Healthy Waterways Strategy 2018-2028
Port Phillip & Westernport, Victoria

Fish

A Technical Report to inform the Healthy Waterways Strategy Mid-term Review

This Technical Report has been developed for Melbourne Water as part of the Healthy Waterways Strategy Mid-term Review through a collective effort with many organisations and individuals. In particular, Melbourne Water thanks:

Report Contributors: Ryan Burrows, Trish Grant, Sharyn Rossrakesh, Al Danger and Rhys Coleman
Evaluation Panel: Michelle Dickson (chair), Tamara Boyd, Leon Metzeling and Ian Rutherfurd
Data provision: James Shelley

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Glossary of Terms and Abbreviations

BAUF	business as usual future (for 2068)
CURR	current, 2018 baseline
eDNA	environmental DNA
HSM	habitat suitability model
HWS	Healthy Waterways Strategy 2018
MW	Melbourne Water
LWD	Large woody debris
SCPO	Sub-catchment Performance Objective
Strategy	refers in this instance as the Healthy Waterways Strategy 2018
UBG	urban growth boundary

Acknowledgement of Traditional Owners

The rivers, wetlands and estuaries of the Port Phillip and Westernport region are part of Country belonging to the Bunurong, Gunaikurnai, Taungurung, Wadawurrung and Wurundjeri Woi-wurrung peoples. These Traditional Owners have lived in and been connected to the land, water, plants and animals of this area for many thousands of years, and we offer our respect to their Elders past and present.

Evaluation overview

This report is one of many background reports feeding into the HWS Mid-term Review Science Inquiry (Melbourne Water 2023a). It presents a limited evaluation of fish status which is a key value in the HWS. The extent to which this technical report has evaluated each key evaluation question (KEQ), and their sub-KEQs, with respect to fish as a value is summarised in Table 1.

Table 1. Summary of the mid-term evaluation KEQs and the extent to which they are presented in this report.

KEQ	Sub-KEQ	Relevance to this report and overview
1 – To what extent have the performance objectives of the Strategy been achieved?	1a. To what extent has collaboration and co-delivery contributed to achieving the Performance Objective targets so far?	This will be answered through the Implementation Inquiry (Melbourne Water, *in prep*).
	1b. To what extent is strategy delivery on track to achieve the Performance Objective targets by 2028?	An overview of progress towards fish related performance objectives is provided in Section 2.
3 – What is the state of waterway values?	3a. To what extent are key values on the target trajectory?	This KEQ is not evaluated for fish in this technical report because required data (e.g. re-run habitat suitability models) was not yet available at the time of analysis. This question was answered as part of the values synthesis and reported in the Science Inquiry Report (Melbourne Water, 2023a).
	3b. What other spatial and temporal trends and patterns for key values are of significance for implementation?	An analysis of nativeness across the region is presented in Section 3, as well as an assessment of changes in species occupancy over time for the Yarra catchment only. The Yarra catchment was the most data rich where all sub-catchment had been sampled. Issues of data storage were raised in this section.
2 – To what extent has progress been made towards the longer-term environmental condition targets for rivers, wetlands and estuaries?	2a. What environmental conditions (e.g. Water quality) and external conditions (e.g. policy) help explain current key value trends?	This question could not be evaluated for fish at this time due to data availability. This question is partially answered as part of the values synthesis and reported in the Science Inquiry Report (Melbourne Water, 2023a).
	2b. To what extent have projected known and emerging future threats changed from 2018? Have any assumptions about impacts to key values changed?	Evaluation of threats is outlined in the Threats technical paper (Melbourne Water, 2023b).

4 -To what extent have the delivery methods of the Strategy been appropriate, effective, and efficient?	4a. To what extent are interventions appropriate and effective for achieving outcomes?	Section 3. provides an overview of interventions relevant to fish management including where intervention monitoring is underway. Evaluation of interventions will be presented in the Interventions Technical Report (Melbourne Water, 2023c).
	4b. What are the key remaining knowledge gaps that need to be addressed in the next 5 years to improve strategy delivery or prepare for the next HWS?	This question is not evaluated for fish. Identification of remaining knowledge gaps is presented in Part F of the Science Inquiry Report (Melbourne Water, 2023a).
	4c. How can collaborative governance enable effective and efficient delivery of the Strategy?	This will be answered through the Implementation Inquiry (Melbourne Water, *in prep*).

Recommendations made within this document will relate to the delivery of the HWS and the attainment of targets across the time frame. They will be based on whether there is sufficient evidence to suggest an area of concern that would benefit from a near-term response. The following recommendations are for consideration in the development of the Science Inquiry Report:

- Explore the potential to extend fish species occupancy models to other major catchments and systems (e.g. Westernport catchment). This would be particularly important for assessing the lowland migratory species, such as Australian grayling, for which river catchment scale occupancy trends are more difficult to detect than regional scale trends.
- A base level of fish monitoring be prioritised to improve the veracity estimates in the future. This is because years with missing survey data impact significantly on the sensitivity of the fish occupancy models and confidence in the model estimates, reducing the dataset's utility.
- Fish data analysis should be extended beyond the fish occupancy models presented so that we can investigate how conditions and threats explain the observed patterns.
- The development of a coordinated data management plan for fish that details the inclusion of individual length, weight, fishing effort, fishing method, how data will be stored and maintained, data QA/QC, data sharing between agencies etc. Such data would provide a critical resource for catchment managers trying to monitor the health of populations through time.
- Environmental flow plans should consider likely consequences to native fish species, and interactions between native and exotic species (meta-community perspective) – e.g. impact of introduced species on native species.
- Continue to invest in in-stream barrier removal and fishways. Evidence suggests that fishways are an effective management lever to support migratory species when they are well maintained and functioning.
- Investigate opportunities for a more pro-active approach to fish habitat restoration and if new performance objectives in priority locations should be considered.

1. Overview of fish as a value

Fish play an important role in waterways; they are usually near the top of the aquatic food chain and also provide food for people and some birds. Their key value recognition is also due to species such as Macquarie perch, Murray cod and river blackfish being highly valued for their recreational value by the fishing community.

We have conducted a very limited evaluation of our relevant fish data and interventions for the purpose of the HWS mid-term evaluation. The extent of our evaluation was constrained by limited data availability:

- the eDNA baselining process is still incomplete and the suitability (e.g. limitations) of this data source is still to be realised for investigating trends in fish distribution change.
- access to fish abundance, health and distribution data, from catch surveys, was hindered by poor data management and large spatial and temporal gaps in the data.

Long-term fish monitoring, evaluation and reporting

A surveillance monitoring program (Melbourne Water Fish Surveillance Monitoring Plan) now exists (Melbourne Water, 2021) to fulfil the following objectives as outlined in the Rivers Monitoring and Evaluation Plan (Rivers MEP, 2020):

- Assess progress towards the HWS targets at the sub-catchment and catchment scale,
- Regularly assess/report the status of fish populations at priority locations,
- Develop a better understanding of fish health at key locations by targeting particular species and key questions.

The primary focus of the Melbourne Water Fish Surveillance Monitoring Plan is to capture information on fish population health for fifteen priority fish species. Information on the broader geographic distribution of fish species in the Melbourne region, including changes to their distribution as a result of external pressures and intervention works, is gained as part of the environmental DNA (eDNA) monitoring program (Tingley, Wu, & Weeks, 2020). Combined information gained from the eDNA and population health monitoring will help generate metrics that aid in the evaluation of the long-term targets outlined in the HWS.

Fish models and target setting

To set targets for fish, the relationship between important characteristics of fish (e.g. abundance and distribution) and the conditions that support them need to be documented. Our understanding of conditions and/or threats that shape important characteristics of fish was captured in a conceptual model for fish (Figure 1) and a quantitative ecological model known as a habitat suitability model (HSM) for fish.

For further information on the HSMs for fish see the HWS Resource document (Melbourne Water, 2020).

Conceptual models

The conceptual model provided a communication tool for the community and agencies to understand what conditions support fish and which management levers are most applicable to drive long-term outcomes for fish (Figure 1). It was also used to support target setting for parameters not included in the HSMs but which were considered important for fish.

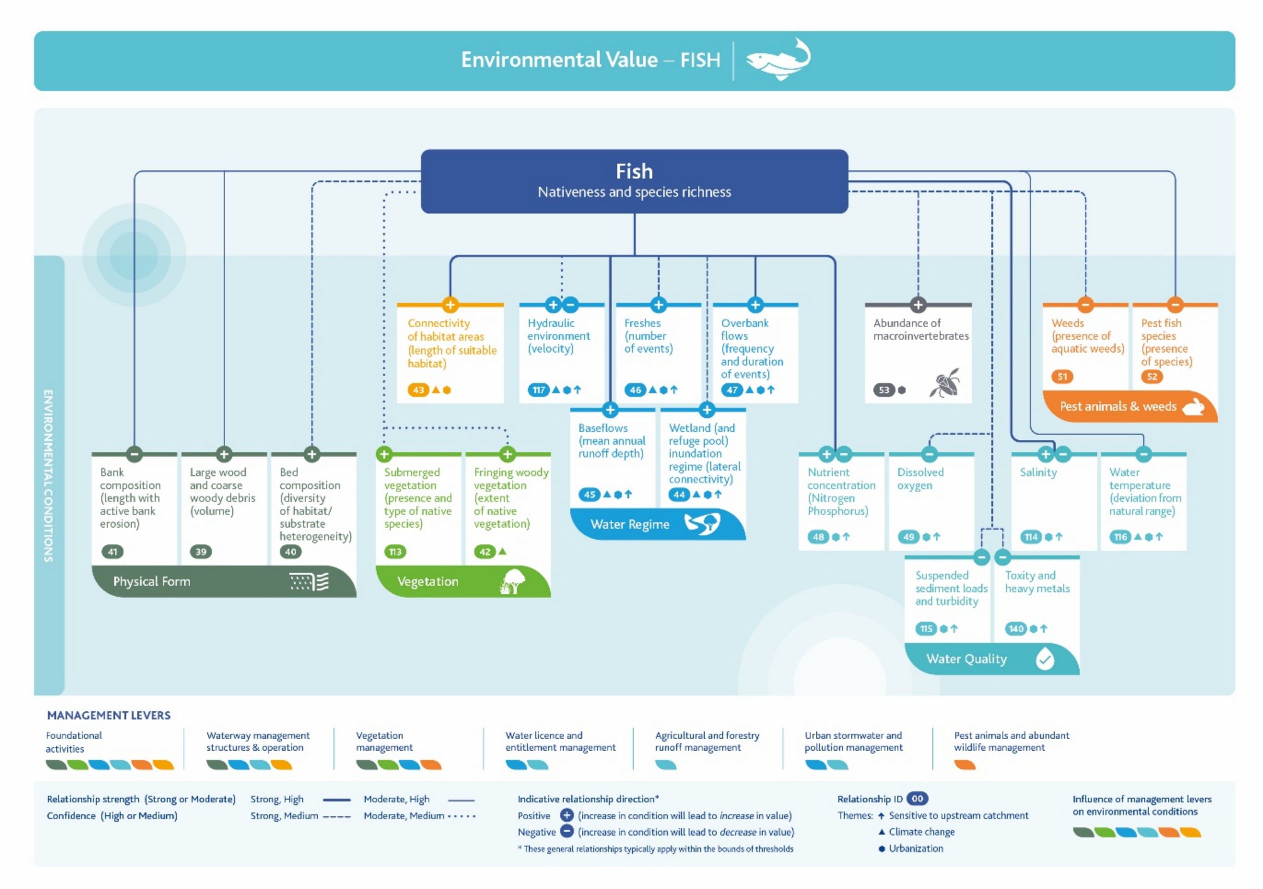

Figure 1. Fish conceptual model highlighting the conditions included in the fish HSMs.

Habitat Suitability Models

Habitat Suitability Models were developed for the HWS in 2018 using data and environmental condition data sets similar to those used for the macroinvertebrate and platypus models. Model runs exploring current fish condition (2016), Business as Usual future in 2068 (BAUF) assuming unmitigated urban development and climate change and modelled scenarios were used to communicate with stakeholders and help to set targets. Please see the Platypus Mid-Term Evaluation Technical Report (Melbourne Water, 2023d) for an overview of the process. One key environmental condition data set unique to the fish HSMs was the inclusion of fish barriers given their criticality for migratory fish. When setting targets, some assumptions were made about which barriers were feasible to remove, even over 50 years. Typically the large barriers associated with water supply dams were not considered to be likely to be removed even over the 50 year time frame. HSMs were developed for 13 individual fish species representing a broader set of native fish species. Estuarine resident fish were not modelled.

A summary of the current (CURR) scenario and the business-as-usual-future (BAUF) Scenario is presented in Table 2.

Table 2. Summary of the current (CURR) scenario and the business-as-usual-future (BAUF) scenario.

Scenario Code	Mean annual air temperature (^{0}C)	Mean annual runoff depth (mm)	Attenuated Forest	Attenuated Imperviousness	Instream Barriers	
					Full	Partial
CURR	2016 values	2016 values	2016 values	2016 values	Barriers in place at 2016	Barriers in place at 2016
BAUF	2016 values + 1.5 ^{0}C	Equivalent to a 25% reduction in the long term mean value at the mouth of the Yarra River*	2016 values	Values reflecting attenuated imperviousness when all parcels within the MW region with 'urban' planning scheme zone codes have been developed to their full capacity	Barriers in place at 2016	Barriers in place at 2016

A number of native fish species are predicted to have greater amounts of suitable habitat under BAUF conditions that are warmer, drier and include urban expansion. An important caveat is that while greater extents of waterways are predicted to be suitable habitat for these species, they may not take up the use of those waterways. The predicted expansion in the range of some fish was largely driven by warmer temperatures, which increased their range of suitable habitat. Actual changes will depend on population processes such as births, deaths and migration and these population processes are not accounted for in the Habitat Suitability Models.

The more common and widespread species (those with a broader tolerance to environmental conditions) increased their range under the BAUF scenario. This resulted in higher richness scores for some sub-catchments, which was at the detriment of the less tolerant native species (e.g. River Blackfish were predicted to decline under BAUF). These results were used with an understanding of the species driving the score.

Targets and performance objectives

Please refer to the HWS Technical Resource Document (Melbourne Water, 2020) for a general outline of the target setting process using HSMs and Zonation.

In the HWS 2013, fish status was determined using a combined score of observed over expected and nativeness. Due to the difficulty in developing the expected species list at a fine spatial scale, it was decided that a simpler native fish richness indicator would be preferable for the HWS 2018 (Melbourne Water, 2020). This index can also be readily generated from the outputs of the HSMs. The sum of species occupancy probabilities at a site can reflect the expected number of species present, and hence is a good estimator of species richness. Table 3 outlines the ratings used for setting targets in the HWS.

Table 3. Fish status metric derived from the HSMs. Occupancy probability for each species is a number ranging from 0 to 1.

Rating	Description	Sum of species occupancy probabilities
Very High	All or almost all native freshwater species recorded in the catchment likely to be present	> 4
High	Most native freshwater species recorded in the catchment likely to be present	3 – 4
Moderate	About half the native freshwater species recorded in the catchment likely to be present	2 – 3
Low	Few freshwater native species recorded in the catchment likely to be present	1-2
Very low	Very few or no native freshwater species recorded in the catchment likely to be present	< 1

Table 4. Key high risk assumptions made in setting the long term targets for fish.

Key assumption	**HSM Predictor variable**
It was assumed that climate change will lead to a 25% reduction in flow at the mouth of the Yarra River as this is an adequate representation of flows for other streams (see Coleman et al 2021).	Flow (mean annual runoff depth mm)
It was assumed that all new urban areas would be adequately treated i.e. there would be no increase in attenuated imperviousness, and there would be a reduction in 25% in attenuated imperviousness for existing urban areas achieved through urban renewal.	Attenuated imperviousness
It was assumed that a 20 m vegetated buffer either side of all priority reaches outside the UGB is achievable in the long term. It was assumed that a 10 m vegetated buffer is feasible to priority reaches within the UGB. It was assumed that mature trees would naturally fall into the water providing large woody habitat and that this wood would largely not be removed.	Attenuated forest cover
It was assumed that fish barrier height was a reasonable proxy for cost. Costs estimates were used to determine the cost benefit of fish barrier removal.	

2. Summary of current management actions and progress

The short-term (one to ten-year) quantitative steps by which long term targets can be achieved are described in the HWS by performance objectives. Performance objectives provide short-term, tangible outcomes which indicate progress towards longer-term outcomes (i.e. change in condition or in key value).

This section provides a summary of the performance objectives that directly relate to protecting or improving fish across the 69 sub-catchments of the region. Progress towards other performance objectives, likely to also protect fish, such as, managing agricultural runoff and protecting physical form can be found on the HWS website report card (https://healthywaterways.com.au).

The main sub-catchment performance objectives (SCPOs) which are assumed to benefit fish are listed in Table 5. The progress toward achieving these performance objectives, summarised to catchment scale, is summarised in Table 6.

Table 5. Main sub-catchment performance objectives (SCPOs) which will benefit fish.

SCPO group	SCPO theme/s	*Examples* of SCPOs covered in this Rivers MEP	Related Regional Performance objectives
Vegetation	As per platypus paper		
Water for the environment	As per platypus paper		RPO-11 Understanding of groundwater dependent ecosystems is improved and opportunities to maintain or improve these continue to be investigated.
Stormwater	As per platypus paper		
Habitat	Improve fish passage	Increase instream connectivity provide fish passage along the Lang Lang River from the mouth to the headwaters by removing barriers at Heads Rd and Western Port Rd.	RPO-18 Critical waterway health assets including stormwater treatment systems, fishways and erosion control structures, are maintained for their designed purpose or the same outcomes are delivered by alternative means.
Pests	n/a	n/a	RPO-31 A risk-based approach is adopted to prevent, eradicate and contain pest plants and animals (including deer) and protect waterway assets.

Table 6. High-level summary of progress toward achieving catchment scale performance objectives that directly and indirectly relate to fish. Sub-catchment performance objectives are grouped by as relating to vegetation (riparian buffer establishment and protection/maintenance of vegetation quality), stormwater (harvest and infiltration), water for the environment in regulated systems and habitat connectivity (fish barrier removal). Where available, the 2028 target is stated along with the progress (on-track (green shading), slightly off-track (orange shading) or off-track (red shading)) toward achieving this target as of 2021.

Catchment	HWS 2018 fish status baseline	BAU trajectory	HWS 2068 fish status target	Vegetation				Stormwater					Water for the Environment		Habitat	
				Riparian buffer (ha)		Protect/maintain vegetation quality (ha/year)		Stormwater –harvest (ML)		Stormwater – infiltration (ML)		Storm water from new development (ML)	Water recovery target (GL) – regulated systems		Fish barriers removed (#)	
				2028 Target	2021 Progress	2028 Target	2021 Progress	2028 Target	2021 Progress	2028 Target	2021 Progress		2028 Target	2028 Progress	2028 target	2028 Progress
Werribee																
Werribee River catchment	Low	Low	Moderate	1755	227	2683	3301	2166	543 (240 actual)	383	0	1593	7	1.1 Entitlement delivery	16	2
Maribyrnong																
Maribyrnong catchment	Low	Low	Moderate	1622	278	1185	164	1271	1045 (21 actual)	311	0	507	5	0 no entitlement	2	2
Yarra																
Yarra catchment	Low	Moderate	High	1500	307	7171	5424	7297	2181 (118 actual)	1914	16	2074	10	0 Entitlement delivery	6	2
Dandenong																
Dandenong catchment	Low	Moderate	Moderate	157	85	330	586	Treat existing	planned	Treat existing	planned	NA	NA	NA	1	1
Westernport																
Westernport catchment	Low	High	High	2849	318	3108	1626	1970	267	713	2	1069	1	0	2	1

As mentioned in the target setting section, it was assumed that mature trees would naturally fall into the water providing large woody habitat and that this wood would largely not be removed. As a result there are no specific performance objectives to actively re-introduce wood back into streams. However, in 2019, DELWP set up a memorandum of understanding between Vic Roads, Melbourne Water and the Port Phillip and Westernport Catchment Management Authority to collaborate on LWD re-introduction using trees being felled for road projects. To date there has not been many (if any) re-introduction projects in our region, and this is partly due to a lack of coordination of opportunities as they arise.

Another example of an opportunistic approach to physical habitat enhancement for fish is a recent project to deploy 32 fish hotels at 8 locations on the Maribyrnong River (https://www.melbournewater.com.au/building-and-works/projects/maribyrnong-river-native-fish-revival-project). The project has been a partnership between multiple agencies and organisation and seeks to restore habitat in an areas of the lower Maribyrnong where habitat has been impacted by the removal of instream woody habitat.

It is worth reconsidering whether a more pro-active approach for fish habitat restoration would be beneficial and if new performance objectives in priority locations should be considered.

3. Evaluation questions and approach

We have conducted a limited evaluation of our relevant fish data and interventions for the purpose of the mid-term review. The extent of our evaluation was constrained by limited data availability:

- new data on works-to-date (revegetation extent, fish way removal, stormwater control) required for the updated Habitat Suitability Models was not available,
- the eDNA baselining process is still incomplete and the suitability (e.g. limitations) of this data source is still to be realised for investigating trends in fish distribution change, and
- access to fish abundance, health and distribution data, from catch surveys, was hindered by poor data management and large spatial and temporal gaps in the data.

The above data was essential for answering KEQ 3a and KEQ 2a, which is why it is not included in this report.

The following section outlines the approach to evaluation of KEQ 3b. and KEQ4a.

NOTE: KEQ 3a was answered as part of the values synthesis work undertaken after this report was finalised. The criteria used to evaluate KEQ 3a for fish is available in the Synthesis Methods Document (Melbourne Water, 2023e) and the results are presented in the Science Inquiry Report (Melbourne Water, 2023a).

KEQ 3b What other spatial and temporal trends and patterns for key values are of significance for implementation?

Evaluation methodology

Melbourne Water contracted Jacobs (Dr James Shelley) to undertake an analysis of collated historical fish data to investigate a) how species richness and nativeness have changed over time at the sub-catchment and catchment scale and b) whether there is any evidence of range expansions or contractions over time using all data.

Additional questions about changes in fish population health and determining likely causes of changes in species richness over time were discussed but, on further investigation of the dataset, it was determined that this was not possible due to a) limited length and weight data and b) the lack of time to adequately investigate covariate analysis to correlate potential causes of temporal range changes.

Despite the data range extending from 1900-2022, it was found that data gathered since the early 1970's was the most useful for inter-annual analysis as surveys of the region became regular and more widespread across catchments from that time.

The information presented in this KEQ is largely the results of the Jacobs analysis for the Yarra catchment, although we present nativeness results for all major catchments. The Yarra catchment had the longest and most consistent annual survey record from 1973 to 2022, and the largest mean number of sites sampled in each year, which were fairly well spread across the sub-catchments.

Nativeness

Species were assigned as being either native or exotic so that the proportion of native versus exotic species could be explored within catchments, between years. As the number of sites surveyed in some years were very low, proportional results could be misleading. For instance, if only two sites were sampled in the Yarra River in 1960 and only native species were found, it would appear that the whole fish community was made up of native species when in reality this is likely an artefact of low replication. To account for this, we filtered out years where there were less than five sites were surveyed within a catchment.

At the sub-catchment level, there was little or no replication of surveys within years. Furthermore, many years had missing data, leading to a very inconsistent record over time. As such, we conducted our analysis at the catchment level only.

Temporal trends in occupancy estimates

Site-occupancy models detection/non-detection data are commonly called 'presence/ absence data', although in reality, these data come from two nested, stochastic processes, one determining the true state of the site (present/absent) and the other governing the observation of the site state (detected/not detected). The first process generates the true distribution of a species for which two possible states exist for each site (present/absent). However, the result of this process is not what we actually observe. Inevitably, a species may be undetected at a site even when it is present, thus the detection probability is less than one.

Without extra data, conventional species distribution models cannot tease apart true occurrence from the detection probability. The extra information required to partition detection/non-detection data into these two components (true occurrence and detection) comes from repeat surveys at some or all sites. The pattern of detection and non-detection in temporal replicates provides information about detection probability that allows an estimate of true occurrence, accounting for imperfect detection.

Site occupancy models were used to analyse the available dataset for the Yarra River catchment only. Repeat surveys at a given site were not available for most years. To overcome this, to calculate the detection probability parameter of the occupancy models, we grouped the data into 3-year time periods, where each year represented a replicate. Not all rivers were surveyed each year, but occupancy models are robust to missing dependent data (Mackenzie et al. 2006).

We converted species catch data into a presence (detection) and absence (non-detection) matrix for six priority species outlined in the Rivers Monitoring and Evaluation Plan (Rivers MEP) (Melbourne Water, 2020) and a further three species that were added out of general interest:

Species	
River blackfish (*Gadopsis marmoratus*)	Native obligate freshwater species
Ornate galaxias (*Galaxias ornatus*)	Native obligate freshwater species
Southern pygmy perch (*Nannoperca australis*)	Native obligate freshwater species
Common galaxias (*Galaxias maculatus*)	Native migratory freshwater species
Short-finned eel (*Anguilla australis*)	Native migratory species
Tupong (*Pseudaphritis urvillii*)	Native migratory species
Pouched lamprey (*Geotria australis*)	Native migratory species (not a priority species in Rivers MEP)
Oriental weatherloach (*Misgurnus anguillicaudatus*)	Exotic (not a priority species in Rivers MEP)
Eastern gambusia (*Gambusia holbrooki*)	Exotic (not a priority species in Rivers MEP)

A single systematic sampling program has not been conducted over the entire study period within the region, and occupancy data came from a wide range of targeted and non-targeted sampling efforts using various methods (but mainly backpack electrofisher). As such, the data was spatially and temporally variable. To deal with this, we aggregated sites by the major sub-catchment they fell into (e.g. Merri Creek sub-catchment). Presence for a given sample year and site was indicated if a species was encountered anywhere within that sub-catchment. We used detection histories for 18 sites (sub-catchments) for the 1973–2022 period to model occupancy dynamics in the Yarra River catchment. We did not include data for years between 1976 and 1983 as few surveys were conducted then, but the dataset otherwise included consistent annual records.

Suitable data existed for each of the priority species outlined in the Rivers MEP that predominantly reside in freshwater habitat. However, there were too few observations of Yarra pygmy perch (*Nannoperca obscura*) and Short-headed lamprey (*Mordacia mordax)* to run the analysis and Australian grayling (*Prototroctes maraena*) were only recorded at one 'site', the Yarra River mainstem, limiting the utility of the analysis in this instance. Furthermore, there were very few observations of the estuarine species, Estuary perch (*Macquaria colonorum*), Black bream (Acanthopagrus butcheri), Pale mangrove goby (*Mugilogobius platynotus*), and Glass goby (*Gobiopterus semivestitus*) to run the occupancy models. For instance, they have not been detected in the last decade. While these species may migrate in and out of the lower reaches of river systems, they are predominantly found in estuarine habitat where there is a general lack of sampling effort.

We created multi-season occupancy models and ran competing models (16 in total) with different parameterizations to estimate occupancy, invasion, and extinction of target species within the Yarra River catchment, following (MacKenzie, Nicols, Hines, & Knuston, 2003). We then assessed the weight of evidence that (1) occupancy was constant or varied among time periods, (2) probability of detection was constant or varied among years, and (3) probability of extinction and invasion were either constant or varied between time periods. In this way, we tested for differences in occupancy among time periods, detectability among time periods, and differences in invasion and extinction rates among time periods.

For this analysis, occupancy refers to a point in time that was a 3-year time period (as discussed above). Model construction focused on our main objective, which was to test the null hypothesis that occupancy did not vary between time periods.

Evaluation results and discussion

Nativeness

History of exotic fish introductions

The fish database provides a historic overview of exotic fish invasions in the region. As the introduction of exotic species constitutes a significant change in the fish community structure and function, we summarise the timeline of these invasions in Figure 2. Years in which exotic fish species were first detected in the Melbourne Region.Figure 2. The first three exotic species detected in the region were Brown trout (*Salmo trutta*), Redfin perch (*Perca fluviatilis*), and Tench (*Tinca tinca*). Each of these species are European sports fish that were purposefully stocked by Europeans in southeastern Australia during the mid to late 1800s. Goldfish, a popular aquarium fish, were the next exotic species to appear in 1950, likely being released from aquaria or escaping from ponds. European carp (Cyprinus carpio) were first detected in the MW management region in 1968. The species was introduced to dams and reservoirs across Victoria, from the mid-1800s, but significant increases in their range were observed from the 1960s, which is consistent with this observation. Roach (*Rutilus rutilus*) were stocked in Australian waters, again in the mid-1800s, but appear to have invaded the Melbourne region much later, being first detected in 1969. Eastern gambusia (*Gambusia holbrooki*) were the next to appear in 1973. The species was first introduced to NSW from the USA in 1920 for the purpose of mosquito control and it has since spread across most of Australia. Oriental weatherloach (*Misgurndus anguillicaudatus*) were first detected in 1980 in the ACT, and then in the Yarra River in 1983. It is likely that they were released from aquaria. Yellowfin goby (*Acanthogobius flavimanus*) were the most recent arrival, being first detected in the Yarra, Werribee, and Maribyrnong river catchments in 1991. It suspected that the species was accidently released in Australia, from Asia, in ballast water, and was originally detected in NSW in the 1970s.

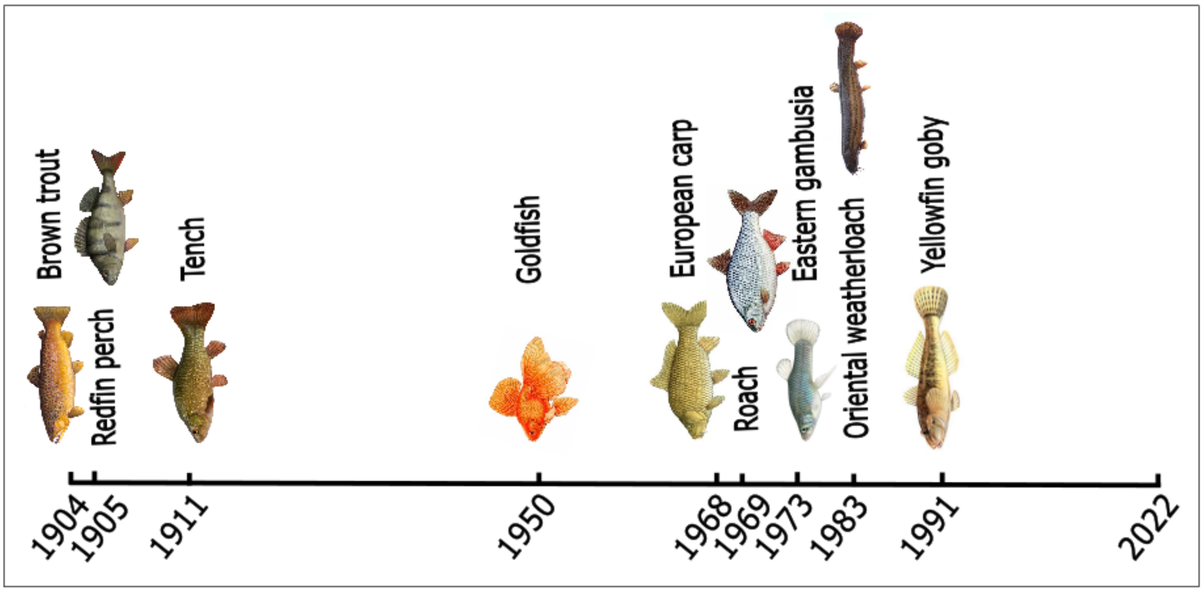

Figure 2. Years in which exotic fish species were first detected in the Melbourne Region.

Nativeness scores through time

Broad sampling (more than five sites) of the Werribee River catchment began in 1979 (Figure 3). The proportion of exotic species made up more than half of the sampled fish community in six individual years but a lack of broad sampling in the catchment over the last decade has meant that recent conditions could not be assessed.

Only years where more than five sites were sampled within the catchment as this was considered minimum sampling coverage needed for interpretable results.

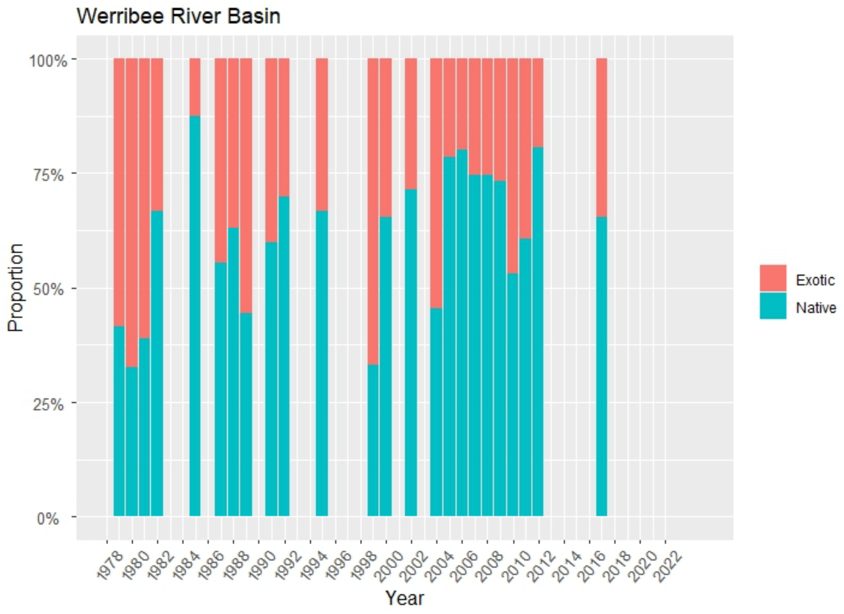

Figure 3. Proportion of native and exotic species, based on species richness, found in the Werribee River by year.

Broad sampling of the Maribyrnong River catchment began in 1968. There was a higher proportion of exotic species than native ones in only one year, 1969 (Figure 4). A lack of broad sampling in the catchment over the last seven years has meant that recent conditions could not be assessed.

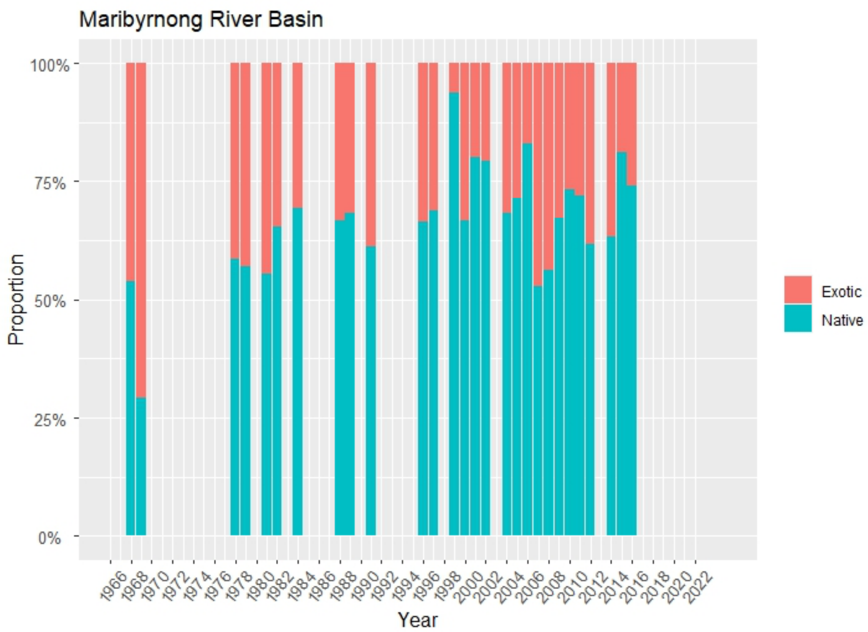

Figure 4. Proportion of native and exotic species, based on species richness, found in the Maribyrnong River by year.

Some broad sampling of the Yarra River catchment occurred in the early 1900s, but regular annual sampling began in 1964. Apart from 1910 and 1911 where greater than or equal to 50% of the sampled fish community was made up of exotic species, native species clearly dominated the community up until 1975, after which exotic species made up a notably larger proportion for a period of time (Figure 5).

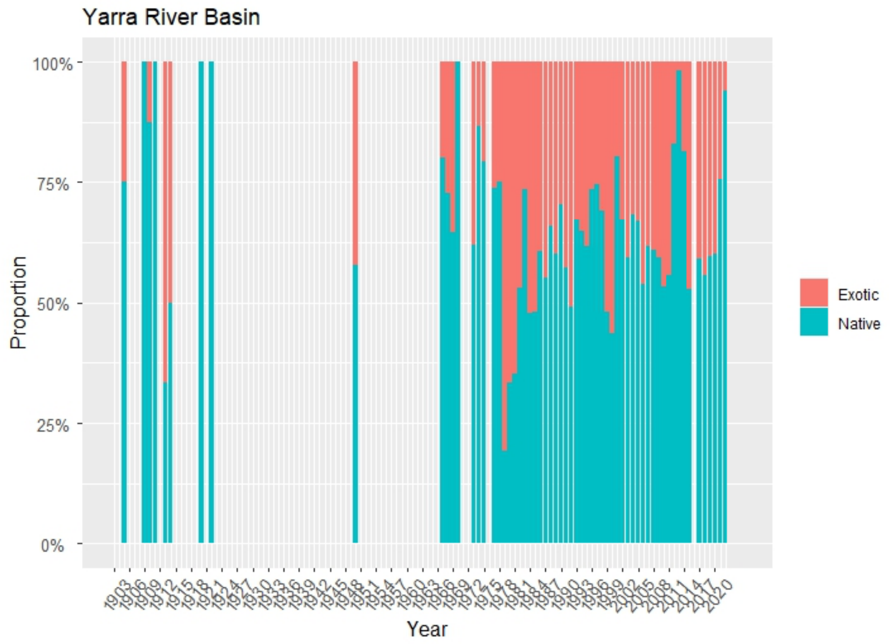

Figure 5. Proportion of native and exotic species, based on species richness, found in the Yarra River by year.

Broad sampling of the Dandenong Creek catchment began in 1982 but has been intermittent. There has typically been a high proportion of exotic species, with more than half of the community being made up of exotic species in nine of the 16 years for which there was data (Figure 6). A lack of broad sampling in the catchment over the last decade has meant that recent nativeness values could not be assessed. Broadly speaking, the Dandenong Creek fish community appears to have a higher proportion of exotic species than other catchments in the region.

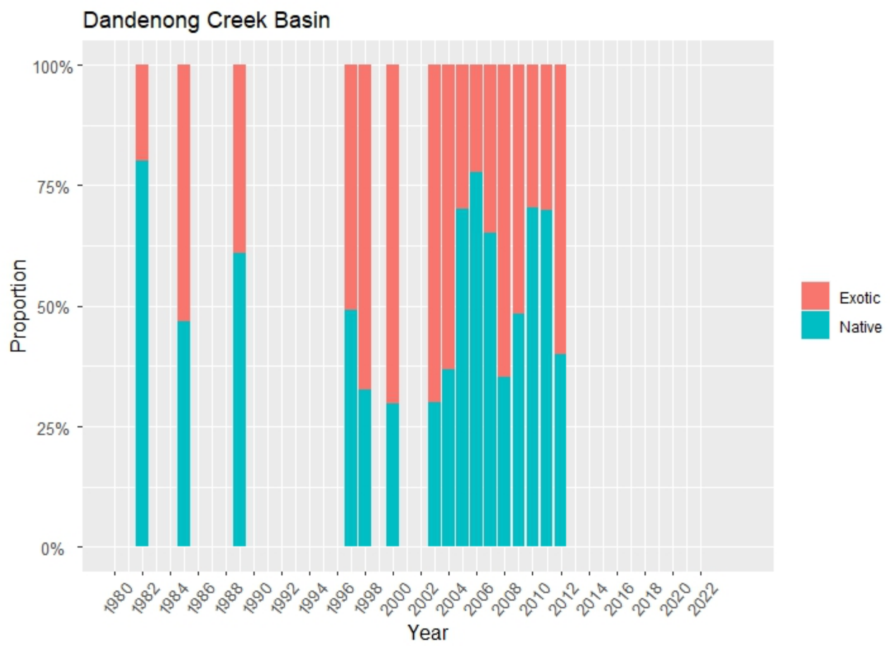

Figure 6. Proportion of native and exotic species, based on species richness, found the Dandenong Creek by year.

Broad sampling of the Western Port catchment began in 1964, but more regular annual sampling (of 5 or more sites) began in 1973. There was a higher proportion of exotic species than native ones recorded in only one year, 1980 (Figure 7). The Western Port catchment has consistently had the lowest proportion of exotic fish species in the community of any of the catchments in the region.

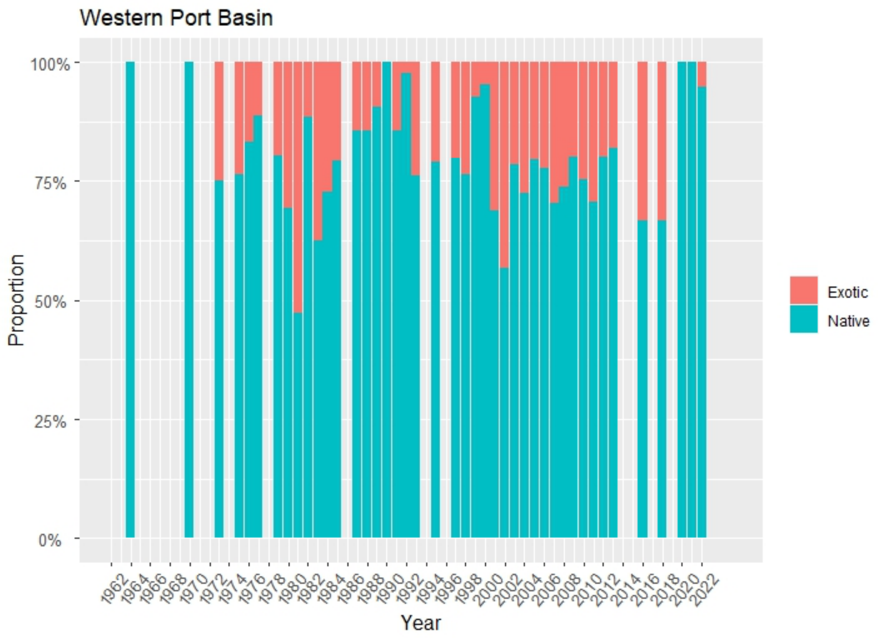

Figure 7. Proportion of native and exotic species, based on species richness, found in the Westernport catchment by year.

Summary of findings

- Exotic species have had a long history in the Melbourne region, with a number of European sports fishes being present from at least the early 1900s.
- Most of the current exotic fauna were in place by 1983, around the time that regular fish monitoring started in most Melbourne region catchments.
- As fish community data availability before the exotic fish introductions is rare, it is difficult to identify changes before and after the introductions based on species richness metrics.
- There is no apparent decline in the proportion of native species, at the river catchment scale, over the study period within the limitations of the available data.
- Nativeness scores were the lowest on average in the Dandenong Creek catchment and highest in the Western Port catchment.

Temporal trends in occupancy estimates in the Yarra River catchment

Based on presence/absence data collected across the Yarra River catchment, we fitted multi-season occupancy models to nine species. We discuss the results of models that best fit the data here.

Native obligate freshwater species

Southern Pygmy Perch

Of the native obligate freshwater species, Southern pygmy perch exhibited the steepest decline in occupancy relative to their historic distribution: Figure 8 shows linear decrease in occupancy between the earliest and latest time periods (95 % $CI_{\phi 1973\text{-}1975}$ = 0.70 ± 0.42–0.98; 95 % $CI_{\phi 2020\text{-}2022}$ = 0.45 ± 0.17–0.72), marking a 36% decrease in mean occupancy estimates.

The decline in occupancy is in part calculated from the number and frequency of detections across the river catchment, but the species does appear to have disappeared from Darebin and Merri Creek where it hasn't been observed since 1987 and 1988 respectively. This would contribute significantly to this result. Estimated occupancy in the Yarra catchment is now below 50%.

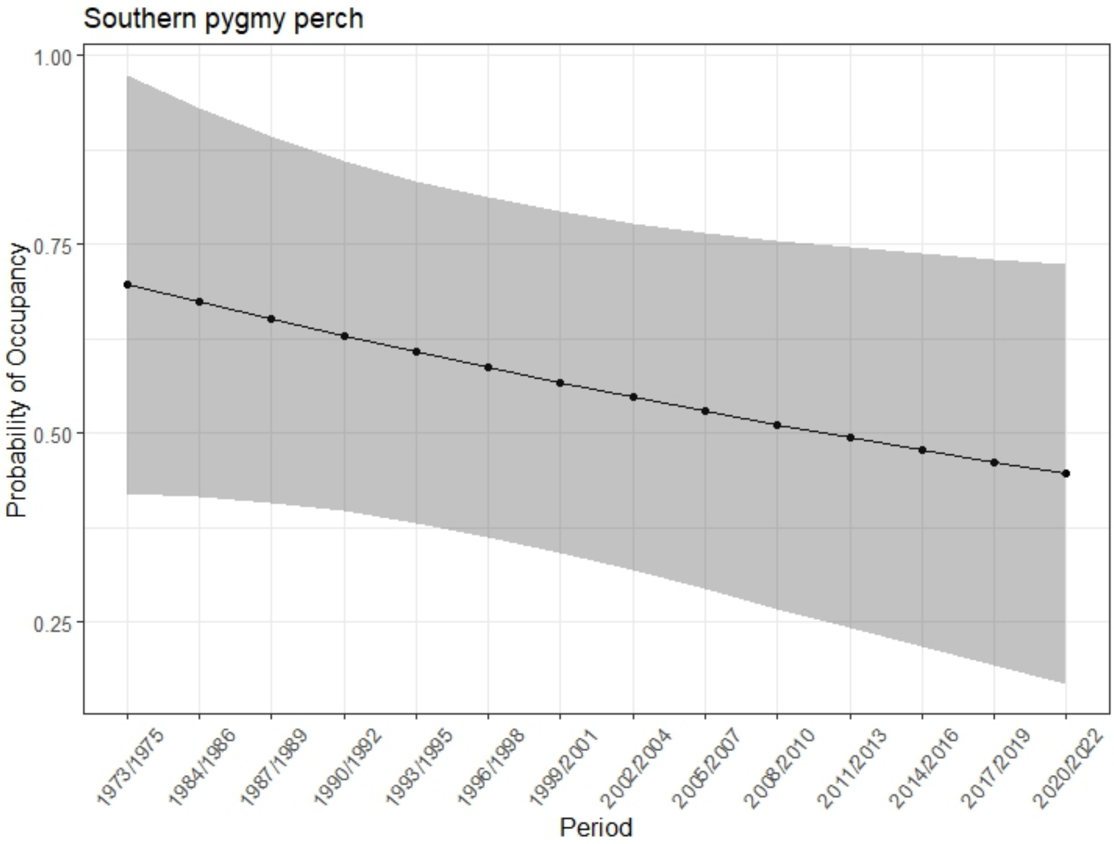

Figure 8. Model-averaged estimates of annual probability of site occupancy for Southern Pygmy Perch.

River blackfish

The results of the River blackfish model indicate a consistent pattern of decline in the probability of site occupancy through time (Figure 9). Along with various changes in the frequency of detection across the catchment, the species has not been detected in Plenty River or Merri Creek since 2007 and 2009 respectively, which would help drive this pattern. The results suggest that the rate of River blackfish occupancy in the Yarra River catchment has fallen below 50%.

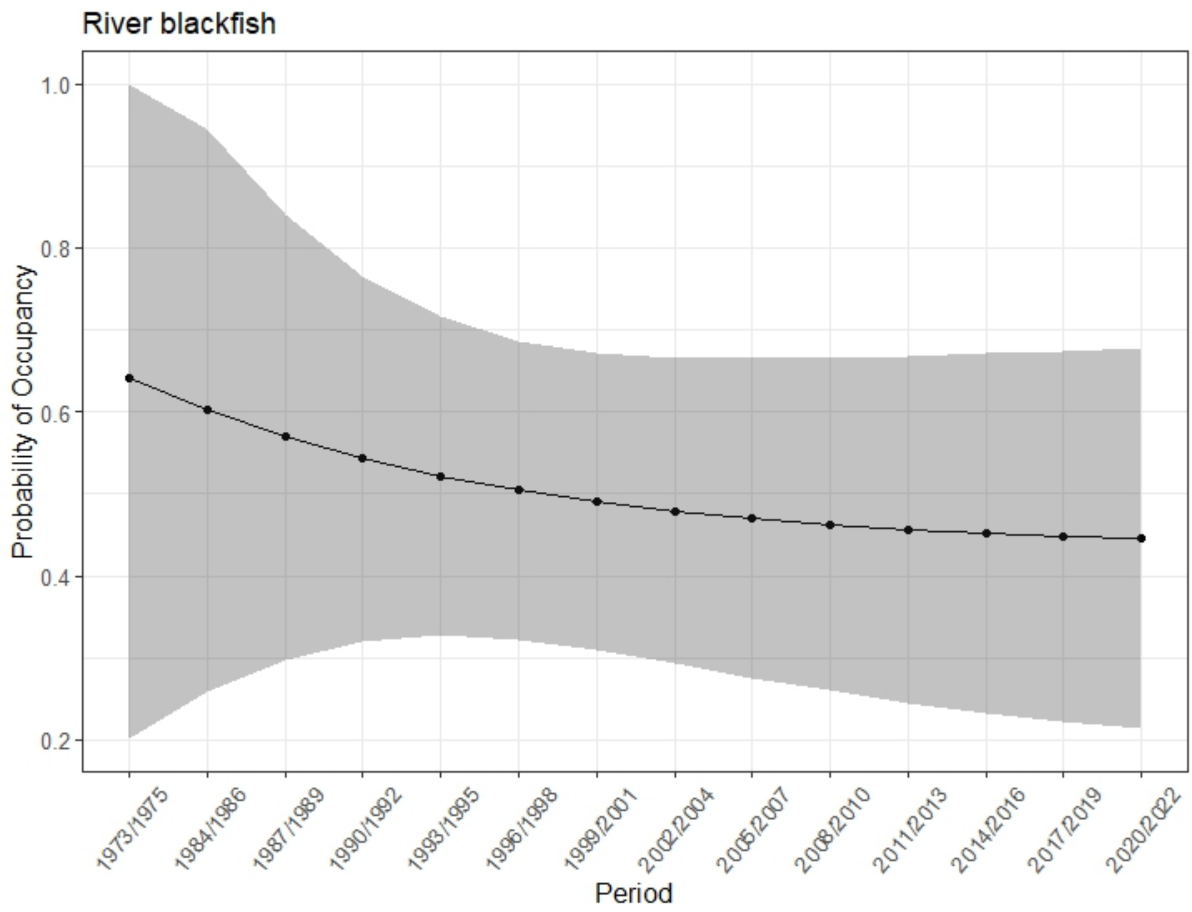

Figure 9. Model-averaged estimates of annual probability of site occupancy for River blackfish.

Ornate galaxias

Models suggest that site occupancy across the Yarra catchment has not changed significantly through time and no trend in either direction was observed.

While no change was detected in Ornate galaxias occupancy, the species has likely experience significant range contractions prior the study period. The species is part of southeast Australia's Mountain galaxias complex, which is known to be highly susceptible to trout predation. Most species within the complex cannot co-exist with trout and only exist in small remnant populations in trout-free refuges (Raadik 2014). Given that Brown trout were introduced in the early 1900s, it seems likely that the declines in range of Ornate galaxias have already occurred and the remaining populations persist in refuges where they are protected from direct trout predation. They have thus found equilibrium for now. The results suggest that the rate of occupancy for Ornate galaxias in the Yarra River catchment is a little over 50%.

Migratory species

Common galaxias

Common galaxias were the only species where occupancy estimates didn't follow a set trend through time (Figure 10). Rather, there were two statistically significant increases between consecutive time periods, and one significant decrease. While we did not attempt to incorporate environmental variables into our analysis to help explain these patterns, such a dramatic increase in occupancy across the catchment would suggest something had changed in a short period of time that made a large amount of habitat available to the species that previously was not.

Common galaxias are an amphidromous species where adults migrate downstream to lay eggs high up on riverbanks, amongst vegetation, near the coast. The eggs hatch when flood waters inundate the eggs and the larvae are swept out to the marine environment where they are carried by the prevailing currents as they feed and grow. They then migrate to the closest river and travel upstream, spreading widely throughout catchments (Augspurger, 2017).

This migratory lifestyle leaves them susceptible to barriers to migration that can prevent upstream movement, but it also means they can quickly recolonise newly available habitat. For further analysis of the role of fishways in supporting the dispersal of migratory species, see KEQ 4a.

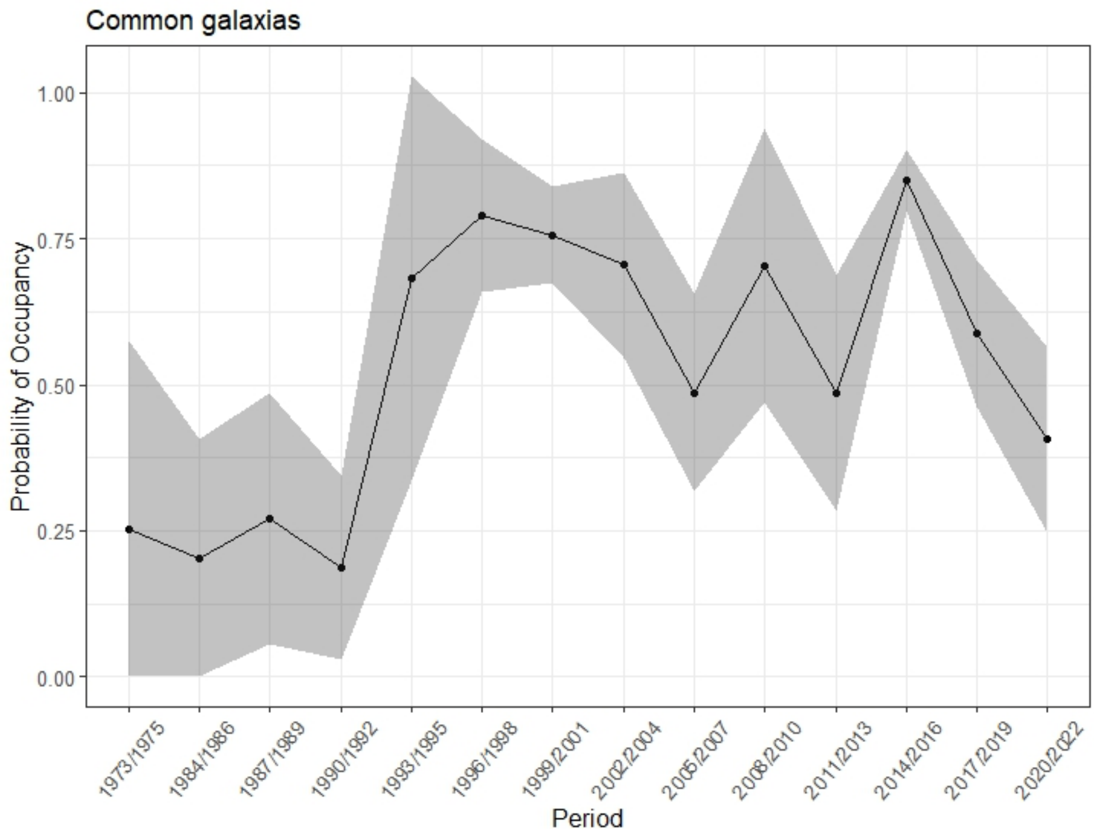

Figure 10. Model-averaged estimates of annual probability of site occupancy for common galaxias.

Short finned eels

Short-finned eel are a catadromous species where adults migrate far out to sea for spawning. The adults then die but the larvae return to their parents' home streams, during which time they develop into juveniles and migrate upstream throughout the catchment over winter and early spring (Allen et al. 2002). In this sense, they would also be subject to barriers to migration like Common galaxias. However, they also have considerable capacity to leave the water environment and navigate across land to circumvent barriers. As such, it is not expected that the Dights Falls weir in the Yarra River would have the same impact on their distribution as, for example, Common galaxias.

Short-finned eel exhibited a large, but non-significant increase in occupancy between the 1973-1975 period and the 1984-1986 period, after which they consistently occupied the entire Yarra River catchment. As there was only a single time-period where Short-finned eel did not occupy all surveyed Yarra sub-catchments, we can only speculate as to the cause of this pattern.

However, it is most likely that this pattern is a sampling artefact, with only a fraction of the Yarra River sub-catchments (all in the upper Yarra) sampled with reliable methods for detecting eels (e.g. electrofisher/rotenone) during the 1973-1975 period (10 of 18 sub-catchments). Regardless of the agent of change, the species has continued to do well since that time.

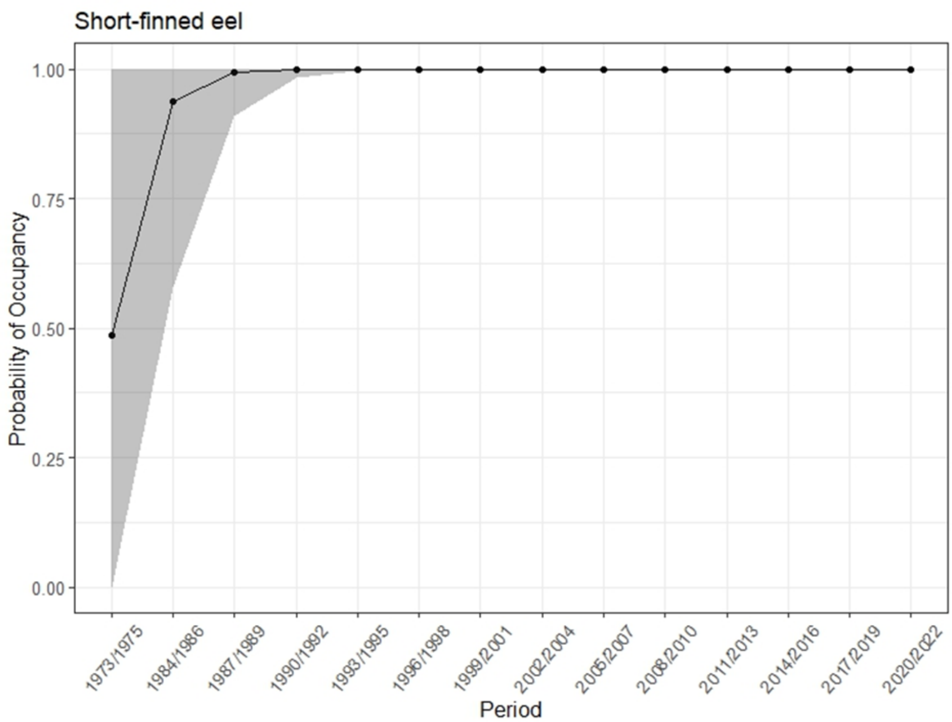

Figure 11. Model-averaged estimates of annual probability of site occupancy for short-finned eel.

Tupong

Tupong are also a catadromous species whose lifecycle broadly reflects that of the Short-finned eel. However, it typically occupies estuarine environments or the lower sections of streams. Tupong populations in the Yarra River catchment are in equilibrium and occupancy has not changed significantly through time (Figure 12).

As the species typically occupies the lower parts of catchments, large increases in occupancy would be unlikely as upstream habitat is not suitable. There were no new observations of the species above

Dights Falls since the construction of the fishway, suggesting that it was not a factor driving the result. Rather, the results reflect an increase in the frequency of observations in the lower Yarra River catchment. Improvements have been made in environmental flows, water quality and habitat in the Yarra River catchment since the initial 1973-1975 time period, which could explain the improvement, but further analysis is needed to clearly distinguish any such driver.

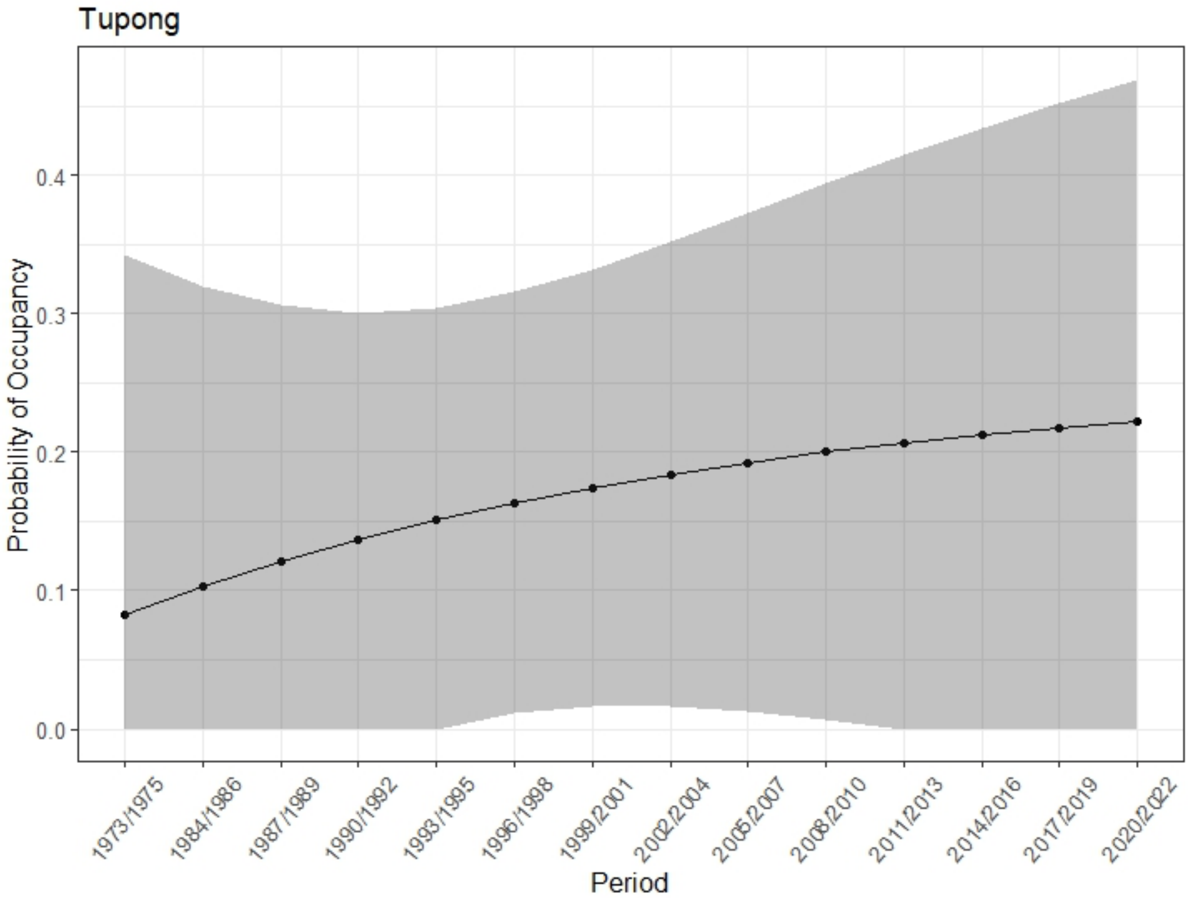

Figure 12. Model-averaged estimates of annual probability of site occupancy for tupong.

Exotic species

We analysed changes in occupancy in the two exotic species, Eastern gambusia (Figure 13) and Oriental weatherloach (Figure 14) that were introduced in 1973 and 1983 respectively. Each of these species are habitat and dietary generalists, are highly tolerant of poor water quality, and are highly fecund, producing thousands of young throughout the year. Such ecological characteristics have allowed them to rapidly invade a great diversity of habitats across Australia and more broadly around the globe (Rowe, 2008); (Lintermans, 2014). As would be expected, each species exhibited evidence of a large increase in occupancy through time in the Yarra River catchment that is beginning to taper off as the number of unoccupied catchments, which they can potentially invade, dwindles.

Eastern gambusia are an aggressive species that compete for habitat with several small-bodied native fish and damage them by nipping their fins (Rowe, 2008). They have a significant negative impact on the occurrence, abundance, and condition of Southern pygmy perch where they occur in sympatry (Macdonald, 2012). It seems likely that the dramatic increase in occupancy of the species has at least in part been responsible for the observed decline in occupancy of Southern pygmy perch in the Yarra River catchment.

The results also provide insight into the speed at which such invasions take place and emphasises the importance of early intervention (e.g. eradication efforts) when new exotic species are detected.

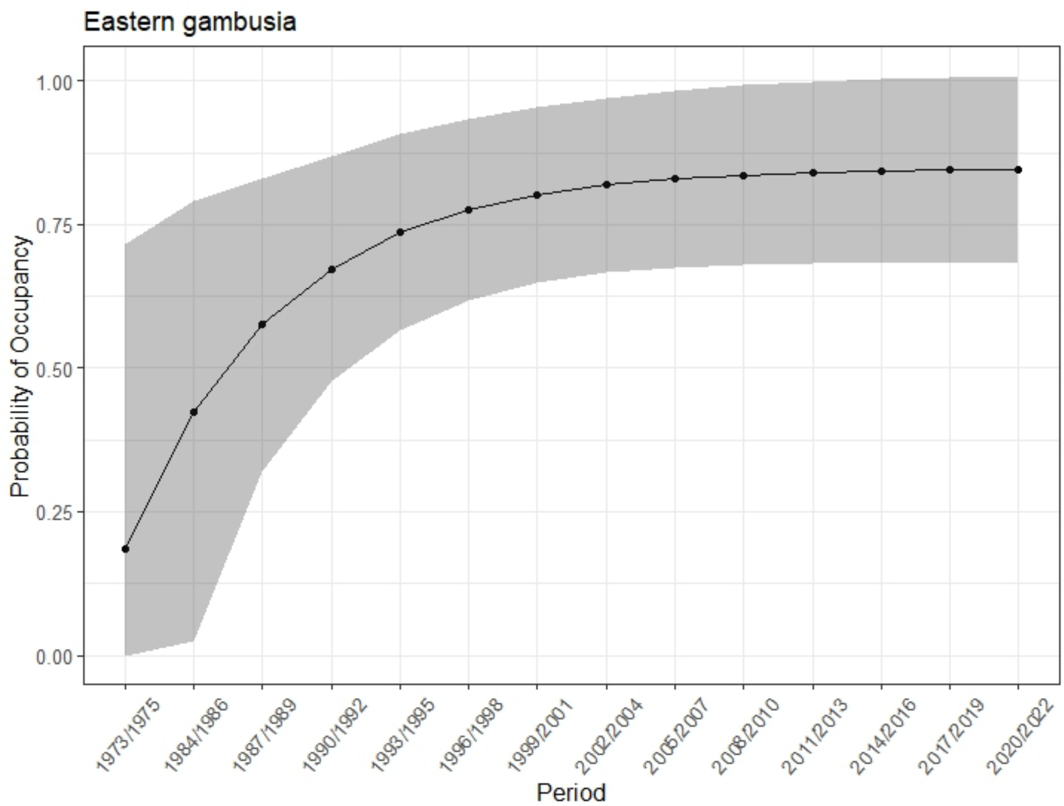

Figure 13. Model-averaged estimates of annual probability of site occupancy for Eastern gambusia.

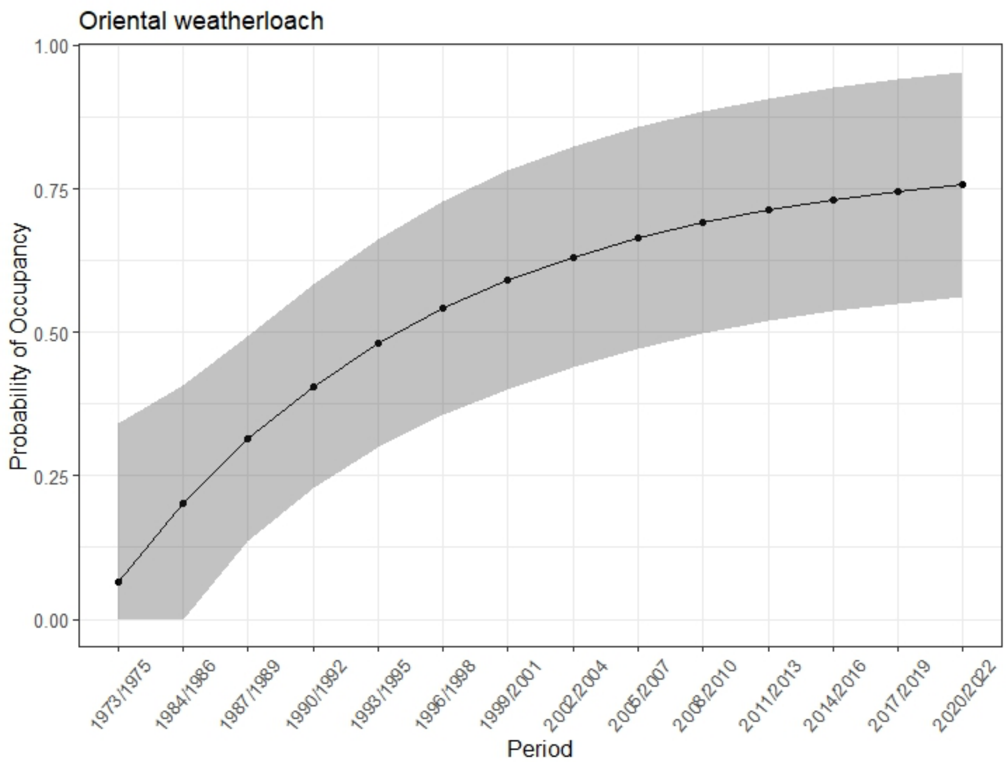

Figure 14. Model-averaged estimates of annual probability of site occupancy for Oriental weatherloach.

Summary

The observed difference in the general population trajectory of migratory and non-migratory species is reflective of national trends in the conservation status of freshwater fishes (Le Feuvre et al. 2016; Lintermans et al. 2020). Generally speaking, non-migratory species have narrower habitat and dietary niches, are less vagile, and are inherently more limited in their ability to disperse within and between river networks than migratory species (Stevens, 2013); (Le Feuvre, 2021).

Being entirely restricted to freshwater environments non-migratory species have limited capacity to avoid deteriorating environmental conditions. This often leads to the development of fragmented populations across catchments, with the isolated populations having a heightened risk of extinction due to their small size and often low genetic diversity (e.g. (Brauer, 2016)). Such patterns are observable in River blackfish, Southern pygmy perch, and Ornate galaxias, among others.

Migratory species have broad distributions across landscapes (i.e. they occupy multiple catchments), thus the risk of decline from changing environmental conditions is spread across a greater area. Furthermore, if conditions improve in a given area, they can be quick to recolonise as they often have an innate sense to swim upstream, against the flow, as returning juveniles

The positive increases in occupancy observed in some of the migratory species analysed here likely reflects improvements in river management that have been made over the last five or so decades such as improved fish passage, environmental flow regimes, and habitat restoration. It's an important and heartening result.

The potential declines observed in non-migratory species reflect the trajectory of these species elsewhere in Victoria, and elsewhere. It's important to note that they were not rapid or particularly large declines, rather reflecting a steady decline. It follows that targeted monitoring of key populations should be conducted to assess finer measures of population health and inform adaptive management.

In summary, our analysis of changes in species occupancy in the Yarra River catchment between 1973 and 2022 indicated three main trends in species range size:

1. the range size of native obligate freshwater species is in equilibrium or is contracting;
2. the range size of native migratory species is in equilibrium or is expanding; and
3. the range size of more recently introduced exotic species has been expanding but has reached or is close to reaching equilibrium.

Most of the observed trends were not considered statistically significant when applying frequentist notions of significance, owing in part to large confidence intervals around occupancy estimates. However, in these cases, the trends are consistent over almost five decades of data collection and meet a-priori expectations, suggesting that they are reflective of actual changes in species occupancy. More data would be required to reduce the observed error and produce more precise estimates, but such data is unlikely to become available for historical time periods. The dataset, as it is, is likely to only be suitable for detecting statistically significant changes when those changes are dramatic. However, expansions and declines in species occupancy are more likely to occur gradually and detecting gradual changes is still important in species management.

Recommendations

- Explore the potential to extend fish species occupancy models to other major catchments and systems (e.g. Westernport catchment). This would be particularly important for assessing the lowland migratory species, such as Australian grayling, for which catchment scale occupancy trends are more difficult to detect than regional scale trends.

- We strongly recommend that a base level of fish monitoring be prioritised to improve the veracity estimates in the future – this includes maintaining eDNA survey effort and fish health monitoring programs. This is because years with missing survey data impact significantly on the sensitivity of the fish occupancy models and confidence in the model estimates, reducing the utility of the dataset. Greater coverage of data on fish species distribution would allow us to extend occupancy modelling beyond just the Yarra River catchment to river systems in the Maribyrnong, Werribee, Dandenong, and Westernport regions. This would allow us to investigate the effectiveness of interventions, such as fishway construction and barrier removal, across the entire MW region. This would be particularly important for assessing the lowland migratory species, such as Australian grayling, for which river catchment scale occupancy trends are more difficult to detect than regional scale trends.

- We recommend that fish data analysis be extended beyond the fish occupancy models presented so that conditions and threats (e.g. environmental flow releases and exotic species presence/richness) can be explored against the observed patterns.

- We recommend the development of a coordinated data management plan for fish that details the inclusion of individual length, weight, fishing effort, fishing method, how data will be stored and maintained, data QA/QC, data sharing between agencies etc. Such data would provide a critical resource for catchment managers trying to monitor the health of populations through time.

KEQ 4a. To what extent are interventions appropriate and effective for achieving outcomes?

For the purpose of this analysis, we have focused on information related to fish specific interventions which have evidence of effectiveness.

As humans modify the landscape to the detriment of aquatic species, it is appropriate to mitigate the impact of these changes.

The creation of barriers (mostly weir creation for stream gauging and water offtake facilitation) to the upstream movement of fish is the primary human-induced disturbance that managers can directly mitigate through targeted investment. The ecological impacts caused to aquatic ecosystems from barriers include:

- Locking up areas of vital habitat for migratory fish species.
- The creation of isolated populations reduces gene flow between fish populations and alters species diversity due to the local disappearance of some species and changes to the abundance of remaining species.
- Increased predation due to the congregation of fish downstream of a barrier.
- Ultimately lead to species extinction. Under the highest threat are anadromous species that spend most of their life in the sea and migrate to freshwater to breed. If these species are

prevented from free migration between feeding and breeding areas, the likely outcome is extinction as no spawning grounds would be present downstream of dams.

As discussed below, we have strong evidence to suggest the main management intervention for fish (barrier removal) works very successfully. Several substantial barriers have been recently mitigated and subsequently assessed to understand intervention effectiveness. In one instance, Dights Falls fishway, additional investment was made to optimise asset performance as a direct result of such intervention monitoring.

Other management levers exist and have been examined (e.g. environmental flow releases, streamside revegetation), but there is less or mixed evidence for success, mainly due to the influence of catchment scale factors (Halliday, Bloink, Robinson, & Campbell, 2022) and the focus on single species or reaches rather than communities and meta-communities.

Evaluation methodology

Information describing the effectiveness of the following two interventions, that are appropriate for fish, were evaluated:

- construction of fishways / removal of barriers to dispersion, and
- environmental flows.

Evaluation results and discussion

The role of fishways in supporting fish

The removal of fish barriers is seen as a key management intervention that can bring almost immediate benefit, particularly to migratory fish. During the HWS development, fish HSM models looked at the benefit of the removal of fish barriers and developed a set of fish barriers to be removed over the strategy time frame. Melbourne Water has a program of works to tackle priority fish barriers for works to improve fish passage. These works include low cost interventions such as regular maintenance to reduce debris build up along partial barriers to the construction of significant expensive fish ways at large weirs.

Yarra catchment

Dights Falls weir on the main channel of the Yarra River, in the lower part of the catchment, was historically a barrier to upstream fish movement under most conditions. In 1993 a rock fishway was installed to better facilitate upstream movement of fish. The fishway was in operation for many years, but monitoring efforts suggested that it had become largely ineffective, and it was upgraded to a vertical slot fishway in 2012. Continued monitoring indicated that the new fishway was only operating adequately for most species under base flow conditions and not during floods. In response, the fishway was again upgraded in 2020. The two significant increases in Common galaxias occupancy coincided with the installation and initial upgrade of the fishway, and these seem like a likely explanation (Figure 15). The reason for the recent decline in occupancy is less clear, but it may be that high flows have coincided with upstream migration of Common galaxias and they have not been able to overcome the barrier under those conditions. Furthermore, it may be that the most recent upgrade of the fishway, which is expected to overcome this issue, has not yet been reflected in the dataset.

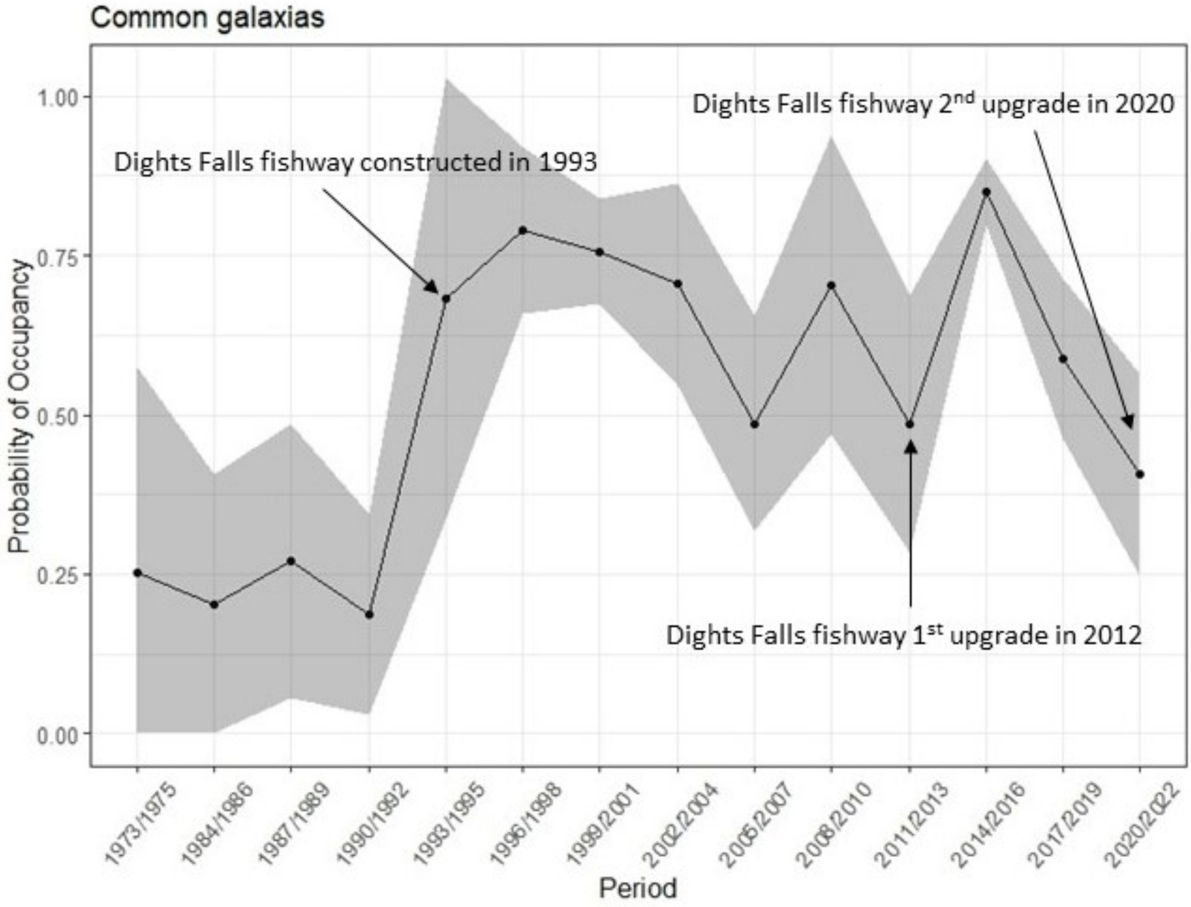

Figure 15. Model-averaged estimates of annual probability of site occupancy for Common galaxias with Dights Falls fishway construction and upgrades indicated.

Dandenong catchment

Work has recently been completed to replace a non-functioning fishway in the Dandenong catchment on the Patterson River. In 2004, investigations found that building fishways would open up more than 180 km of fish habitat in the Dandenong Creek catchment and greatly benefit the distribution of native migratory fish. The project was completed in April 2022 and early monitoring results from November 2021 indicate that the cone fishway is already helping fish to move upstream. Fish caught above the fishway include Common Galaxias, Spotted Galaxias, Lamprey and surprisingly, nine juvenile Australian Grayling (Photo 1, below). It's believed the last record of this species in the Dandenong Creek system was almost 40 years ago. Given the analysis of low nativeness presented in the Dandenong catchment presented in KEQ 3b, (Figure 6), the detection of additional native species above the fishway is encouraging. This project was reported last year as a case study for the HWS Annual Report and is the priority fish barrier removed for the Dandenong catchment indicated in Table 6.

https://healthywaterways.com.au/case-studies/2021/improving-fish-passage-in-dandenong-creek

Photo 1. Juvenile Australian grayling detected moving up the new cone fishway at Pillars Crossing on the Dandenong Creek in 2021. Credit: Chris Bloink

Westernport catchment

A critical illustration of the constraints that key migratory species face when barriers are not addressed is clear from our recent, but preliminary (eDNA baselining process is not yet completed), eDNA data results. Environmental DNA samples collected in 2021/22 have detected Australian grayling, a species listed as vulnerable under the Environmental Protection and Biodiversity Conservation Act (EPBC Act), moving through the Bunyip River system into the Tarago River (Figure 16). By contrast, the fish are only able to access the downstream reach of the Lang Lang River due to the presence of a large weir drop structure at Heads Road.

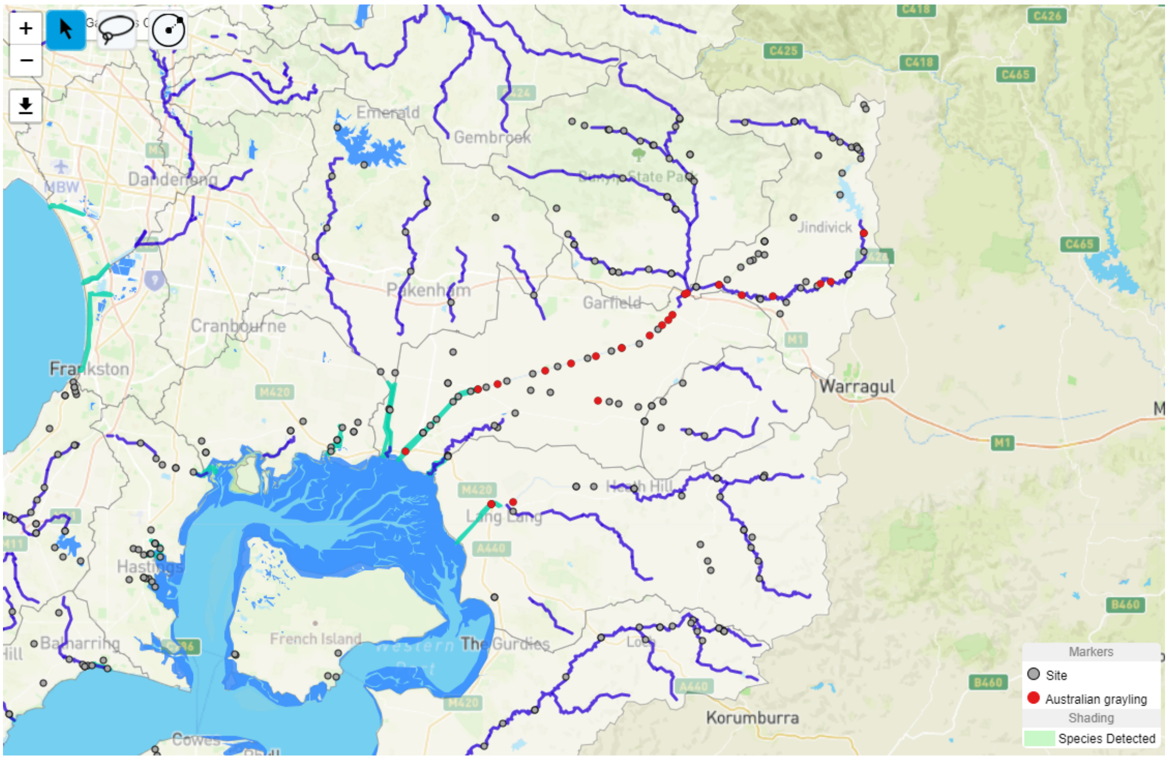

Figure 16. Map of Australian grayling distribution (as detected by eDNA sampling in 2021/22) illustrating the role the Heads Road weir plays in restricting distribution in the Lang Lang River compared with the nearby Bunyip River. Red dots indicate positive detection for Australian grayling. Grey dots indicate sampling with no detection.

The Lang Lang fish barrier is one of the priority fish barriers and is ranked as the highest benefit barrier to remove across the whole region. The HWS Annual Report of 2022 reported that the Westernport catchment as significantly off-track for fish passage due to the lack of progress at Heads Road.

These results collectively highlight the importance of fishway construction, maintenance and ongoing functional assessment as key management interventions that are critical for the support of fish across the region.

Effectiveness of delivering environmental flows

Melbourne Water Environmental Water Resources team has monitored fish populations in Jacksons (treatment) and Riddells Creek (reference, no flow delivery) over a five year period to determine if the fish community improves over time, and whether any changes can be attributed to the delivery of environmental water from Rosslynne Reservoir (Halliday, Bloink, Robinson, & Campbell, 2022).

What did we find?

The native fish populations did not broadly improve over time following the delivery of environmental water from Rosslynne Reservoir. Ornate galaxias showed less signs of recruitment in reaches subject to the delivery of environmental water, and there was a strong population of predatory Brown trout which may have had a strong top-down influence on native fish such as Ornate galaxias.

The unregulated reference reach of Riddells Creek fared slightly better over this time. The prevalence of Ornate galaxias in Riddells Creek is likely to be primarily attributable to the relative absence of Brown trout, with Ornate galaxias being adapted to periods of intermittent flow. Ornate galaxias are capable of surviving in isolated pools during periods of cease to flow (potentially prolongated if suitable pool habitat prevails) (Raadik, 2014).

Hydrological disturbances, such as periods of low flow, have been found to benefit native galaxias (*Galaxias anomalus*) at the expense of introduced trout in New Zealand, likely because native species are more adapted to the environmental conditions (e.g. low dissolved oxygen) that characterize low flow periods (Leprieur, et al., 2006).

It is possible that the delivery of environmental water, on top of high base flows from the Gisborne recycled water treatment plant in a naturally intermittent system, has enhanced conditions that benefit trout and increased predation pressures on native species.

The water regime (including a lack of cease to flow periods, little variation in flows and lack of water to meet flow recommendations) was one factor thought to have influenced the fish community. The report also notes discharge from the Gisborne recycled water treatment plant, degraded riparian vegetation, bank erosion, sedimentation and exotic species also contribute to the overall decline (Halliday, Bloink, Robinson, & Campbell, 2022).

Melbourne Water's e-flows team continue to advocate for an environmental entitlement in the Maribyrnong, and upgrades that would allow the delivery of the required volume of environmental water. This team plans to conduct a FLOWS study of the Maribyrnong in the near future, which will take the results of this study into consideration and any information gained through other sources.

Recommendations

- Environmental flow plans should consider likely consequences to, and interactions among, multiple species (meta-community perspective) – e.g. impact of introduced species on native species.

- Continue to invest in in-stream barrier removal and fishway installation, with a particular focus on the large weir drop structure at Heads Road in the Lang Lang River. Evidence suggests that fishways are an effective management lever to support migratory species when they are well maintained and functioning.

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Contact: Waterway.Strategy@melbournewater.com.au