abundance Diadromous fish distribution, movement and fish species size structure

Setting aside specific design issues, it is also important to recognise that monitoring is expensive, and hence monitoring effort must be distributed in a coordinated fashion. To this end, we recommend Melbourne Water adopt a structured process to determine when and where to undertake intervention monitoring. This should take into account a number of factors, such as, existing knowledge regarding the effectiveness of particular interventions, their relative costs and expected benefits. For example, cases where the costs are high and the expected outcomes (or effectiveness) are poorly understood, would be strong candidates for intervention monitoring. It is also important to consider whether multiple stressors may be acting in unison, and how that will affect expected short-term outcomes. For example, barrier removal may be a perfectly logical intervention, but one that will not show a benefit in the short-term if water-quality is an issue, or past impacts mean the target species will take time to re-establish. Such situations may dictate a decision about when NOT to monitor, because *a priori* it is recognised that other pre-conditions, or other works programs must be undertaken before there is an expectation of a response in terms of population numbers or other response variables. These examples emphasise the need for coordination among different teams in designing intervention monitoring (e.g. among teams responsible for riparian management, environmental flows, fishways etc.).

Recommendations

This discussion paper provides the project team's guidance on considerations and the overarching requirements for developing a fish surveillance monitoring program in the MW region. Our recommendations are:

1. Review and update of the MW fish database to ensure that the full range of data on fish distributions is captured.
2. Two fish monitoring designs (broad scale presence/absence monitoring and focused monitoring) are undertaken in the MW region to enable accurate and informative reporting on the status and trajectory of fish populations.
3. Broad-scale monitoring should be conducted principally by eDNA sampling (Program 1) with additional presence data from the focused monitoring (Program 2). However, for some

priority species further eDNA sampling sites will need to be established and may require surveying more frequently. A more detailed assessment of MW proposed eDNA sampling sites versus species distributions should also be conducted, to ensure enough sampling is occurring in expected locations of priority species.

4. Focused monitoring (Program 2) should include monitoring of agreed priority species and/or locations/regions of significance. This sampling should be conducted at least once every two years to track population changes.
5. Whilst we have provided a preliminary list of priority species, decisions on the final list of priority species and any locations of significance for focused monitoring should be made in consultation with MW staff, should incorporate community values, and be informed by existing knowledge of species' distributions.
6. If reporting of current fish status and fish trajectory is required soon, MW should consider analysing existing suitable datasets. This could include analysis of both frequency of species presence information and where available, quantified changes in abundance, distribution and population structure.
7. Reporting should include both simple report card style annually reporting of current status, and also 4-5 yearly quantitative analysis of trajectories and population data to report against targets and inform any required management interventions.

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Appendix I – List of references and data sets in Melbourne Water Fish Database

Figure 1a: Reports or data sources (x axis) and surveys over time (y axis) as recorded in the Melbourne Water fish database.

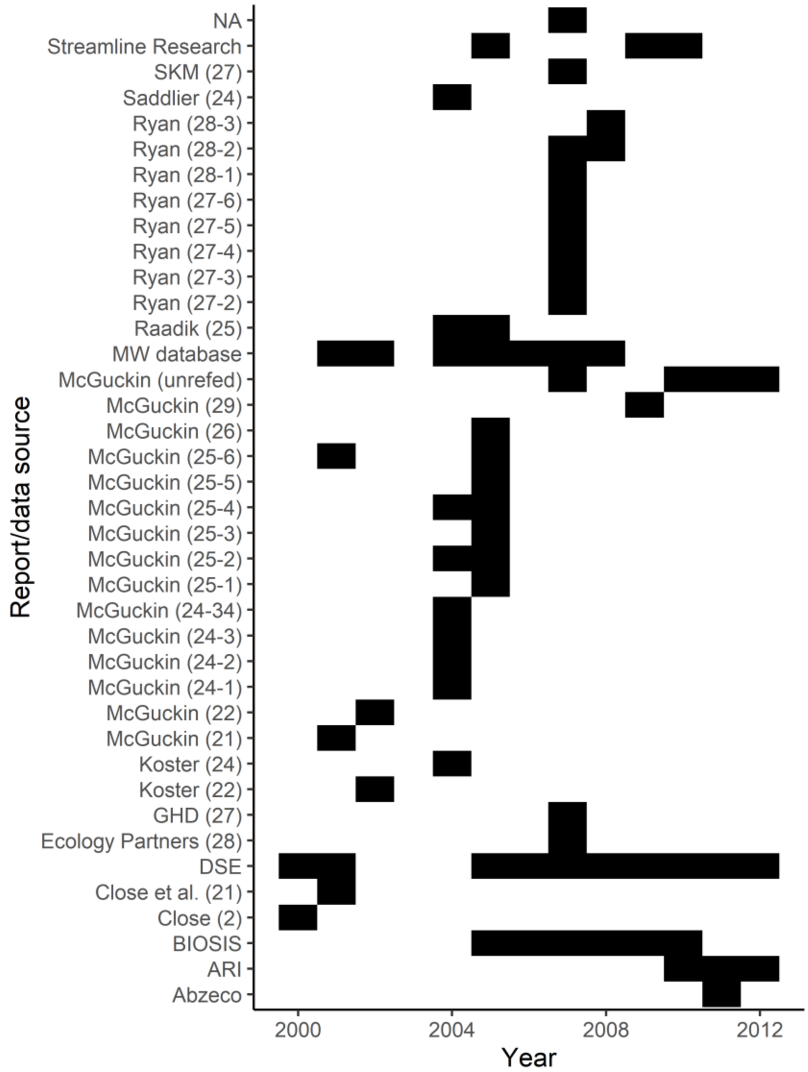

Table A2 References contained in the Melbourne Water fish database indicating the start and end years of survey effort

Reference	Shortened name	Start year	End year
Close, P, Koster, W, & Lyon, J, (21). An assessment of the aquatic faund in four Western Port sub-catchments (Victoria): Cardinia, Gum Scrub, Toomuc and Deep Creeks	Close et al. (21)	2001	2001
Close, P. (2). An assessment of the aquatic fauna of Kororoit Creek, Victoria: Arthur Rylah Institute for Environmental Research.	Close (2)	2000	2000
Ecology Partners. (28). Flora, Fauna and Aquatic assessment , and Net Gain Analysis of the proposed Western Trunk Sewer Aqueduct Replacement across the Werribee River, Werribbe, Victoria: On behalf of Parsons Brinckerhoff Pty.	Ecology Partners (28)	2007	2007
GHD. (27). Report for Little River Fish Survey. Report prepared for Melbourne Water.	GHD (27)	2007	2007

John McGuckin-Streamline Research	McGuckin (unrefed)	2007	2012
Koster, W. M. (22). An assessment of the aquatic fauna in Gardiners, Scotchmans, Back and Damper Creeks. Report prepared for Melbourne Water, Arthur Rylah Institute for Environmental Research.	Koster (22)	2002	2002
Koster, W.M. 24. Assessment of the fish assemblages in Jackson?Â•s Creek, Victoria. Report to Southern Rural Water, Melbourne Water and Western Water. Freshwater Ecology Section, Arthur Rylah Institute for Environmental Research	Koster (24)	2004	2004
McGuckin, J (24), Pindara Estate - Drainage Reserve, Stage 8 and 9 - fish fauna investigation	McGuckin (24-1)	2004	2004
McGuckin, J (25) Fish Survey of the Upper Maribyrnong River Basin	McGuckin (25-6)	2001	2005
McGuckin, J. (21). Riparian and instream habitat, instream barriers and fish survey along Cardinia Creek: Streamline Research.	McGuckin (21)	2001	2001
McGuckin, J. (22). Investigative fish survey Yallock Creek Catchment. Report prepared for Melbourne Water, Streamline Research Pty. Ltd.	McGuckin (22)	2002	2002
McGuckin, J. (24). Fish passage in the Maribrynong River (a survey above and below modified instream structures): Streamline Research Pty. Ltd.	McGuckin (24-3)	2004	2004
McGuckin, J. (24). Fish passage in the Tarago River at Fishers Road, Drouin. Report prepared for Melbourne Water, Streamline Research Pty. Ltd.	McGuckin (24-2)	2004	2004
McGuckin, J. (24b). Dwarf galaxias (Galaxiella pusilla) survey of selected sites in the Dandenong and Eumemmerring Creek systems: Streamline Research Pty. Ltd.	McGuckin (24-34)	2004	2004
McGuckin, J. (25). A survey of fish fauna in the Moonee Ponds Creek Catchment. Report prepared for Melbourne Water.	McGuckin (25-1)	2005	2005
McGuckin, J. (25). Fish fauna considerations of removal or modification of Badger Creek weirs. Final report prepared for GHD, Strealine Research Pty. Ltd.	McGuckin (25-2)	2004	2005
McGuckin, J. (25). Fish passage and the Bunyip Diversion Weir: Streamline Research Pty. Ltd.	McGuckin (25-3)	2005	2005
McGuckin, J. (25). Fish passage in Woori Yallock Creek and the Little Yarra River at two nominated instream structures. Report prepared for Melbourne Water, Streamline Research Pty. Ltd.	McGuckin (25-4)	2004	2005
McGuckin, J. (25c). Fish survey of O?Â•Grady Road, Hallam and surrounds: Streamline Research Pty. Ltd.	McGuckin (25-5)	2005	2005
McGuckin, J. (26). A fish survey of selected Yarra River tributaries between Yarra Glen and Melbourne: Streamline Research Pty. Ltd.	McGuckin (26)	2005	2005
McGuckin, J. (29b). Dwarf galaxias investigation in the Tirhatuan Wetlands, the Police Road Retarding Basin and at selected locations throughout the Dandenong Creek valley: Streamline Research.	McGuckin (29)	2009	2009

Raadik, T. (25). Aquatic fauna assessment of Steels, Dixons and Pauls Creeks, Yarra Glen, Victoria. Report prepared for Melbourne Water, Arthur Rylah Institute for Environmental Research.	Raadik (25)	2004	2005
Ryan, T. (27). A fish survey of Stony Creek: Streamline Research Pty. Ltd.	Ryan (27-6)	2007	2007
Ryan, T. (27). A fish survey of the Upper Tarago River, Muddy and Brandy Creeks: Streamline Research Pty. Ltd.	Ryan (27-1)	2007	2007
Ryan, T. (27). A survey of aquatic biota in the Hoddles Creek catchment: Streamline Research.	Ryan (27-2)	2007	2007
Ryan, T. (27). A survey of aquatic fauna in the Woori Yallock Creek catchment: Streamline Research.	Ryan (27-3)	2007	2007
Ryan, T. (27). A survey of fish in the Ararat Creek catchment: Streamline Research Pty. Ltd.	Ryan (27-4)	2007	2007
Ryan, T. (27b). A snapshot survey of fish in the Patterson River estuary and Lakes: Streamline Research Pty. Ltd.	Ryan (27-5)	2007	2007
Ryan, T. (28). A fish survey of the lower Tarago and Bunyip Rivers: Streamline Research Pty. Ltd.	Ryan (28-1)	2007	2007
Ryan, T. (28). A seasonal assessment of fish below Dights Falls: Streamline Research Pty. ltd.	Ryan (28-2)	2007	2008
Ryan, T. (28). Plenty River catchment fish survey report. Report prepared for Melbourne Water, Streamline Research Pty. Ltd.	Ryan (28-3)	2008	2008
Saddlier, S. R., Clemann, N.,. (24). Tamarisk Creek Wetland: fish, herpetofauna and habitat assessment: Arthur Rylah Institute for Environmental Research.	Saddlier (24)	2004	2004
SKM. (27). Bass River Fish Survey Report. Report prepared for Melbourne Water.	SKM (27)	2007	2007
Other data sources			
Abzeco	Abzeco	2011	2011
ARI	ARI	2010	2012
BIOSIS	BIOSIS	2005	2010
DSE	DSE	2000	2012
MW Fish database	MW database	2001	2008
Streamline Research	Streamline Research	2005	2010

GHD (2018b) Western Treatment Plant Fish Monitoring 2017. Report prepared for Melbourne Water by GHD Pty Ltd, Melbourne.

McGuckin, J. (2008.) A Fish Survey of the Western Treatment Plant. Report prepared for Melbourne Water by Streamline Research Pty Ltd, Melbourne.

McGuckin, J. (2009) A Fish Survey of the Lake Borrie Ponds and Little River Estuary. Report prepared for Melbourne Water by Streamline Research Pty Ltd, Melbourne.

Appendix II – Summary of fish data base issues

Our primary concern was to be able to use the fish dataset to map fish distributions and numbers of species within catchments. For this reason, we focused on wrangling the coordinate data. The following columns were added to the data set.

unique_record_id

This is a unique number for each record. This was done so that if sorting is conducted on subsequent versions of the database records can easily be matched up.

Lat_new; Long_new

These are latitude and longitudes that have been converted from the easting and northings provided for most records, using the QGIS field calculator. Not all records had easting northing coordinates. Coordinates with latitudes and longitudes were copied across from the LONGMOD and LATMOD columns.

The columns have been ordered in the data frame so that latitude is followed by longitude; this makes copying individual points into software such as google maps easier.

Subc_ms_found

Point coordinates were matched to the subcs of the MWregion_subc_260117 layer. There were many points that fell outside any subc. Where these occurred in the mouths of estuaries they were manually copied into the Subc_ms_found column

The process of intersecting the points to the subc layer resulted in additional columns appended to the data, these are attributes of the subcs and start with nextds (next subc down stream) and end at scAIUlt.

Further improvements that could be made to the fish dataset:

The following are suggested improvements that could be made to the dataset to make it more user friendly and useful.

- Meta-data: There should be a metadata sheet that informs the user what each of the columns represent and what the values in them code for. For instance there are three columns (UMELB_SNAP, UMELBMODEL, UMELBWATER) that appear to have codes for each record but what the codes mean is not clear.
- Coordinates: There are 13 records that have no coordinates and 44 that fall outside the subc layer and need checking – including some that are clearly incorrect. These should be added and checked. Additionally, there are records for which the coordinates did fall within a subc but that are likely to be incorrect. For instance, Centre Rd Channel is a wetland that occurs near Centre Road in subc DAND2262 but Centre Swamp Drain is positioned in a residential zone in subc MORD322 without indication of a swamp.
- Null values: There is a mixture of null values including cells that are blank or have NA or 0 values. These should be standardised and all null values filled in – my suggestion is to use NA.
- Missing dates: There are 41 records with missing dates. Most of these attributed to DSE studies.
- GEARTYPE: The GEARTYPE column includes multiple spellings of what are likely the same gear type. For instance, observation, observed and OBS; for backpack electrofishing, BPEF, EF/BP and EFBP; and for boat electrofishing, EF (Boat), EF/Boat and EFBO. These should be consistent. Also, GEARTYPE refers more to the type of observation that was made rather than the type of gear. For instance, it includes values such as stocking, translocation and observation.
- Feature names: Began creating a field of just main river names. The WATERBODY column has something like this; however, it is a mix of river names and sites, for instance Cardinia Creek and Cardinia Crk @ Ballarto Rd. There is also multiple spellings of some features e.g. Anderson Creek should be Anderson. This task became too large, partly because a decision needs to be made about what would best be captured by this field. For instance, should in stream reservoirs be attributed to the stream on which they sit or be separate entities. Similarly, with floodplain wetlands. There are also multiple features that are not well defined, such as Dam, Dam 1, Dam2 and Wetland, Wetlands etc. These will need to be checked to see if they are each separate features or if multiple features have been described the same.