

Re-running habitat suitability models with works-to-date and ten-year planned works

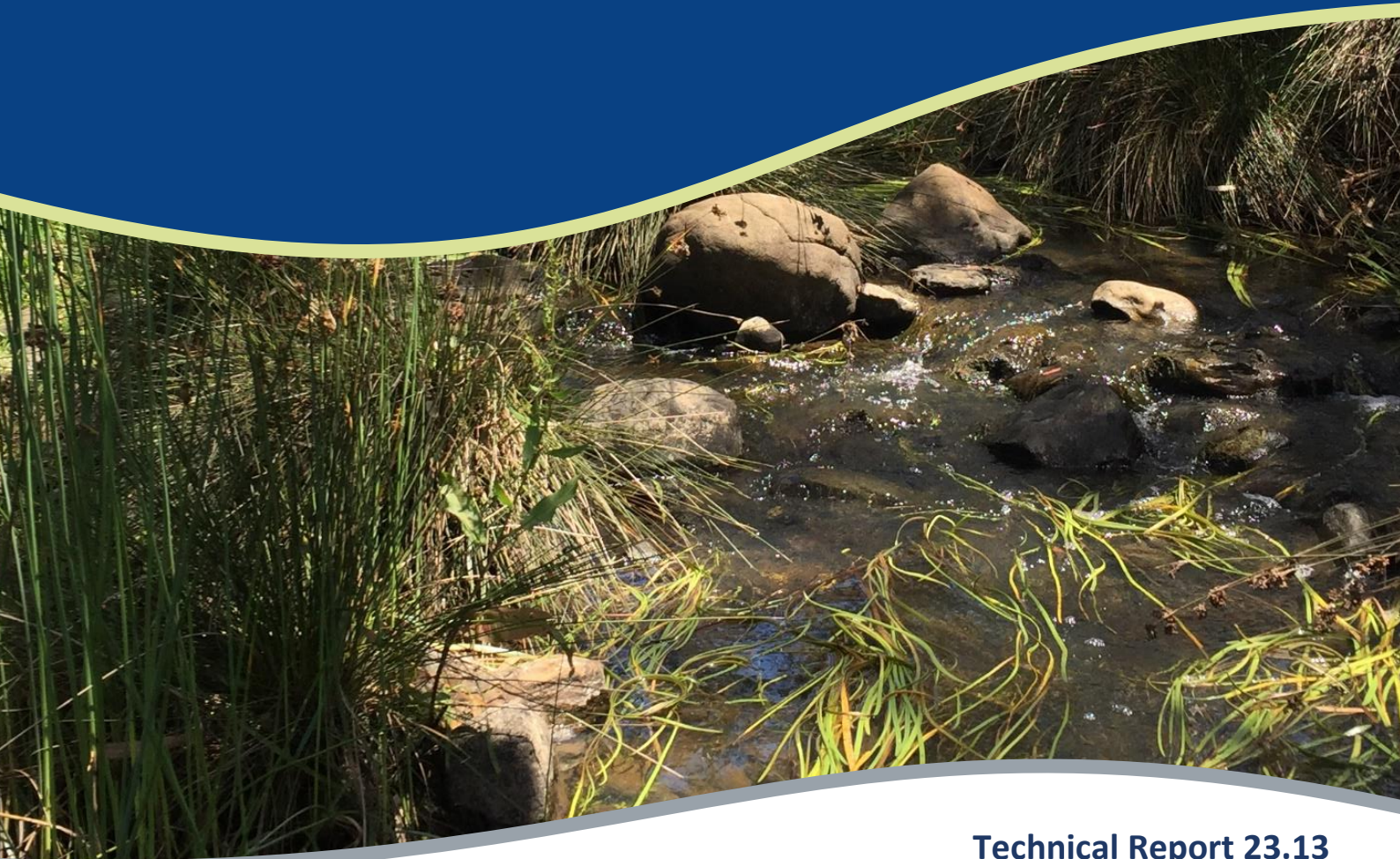
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Re-running Habitat Suitability Models with Works-to-Date and Ten-year Planned Works

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Acknowledgment of Country

The University of Melbourne acknowledges the Traditional Owners of the unceded land on which we work, learn and live: the Wurundjeri Woi Wurrung and Bunurong peoples (Burnley, Parkville, Southbank and Werribee campuses), the Yorta Yorta Nation (Dookie and Shepparton campuses), and the Dja Dja Wurrung people (Creswick campus).

The University also acknowledges and is grateful to the Traditional Owners, Elders and Knowledge Holders of all Indigenous nations and clans who have been instrumental in our reconciliation journey.

We recognise the unique place held by Aboriginal and Torres Strait Islander peoples as the original owners and custodians of the lands and waterways across the Australian continent, with histories of continuous connection dating back more than 60,000 years. We also acknowledge their enduring cultural practices of caring for Country.

We pay respect to Elders past and present and acknowledge the importance of Indigenous knowledge in the Academy. As a community of researchers, teachers, professional staff and students we are privileged to work and learn every day with Indigenous colleagues and partners.

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1 Introduction/Background

As part of the Healthy Waterway Strategy development process we developed habitat suitability models (HSMs) for stream macroinvertebrates, native fish and platypus. The input data, model development process and details of how the models were used for action prioritisation are described

in Chee *et al.* (2020). Here we provide a brief overview as background for the analysis this report is concerned with. Habitat Suitability Models (HSMs) analyse the relationships between the environmental characteristics at sites where a family/species is detected (and also at sites where the family/species is *not* detected) to develop a quantitative model that predicts how suitable any given stream reach is for the family/species. Higher habitat suitability implies higher probability of occurrence.

For each taxonomic group that we modelled (i.e. macroinvertebrate families, fish species and platypus), we used a carefully selected candidate set of 10-12 environmental predictors to describe:

- a) ecologically-relevant aspects of natural environmental variability across the region (*sensu* Austin 2002) and
- b) human impact variables that reflect primary mechanisms by which they alter natural environmental variation (e.g. land cover change)

Given our interest in strategic planning for future challenges, we focused on climatic, physiographic and catchment land use (human impact) predictors. The rationale for our approach to predictor selection was to develop models that would provide direct predictions of the biotic response to climatic changes, land use changes, mitigating management actions, and their interactions. Our set of environmental predictors therefore included variables such as catchment area, mean annual air temperature, mean annual runoff depth (an indicator of stream perenniality and variability), attenuated imperviousness (a measure of the amount of impervious cover that drains into a stream reach, and reflects stormwater runoff impact) and attenuated forest cover (a measure of the influence of forest cover alongside, upstream and elsewhere within the watershed of a given reach; Walsh & Webb, 2013, 2014) (Table 1). The impact of impervious surfaces and forest cover on a given reach depends on its distribution and spatial configuration within the catchment and dissipates with overland distance from the reach. So attenuated imperviousness and forest cover were spatially optimised (weighted by overland distance) to match the most plausible mechanistic pathways of influence (Table 1).

We used our 67 instream HSMs (52 for non-weedy macroinvertebrate families, 13 for native fish species, 1 for male-female platypus and 1 for female-only platypus) to estimate biodiversity values at 8,000+ stream reaches across the Port Philip and Western Port (PPWP) region, make predictions of how those values are likely to change under projected future scenarios of urban growth and climate change, and quantify expected benefits of specific management actions or combinations of actions (Chee *et al.* 2020). By considering expected benefit (computed for all modelled taxa) along with reach-specific costs associated with candidate actions, we identified the most cost-effective management action at any given reach. We then analysed this map of cost-effective actions with spatial conservation prioritisation software (Zonation) to rank all 8,000+ reaches showing where we should optimally act first to protect and improve stream biodiversity (Chee *et al.* 2020).

Table 1 Definition/description and units of environmental variables used in the development of the macroinvertebrate, fish, and platypus habitat suitability models. (Adapted from Chee et al. 2020)

	Environmental Predictor	Definition/Description	Units	Macro-invertebrates	Fish	Platypus
1	CatIgneous	Percentage of catchment overlying igneous rocks (e.g. granites, basalts, grandiorite, rhyolite and gabbro).	%	✓	✓	✓
2	Catchment Area [CatchmentArea_km2_InclDams]	Area of the watershed (i.e. sum of area of all upstream contributing subwatersheds, <i>including</i> large dams and all the subwatersheds that drain into the large dams)	km ²	✓	✓	✓
3	Mean Annual Runoff Depth [meanAnnQ_mm]	Mean annual runoff depth in the absence of human impacts (mm/year). This measure is a watershed-standardized measure of annual stream discharge. It is calculated by taking mean annual totals of monthly accumulated surface water surplus (derived from a simple water balance model using long-term rainfall and potential evapotranspiration data) and dividing by watershed area (Walsh & Webb 2014).	mm/yr	✓	✓	✓
4	Antecedent Runoff [SRI_48mth_weighted]	48 month (long-term) standardised runoff index (SRI), which is derived by fitting a log-normal distribution to long-term monthly estimates of average upstream runoff depth transformed to a standard normal-deviate (i.e. with zero mean and unit variance). A weighted moving average (window width of 48 months) with a linear decay function was applied to SRI values derived from monthly runoff data. Default = 0, which denotes <i>mean</i> 48mth weighted antecedent runoff. -1 denotes drier than mean antecedent runoff conditions; +1 indicates wetter than mean antecedent runoff conditions	NA	✓	✓	✓
5	Instream Full Barriers (at multiple timepoints)	Total number of instream <i>full</i> barriers to movement along the downstream flowpath at multiple timepoints including pre-2007, 2007, 2008, 2009, 2012 and 2014. (Gaps in timepoints reflect years where no additional full barriers were removed relative to the preceding timepoint.) Full barriers include structures, generally >5 m in height, such as high dam walls that are likely to block fish passage even during large flow events.	NA	--	✓	--
6	Instream Part Barriers (at multiple timepoints)	Total number of instream <i>partial</i> barriers to movement along the downstream flowpath at multiple timepoints including pre-1997, 1997, 1999, 2000, 2002, 2004, 2005, 2006, 2007, 2008, 2009, 2010 and 2016). (Gaps in timepoints reflect years where no additional	NA		✓	

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		partial barriers were removed relative to the preceding timepoint.) Partial barriers refers to features, generally <5 m in height that have the potential to permit fish passage on occasion, such as during high flow events.				
7	Mean Annual Air Temperature [mnAnnAirTm_deg]	Average annual mean (monthly) air temperature for the reach and immediate environs.	°C	✓	✓	✓
8	Attenuated Forest Cover (in 2006) [AttForest_L35W1000_2006]	A measure of the amount of forest cover alongside as well as upstream of the stream segment in 2006. Laterally, attenuated forest cover is calculated as exponentially weighted overland with a half-decay distance of 35 m from the stream AND exponentially weighted upstream with a half-decay distance of 1000 m. Range = 0–1.	NA	✓	✓	
9	Attenuated Forest Cover (in 2006; laterally unweighted variant) [AFb10L1000]	A measure of the amount of forest cover alongside as well as upstream of the stream segment. Laterally, Afb10L1000 is calculated as unweighted ≤ 10m from the stream, and exponentially weighted upstream with a half-decay distance of 1000 m. Range = 0-1.	NA			✓
10	Attenuated Imperviousness (in 2006) [AttImp_L9]	A measure of the influence of runoff from impervious surfaces extant in 2006 on the reach through the stormwater drainage system associated with urban land. Computed as the ratio of attenuated impervious area in the watershed (using a half-decay distance of 9.4 m) to watershed area. Range = 0–1.	NA	✓	✓	--
11	Minimum Attenuated Imperviousness within 4km (in 2006) [AttImpMin4k_L9]	A measure of the influence of runoff from impervious surfaces on the reach through the stormwater drainage system associated with urban land. Computed as the ratio of attenuated impervious area in the watershed (using a half-decay distance of 9.4 m) to watershed area. Range = 0 – 1. This variant selects the minimum AI value within 4km of a site in the downstream direction. The value of 4 km closely approximates the mean maximum home range length of radio-tagged adult males and females occupying lotic systems in south-eastern Australia.	NA	--	--	✓
12	Nspring	Number of spring sample units per sample-pair. This predictor allows us to account for seasonal variation. Range = 0-2; Default = 2	NA	✓	--	--
13	Nriff	Number of riffle sample units per sample-pair. This predictor allows us to account for inter-habitat variation. Range = 0–2; Default = 1	NA	✓	--	--
14	processN	Sorting method; 0 = 'lab-sorted'; 1 = 'field-sorted'	NA	✓	--	--

2 Scenarios of interest

Scenarios of interest are used to explore the impacts of works-to-date (WTD) and 10-year planned works. The CURR (current) scenario reflects estimates of various environmental measures as at 2016 (Table 2). The WTD and 10-year planned works scenarios are described in Table 3. With respect to the WTD and 10-year planned works timeframe, we are primarily interested in three management actions, namely, revegetation of (the riparian zone of) stream reaches, stormwater works and installation of fishways (Table 3). Revegetation and stormwater works are relevant to macroinvertebrate families, platypus and native fish species, but obviously, the fishways action relates primarily to fish. In this report, we compare the near-term WTD and 10-year planned works scenarios against CURR to understand and track the predicted impact that interventions (within Melbourne Water's control) have on habitat suitability for in-stream macroinvertebrates, platypus and native fish species. Note that for native fish (and just native fish) we examine the impact of revegetation, stormwater works and fishways actions on their own and in combination (Table 3; Section 6).

Table 2 Details of the CURR (current) and BAUF (business-as-usual-future) scenarios used in the development process of the Healthy Waterway Strategy 2018.

Scenario Code	Mean annual air temperature (°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 °C, capped at 15.8 °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 PPWP region with urban planning scheme zone codes have been developed to their full capacity. Includes infill in existing urban areas and future—planned but as yet undeveloped—new urban areas.	Barriers in place at 2016	Barriers in place at 2016

*For the purposes of long-term strategic planning over a 50-year horizon, we devised a scenario called the business-as-usual future (BAUF). This scenario focused on important widespread threats in the form of warming, drying and increased impervious cover (due to urbanisation). Warming was represented by a 1.5°C increase in mean annual temperature, capped at a maximum of 15.8°C. Drying was represented by a reduction in mean annual runoff depth (equivalent to a 25% reduction in long term mean annual discharge at the mouth of the Yarra River, Table 2). These values for temperature increase and reduction in runoff were chosen to be broadly consistent with DELWP (2016), and still largely within the ‘experience’ of the training data used to develop our models. (The exception here is the Little River catchment where the assumed magnitude of future warming and drying went beyond the ‘experience’ of training data.) The extent of future impervious land cover was estimated using Victoria’s VicMap Planning dataset’s planning scheme zone data (downloaded 21 Sept 2017 from <https://www.data.vic.gov.au/data/dataset/vicmap-planning>). See Chee *et al.* (2022) for how different combinations of temperature and runoff projections (that became available post-HWS 2018) and mitigating actions operating on their own or in particular combinations might impact on instream biota.

Table 3 List of action scenarios explored in this report. The scenarios shaded in light grey apply only to native fish (i.e. they are not used with macroinvertebrates and platypus).

	Scenario	Description
1	Works-to-date WTD	Like CURR, but with WTD attenuated forest cover (see section 3.1) AND WTD attenuated imperviousness (see section 3.2) AND WTD fishways (see section 3.3)
2	10-year planned works	Like CURR, but with 10-year planned works attenuated forest cover (see section 3.1) AND 10-year planned works attenuated imperviousness (see section 3.2) AND 10-year planned works fishways (see section 3.3)
3	10-year planned revegetation-only	Like CURR, but with 10-year planned works attenuated forest cover (see section 3.1) as the only action

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4	10-year planned stormwater-only	Like CURR, but with 10-year planned works attenuated imperviousness (see section 3.2) as the only action
5	10-year planned fishways-only	Like CURR, but with 10-year planned works fishways (see section 3.3) as the only action

3 Construction of inputs required for works-to-date (WTD) and 10-year Planned Works Scenarios

In order to use our HSMs to estimate the impact of works-to-date (WTD) and 10-year planned works, we first had to:

- a) collate data representing WTD (i.e. changes from CURR scenario used in the HWS 2018 development process, see Table 2)
- b) translate WTD and 10-year planned works of revegetation, stormwater management and fishway construction into HSM predictors for attenuated forest cover, attenuated imperviousness and number of (partial and full) instream barriers respectively

The approach and methods for doing so are described in the sections below.

3.1 Attenuated Forest Cover

Works-to-date (WTD)

We lack the appropriate data to comprehensively characterise on-ground changes in tree/forest cover that have come about since ~2016 (representative of the CURR scenario, see Table 2) for the entire PPWP region. For instance, there could be tree cover gains from revegetation activities undertaken by councils, not-for-profit organisations, community groups and private landholders that are not mapped and tracked. Likewise, there would be tree cover losses from human as well as natural disturbances such as vegetation clearing and fire, storm and windthrow events.

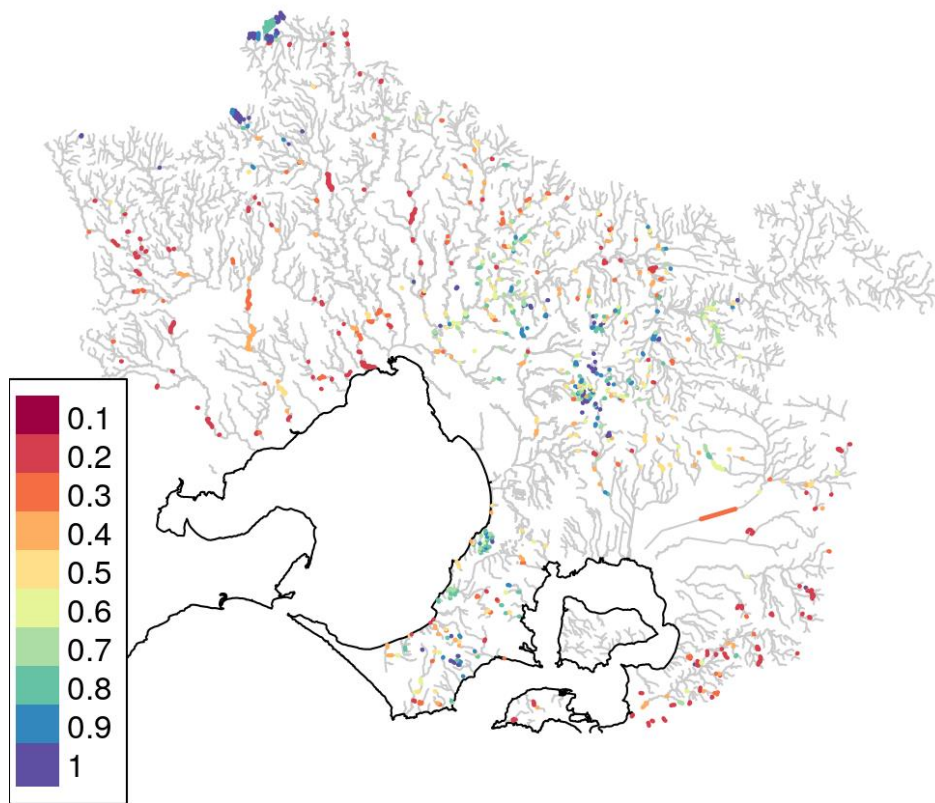
Our analysis of updating attenuated forest cover due to WTD relies on data from Melbourne Water's in-house systems. Vegetation establishment data for 2018-2021 inclusive, were extracted from Melbourne Water systems for recording revegetation work under capital works and incentive-based programs. The relevant systems containing data captures from the Rural Land Program (RLP), Waterway Health Investment Planning (WHIP) and Waterway Planning Target Mapper (WPTM) were interrogated by Andrew Schwarz, quality-assessed via basic questions (e.g. was the revegetated area mapped? Did the area drawn match corroborating maps?) and pre-processed if necessary. For instance, WHIP data used to be recorded as lines rather than polygons. Polygons representing revegetated areas were approximated by buffering line records by 20 m. Where a recorded line was short, this resulted in circular-shaped polygons.

Polygons were overlaid and overlapping or intersecting polygons were dissolved to obtain the largest revegetation 'footprint' at locations that had repeat revegetation works (and therefore polygon records). Repeat revegetation works may occur for weed removal, vegetation re-establishment, ground/mid-storey re-establishment or some/all of the above. The amalgamated data was then integrated with existing lidar-derived estimates of tree canopy cover across the PPWP (in 2006) to estimate WTD attenuated forest cover. Figure 1A shows locations of WTD revegetation coloured by the proportion of those areas that were already revegetated in 2006. The estimated change in attenuated forest cover from WTD revegetation is shown in Figure 1B. Resulting changes to

attenuated forest cover estimates were small (Figure 1B). Only a small number of reaches are expected to increase in attenuated forest cover by >0.2 . Increases of >0.4 are likely what is required to achieve detectable effects on habitat suitability, and very few reaches have achieved such increases (Figure 1B).

Note that the lidar-derived tree cover does not distinguish between native and woody weed vegetation and may include woody weed vegetation cover. Vegetation works that overlap extant lidar-derived tree cover may well improve vegetation quality because it removes woody weeds and re-establishes native vegetation or reinstates ground and mid-storey native vegetation. But our HSMs use attenuated forest based on tree cover and do *not* take into account vegetation quality. In other words, improvements in vegetation quality rather than cover will not translate into improved attenuated forest cover or habitat suitability in HSM predictions. This is an important point to be aware of.

A.



B.

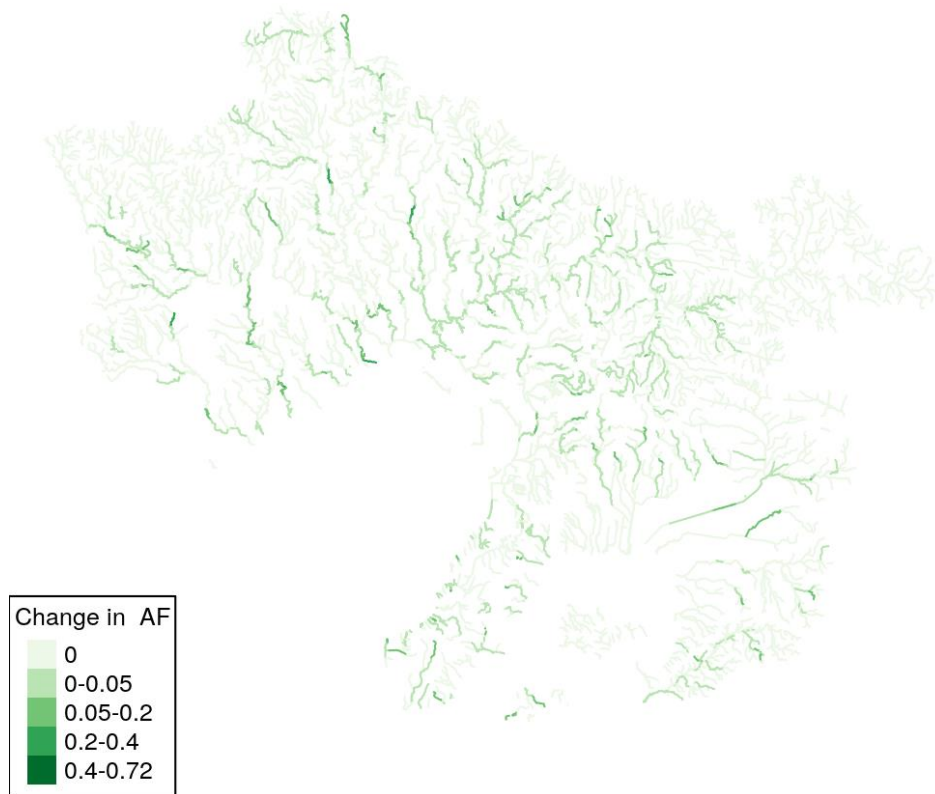


Figure 1 A. Areas of works-to-date (i.e. 2022) revegetation, coloured by proportions of those areas that were already vegetated in 2006. B. Estimated change in attenuated forest cover.

10-year Planned Works

Melbourne Water provided a list of 4,781 vegetation priority subcatchments in the 10-year planned works program. To estimate change in attenuated forest cover under 10-year planned works, a 20 m forest buffer was assumed to be achieved along all stream reaches in the 4,781 vegetation priority subcatchments. The buffered reach data was then integrated with existing lidar-derived estimates of tree canopy cover across the PPWP (in 2006) to estimate 10-year planned works attenuated forest cover. The estimated change in attenuated forest cover due to 10-year planned works is shown in Figure 2. If this level of revegetation works was achieved, many reaches would see an increase in attenuated forest cover of >0.4 (Figure 2), and we would expect this to result in detectable effects on habitat suitability for in-stream biota throughout the PPWP region.

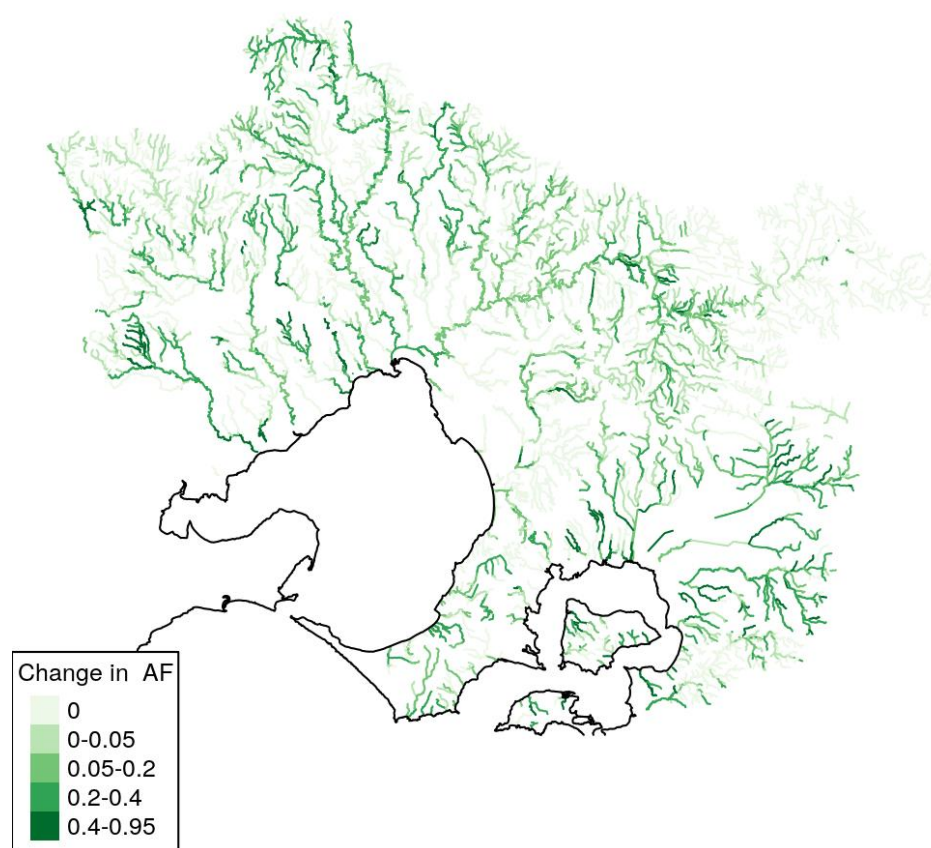


Figure 2 Estimated change in attenuated forest cover from 10-year planned revegetation works.

3.2 Attenuated Imperviousness

Works-to-date (WTD)

We lack the appropriate data to characterise changes in (total and effective) imperviousness that have come about since ~ 2016 (representative of the CURR scenario, see Table 2) for the entire PPWP region. Instead, we focus on quantifying imperviousness changes in Melbourne Water's designated stormwater priority areas.

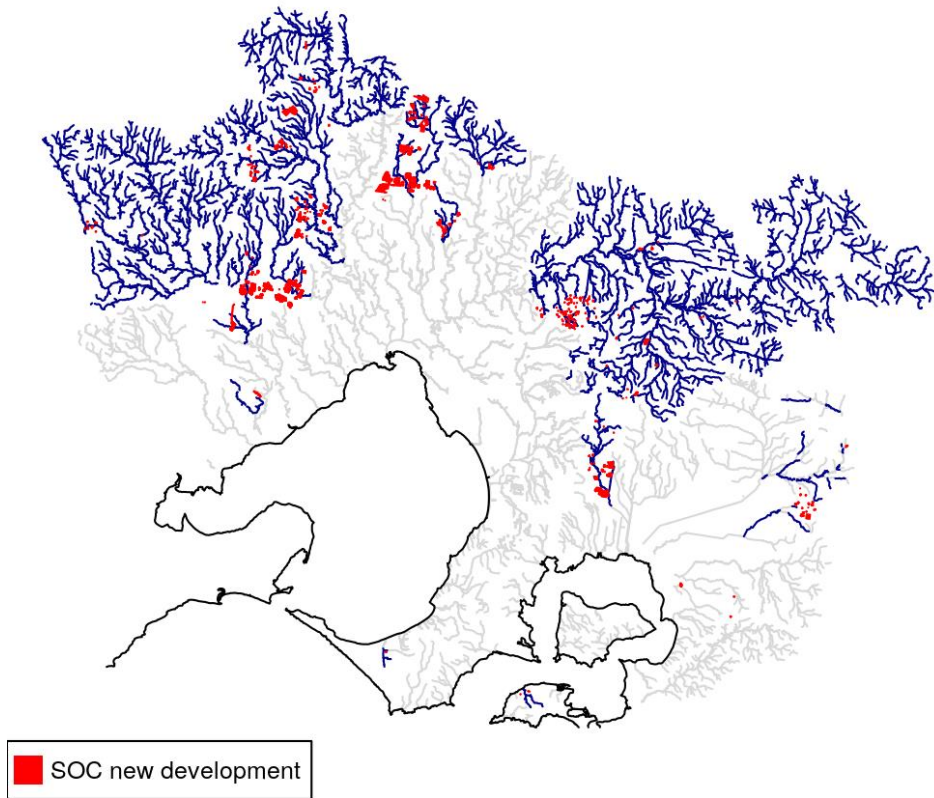
Statement of compliance (SoC) data from 2019 to 2022 for the stormwater priority areas (Figure 3A) (obtained and compiled by WaterTech) was used to estimate growth in directly-connected imperviousness since the CURR estimate used in the HWS 2018 development process. Areas of new development identified in the SoC data in each subcatchment were divided by 0.5 to estimate new directly-connected impervious (DCI) areas. A multiplier of 0.5 was used assuming an impervious fraction of new developments between 0.5 and 0.65, accounting for a small reduction in effective imperviousness resulting from stormwater control measures designed to meet the urban stormwater guidelines of Victorian Stormwater Committee (1999). Note that we currently lack data on developments (greenfield and infill) that were built between 2016 and 2019 (i.e. after the CURR scenario estimate and before the available SoC data), so the estimate of the growth of stormwater impacts in this analysis is likely an underestimate of true urban growth in these areas.

The new subcatchment DCI area estimates of all upstream subcatchments were summed for each subcatchment (and divided by catchment area) to estimate catchment DCI in 2022. These recalculations were applied only to streams flowing through the stormwater priority areas (Figure 3B).

10-year Planned Works

Even with data on approved and registered Precinct Structure Plans (PSPs) we do not know *where* and *when* greenfield developments will occur in the PPWP region between now and 2028, with any precision. Without explicit spatial data on the distribution and location of this near-future development, there is really no basis upon which to generate 10-year attenuated imperviousness estimates. For the 10-year planned works scenario, we therefore use WTD attenuated imperviousness estimates in effect, assuming no worsening (but also no improvement) of attenuated imperviousness throughout the PPWP region.

A.



B.

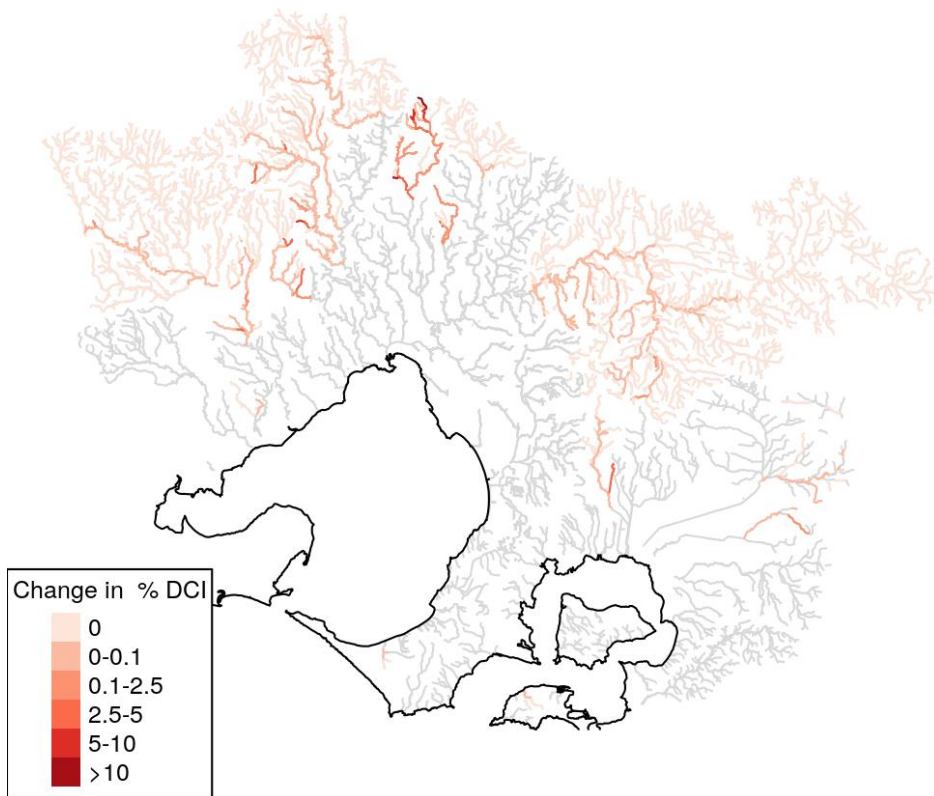


Figure 3 A. Distribution of 'Statement of Compliance' (SoC) new development polygons (red) within designated stormwater priority areas. B. Percentage change in DCI (attenuated imperviousness) relative to that of the CURR scenario used in the

HWS 2018 (see Table 2) as a result of developments covered by 2019-2022 Statements of Compliance. In both A and B, stream reaches outside stormwater priority areas are coloured grey.

3.3 Fishways

Melbourne Water provided a list of fishways to overcome instream barriers within waterways. The details of WTD and 10-year planned works fishways are shown in Table 4.

Table 4 List of 10-year planned fishways to overcome instream barriers to fish movement within PPWP waterways. Rows shaded in light blue are the fishways that have been completed in works-to-date (WTD).

ID	Severity	Type	Catchment	Mgt Unit	Subc
747	Full	Drop structure	Yarra	Darebin Creek	YARR7044
344	Partial	Gauging weir	Werribee	Werribee River Middle	WERR1578
347	Partial	Crossing	Werribee	Toolern Creek	WERR1397
354	Partial	Crossing	Werribee	Werribee River Lower	WERR1654
706	Partial	Weir	Maribyrnong	Maribyrnong River	MARI1820
707	Partial	Weir	Maribyrnong	Taylors Creek	MARI1782
760	Partial	Pipe	Yarra	Darebin Creek	YARR6120
808	Partial	Drop structure	Westernport	Lang Lang River	LANG160
881	Partial	Crossing	Werribee	Werribee River Lower	WERR1753
891	Partial	Crossing	Werribee	Little River Lower	LITT366
893	Partial	Crossing	Werribee	Little River Lower	LITT368
2	Full	Dam	Yarra	Yarra River Upper (Source)	YARR5274
44	Full	Weir	Yarra	Watts River (Rural)	YARR5288
352	Full	Weir	Werribee	Werribee River Lower	WERR1684
358	Full	Weir	Yarra	Yarra River Upper (Source)	YARR6649
361	Full	Weir	Yarra	Watts River (Rural)	YARR5964
716	Full	Gauging weir	Westernport	Lang Lang River	LANG95
882	Partial	Natural rock	Werribee	Werribee River Lower	WERR1721
883	Partial	Weir	Werribee	Werribee River Lower	WERR1718
884	Partial	Weir	Werribee	Werribee River Lower	WERR1718
885	Partial	Weir	Werribee	Werribee River Lower	WERR1718
886	Partial	Natural rock	Werribee	Werribee River Lower	WERR1714
887	Partial	Natural rock	Werribee	Werribee River Lower	WERR1699
888	Partial	Natural rock	Werribee	Werribee River Lower	WERR1684
889	Partial	Natural rock	Werribee	Werribee River Lower	WERR1684
892	Partial	Crossing	Werribee	Little River Lower	LITT366
894	Partial	Weir	Werribee	Little River Lower	LITT361
895	Partial	Gauging weir	Werribee	Little River Lower	LITT361

4 Macroinvertebrates

The stacked barplots of stream lengths in each LUMaR rating category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (Figure 4). Despite the works-to-date, the length of streams in the 'Very Poor' and 'Poor' categories have increased slightly relative to the CURR scenario. But if the 10-year planned works are achieved, this is predicted to reverse the decline and substantially increase the length of streams in both the 'Good' and 'Very Good' LUMaR rating categories (Figure 4).

Length of stream reach in each lumar rating category by scenario

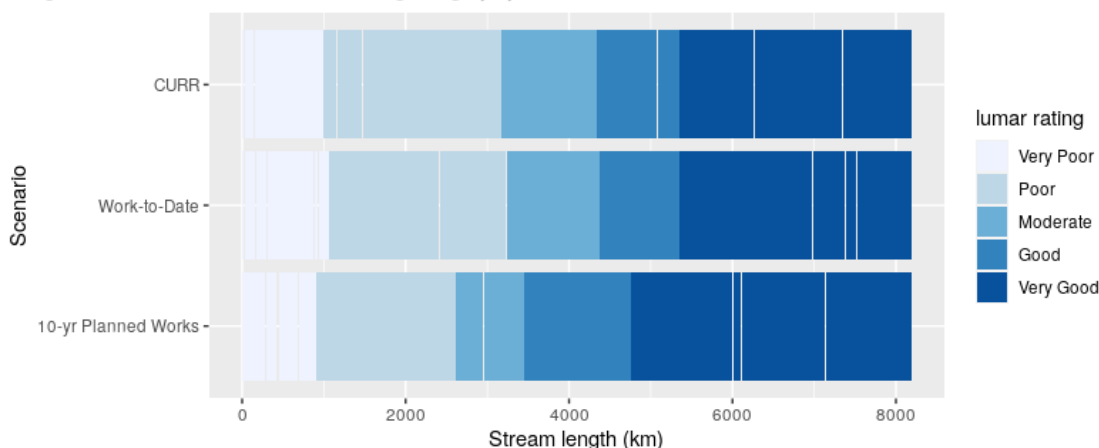


Figure 4 Stacked barplots of stream lengths in each LUMaR rating category by scenario (see Table 2 and Table 3 for details). The intervals for the LUMaR rating categories are: Very Poor -0.3 – 0.05, Poor 0.05 - 0.35, Moderate 0.35 - 0.5, Good 0.5 - 0.65, Very Good 0.65 - 1.0.

The spatial distribution of LUMaR ratings under the CURR, WTD and 10-year planned works scenarios are shown in the top, middle-left and bottom-left images respectively in Figure 5. The 'difference' maps highlight the particular areas within the PPWP region where WTD predicts LUMaR increases or decreases relative to CURR (middle-right, Figure 5), and likewise, for 10-year planned works (bottom-right, Figure 5). For WTD, the changes are predominantly decreases in specific reaches in the sub-catchments (a management boundary used by Melbourne Water and the HWS and is not necessarily a hydrologically delineated drainage boundary) of Kororoit Creek Lower, Jacksons Creek, Emu Creek, Merri Creek Upper, Darebin Creek, King Parrot and Musk and Yallock Drain in Bunyip Lower (middle-right, Figure 5). For 10-year planned works, the changes are predominantly increases in reaches broadly distributed across the PPWP region, from reaches in the sub-catchments of Little River Upper in the west, to Toolern Creek, Kororoit Creek Upper, Deep Creek Upper, Merri Creek Upper, Yarra River Middle, Bunyip River Middle and Upper, Tarago River, Lang Lang River, Cardinia, Toomuc, Deep and Ararat Creek, Mornington Peninsula Western Creeks and Mornington Peninsula South-Eastern Creeks (bottom-right, Figure 5).

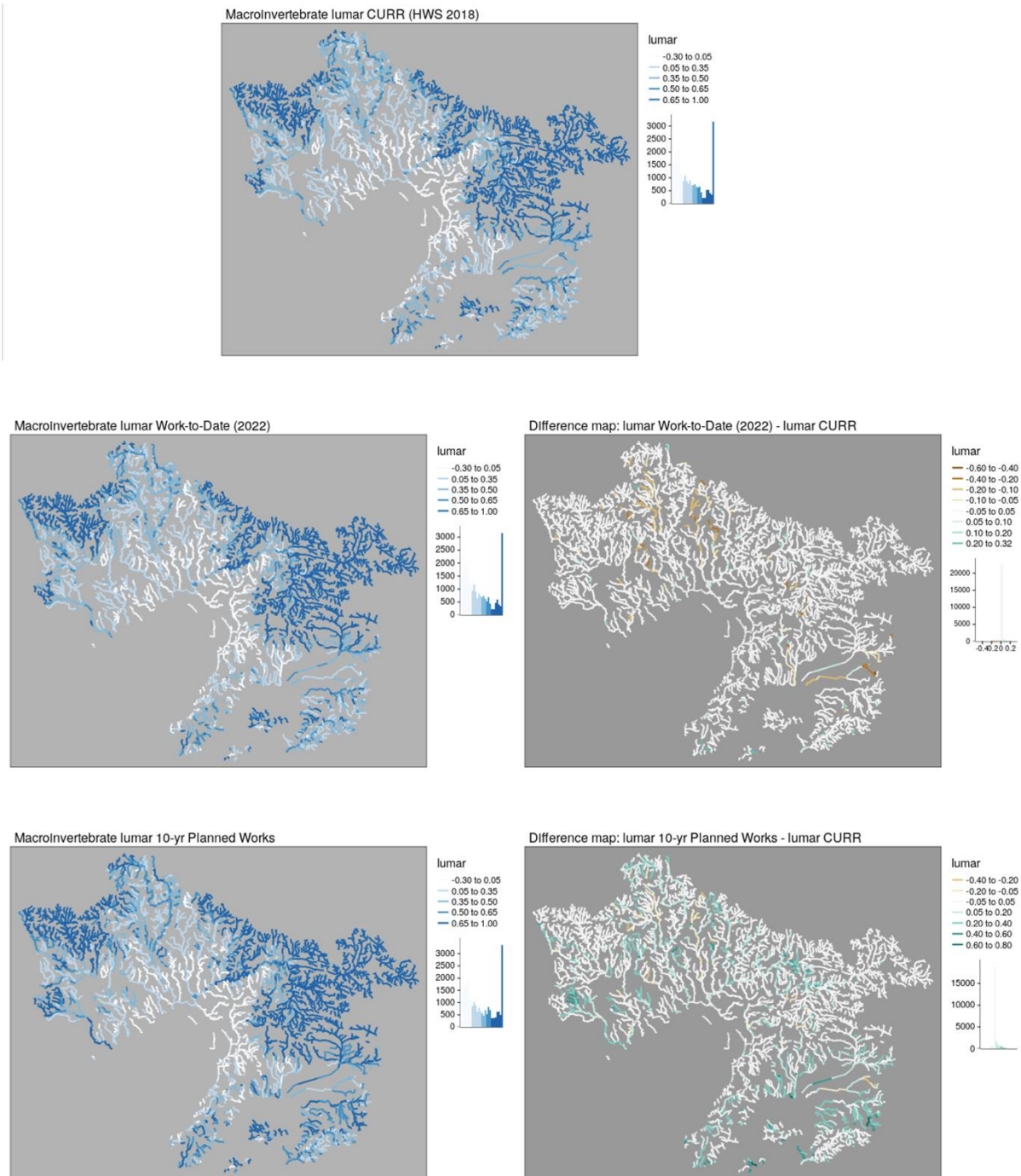


Figure 5 Mapped predictions of LUMaR values across the PPWP region under the CURR scenario used in the HWS 2018 (top), the works-to-date (WTD) scenario (middle-left) and the 10-year planned works scenario (bottom-left). Deeper blues indicate higher LUMaR values. ‘Difference’ maps show where predicted LUMaR under WTD (middle-right) and under 10-year planned works (bottom-right) differs from that of the CURR scenario used in HWS 2018. On this diverging colour scale darker browns indicate lower LUMaR values relative to CURR, white indicates little difference and deeper blue-greens indicate higher LUMaR values relative to CURR.

5 Platypus

This section presents results from the female-only platypus HSM, the male-female ‘AllPlatyHWS’ HSM and the male-female ‘AllPlatyColeman’ HSM.

Female Platypus ('FemPlaty')

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (Figure 6). Despite the works-to-date, there is no particular improvement of note relative to the CURR scenario. But if the 10-year planned works are achieved, this is predicted to substantially increase the length of streams in the 'Low' category, increase the length of streams in the 'Moderate' category and slightly increase the length of streams in the both the 'High' and 'Very High' categories (Figure 6).

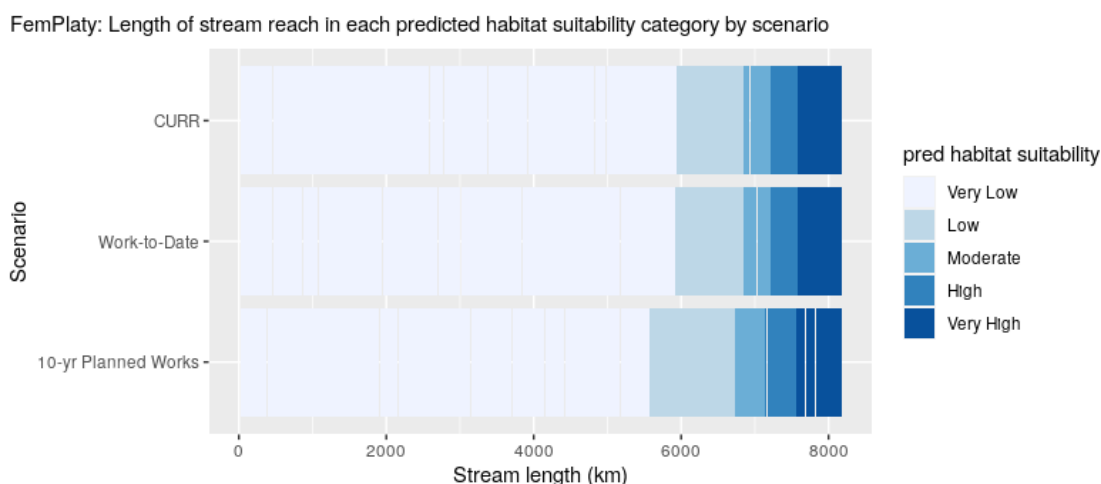


Figure 6 Stacked barplots of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for female platypus. The intervals for the predicted habitat suitability categories are: Very Low 0 - 0.10, Low 0.10 - 0.20, Moderate 0.20 - 0.30, High 0.30 - 0.40, Very High 0.40 - 1.0.

The mapped habitat suitability of female platypus under the CURR, WTD and 10-year planned works scenarios are shown in the top, middle-left and bottom-left images respectively in Figure 7. Areas of high predicted habitat suitability for female platypus, who have particular habitat requirements for nesting sites and for foraging to support lactation (Serena & Grant, 2017), are concentrated in reaches in the sub-catchments of Yarra River Upper (Source), Yarra River Upper (Rural), Yarra River Middle, Watts River (Source), Woori Yallock Creek, Little Yarra River and Hoddles Creek, Bunyip River Middle and Upper and Tarago River. In the west, there are reaches of moderate habitat suitability for female platypus in reaches in the sub-catchments of Deep Creek Lower and Lerderderg River.

The 'difference' maps highlight the particular areas within the PPWP region where WTD predicts habitat suitability increases or decreases relative to CURR (middle-right, Figure 7), and likewise, for 10-year planned works (bottom-right, Figure 7). For WTD, there are no changes of note. For 10-year planned works, the changes are predominantly small increases in reaches within the sub-catchments of Deep Creek Upper, Jacksons Creek, Bunyip River Middle and Upper, Tarago River and Lang Lang River (bottom-right, Figure 7).

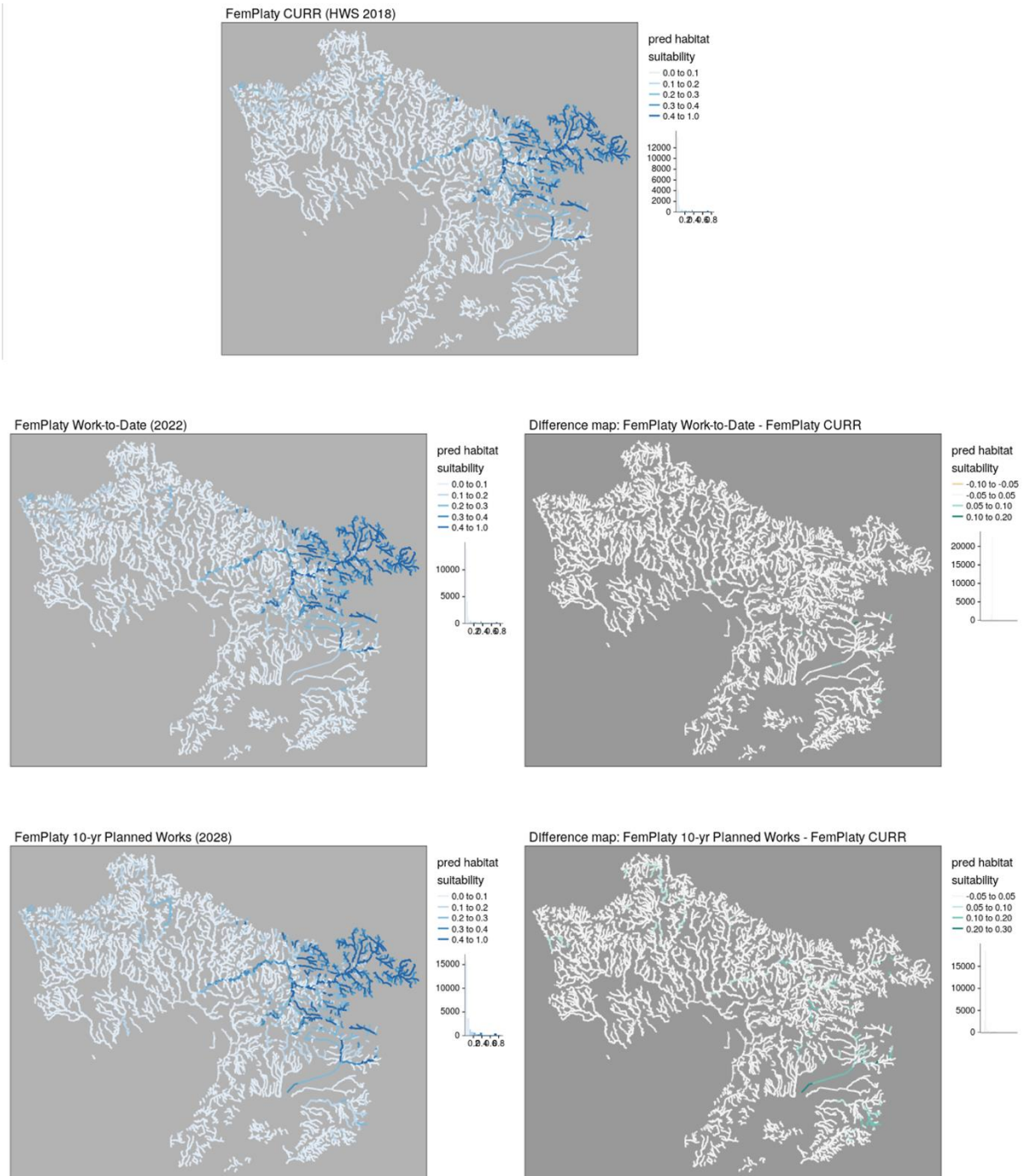


Figure 7 Mapped predictions of female platypus habitat suitability across the PPWP region under the CURR scenario used in HWS 2018 (top), the works-to-date (WTD) scenario (middle-left) and the 10-year planned works scenario (bottom-left). Deeper blues indicate higher predicted habitat suitability. ‘Difference’ maps show where predicted habitat suitability under WTD (middle-right) and under 10-year planned works (bottom-right) differs from that of the CURR scenario used in HWS 2018. On this diverging colour scale darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and deeper blue-greens indicate higher predicted habitat suitability relative to CURR.

Male-Female Platypus (‘AllPlatyHWS’ and ‘AllPlatyColeman’)

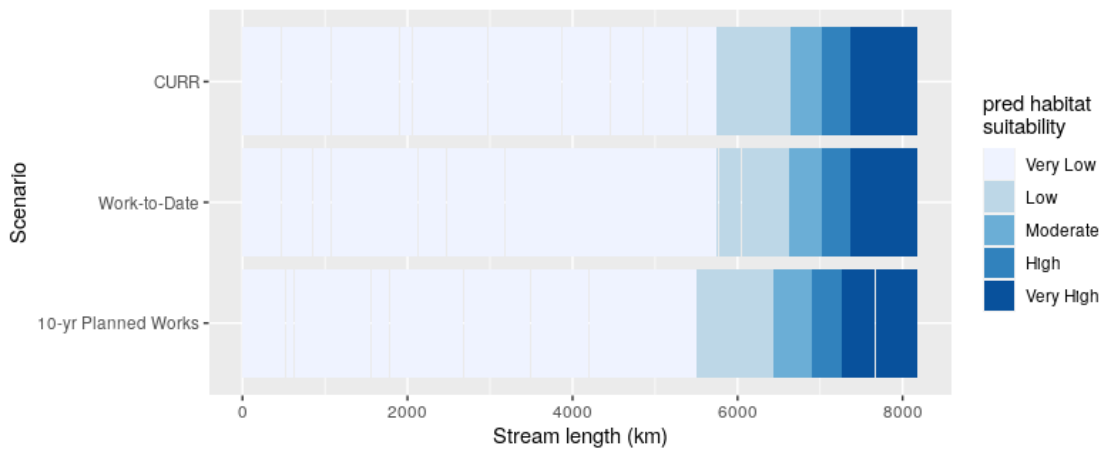
The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale. The top image in Figure 8 shows the stacked barplots for scenario predictions using the

male-female ‘AllPlatyHWS’ HSM, and the bottom image in Figure 8 shows the stacked barplots for scenario predictions using the male-female ‘AllPlatyColeman’ HSM.

Despite the works-to-date, there is no particular improvement of note relative to the CURR scenario—this is the case with both ‘AllPlatyHWS’ and ‘AllPlatyColeman’. But if the 10-year planned works are achieved, the ‘AllPlatyHWS’ HSM predicts an increase the length of streams in the ‘Moderate’ and ‘Very High’ category (top image, Figure 8). With respect to the ‘AllPlatyColeman’ HSM, the prediction is for an increase in the length of streams in the ‘Very High’ category (bottom image, Figure 8).

As we can see from comparing the two sets of stacked barplots, the ‘AllPlatyColeman’ HSM predicts a much greater length of stream in the ‘Low’, ‘Moderate’, ‘High’ and ‘Very High’ categories relative to the ‘AllPlatyHWS’ HSM (Figure 8).

AllPlatyHWS: Length of stream reach in each predicted habitat suitability category by scenario



AllPlatyColeman: Length of stream reach in each predicted habitat suitability category by scenario

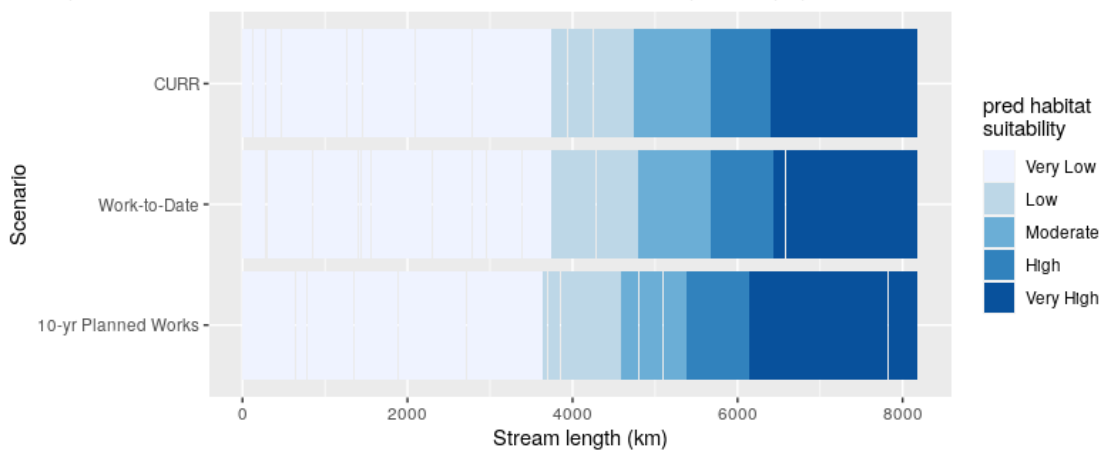


Figure 8 Stacked barplots of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the ‘AllPlatyHWS’ (middle-left) and the ‘AllPlatyColeman’ (bottom-left) male-female platypus models. The intervals for the predicted habitat suitability categories are: Very Low 0 - 0.10, Low 0.10 - 0.20, Moderate 0.20 - 0.30, High 0.30 - 0.40, Very High 0.40 – 1.0.

The mapped habitat suitability of male-female platypus under the CURR, WTD and 10-year planned works scenarios when using the 'AllPlatyHWS' HSM is shown in the top, middle-left and bottom-left images respectively in Figure 9. Areas of high predicted habitat suitability are pretty similar to that for female platypus (Figure 7), and are concentrated in reaches in the sub-catchments of Yarra River Upper (Source), Yarra River Upper (Rural), Yarra River Middle, Watts River (Source), Woori Yallock Creek, Little Yarra River and Hoddles Creek, Bunyip River Middle and Upper and Tarago River. In the west, there are reaches of moderate habitat suitability for female platypus in reaches in the sub-catchments of Deep Creek Lower, Jacksons Creek, Werribee River Upper, Werribee River Middle and Werribee River Lower.

The 'difference' maps highlight the particular areas within the PPWP region where WTD predicts habitat suitability increases or decreases relative to CURR (middle-right, Figure 9), and likewise, for 10-year planned works (bottom-right, Figure 9). For WTD, there are no changes of note. For 10-year planned works, the changes are predominantly small to moderate increases in predicted habitat suitability in reaches within the sub-catchments of Deep Creek Upper, Deep Creek Lower, Jacksons Creek, Yarra River Lower, Yarra River Middle, Yarra River Upper (Rural), Woori Yallock Creek, Bunyip River Middle and Upper and Tarago River (bottom-right, Figure 9).

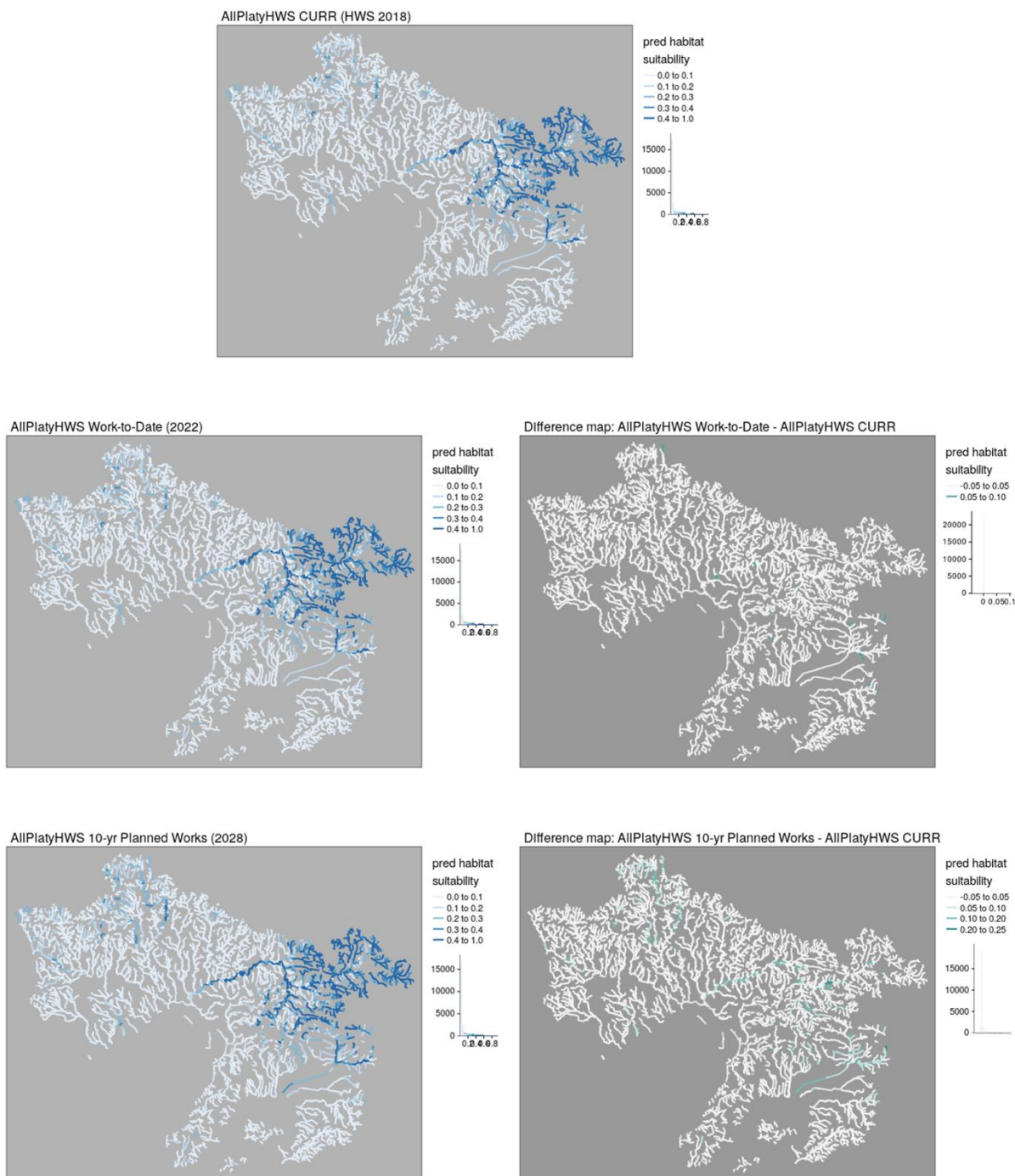


Figure 9 Mapped predictions of 'AllPlatyHWS' model male-female platypus habitat suitability across the PPWP region under the CURR scenario used in HWS 2018 (top), the works-to-date (WTD) scenario (middle-left) and the 10-year planned works scenario (bottom-left). Deeper blues indicate higher predicted habitat suitability. 'Difference' maps show where predicted habitat suitability under WTD (middle-right) and under 10-year planned works (bottom-right) differs from that of the CURR scenario used in HWS 2018. On this diverging colour scale darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and deeper blue-greens indicate higher predicted habitat suitability relative to CURR.

The mapped habitat suitability of male-female platypus under the CURR, WTD and 10-year planned works scenarios when using the 'AllPlatyColeman' HSM is shown in the top, middle-left and bottom-left images respectively in Figure 10. Areas of high predicted habitat suitability are concentrated in reaches in the sub-catchments of Yarra River Upper (Source), Yarra River Upper (Rural), Yarra River

Middle, Watts River (Source), Woori Yallock Creek, Little Yarra River and Hoddles Creek, Bunyip River Middle and Upper and Tarago River. In the west, there are reaches of moderate habitat suitability for female platypus in reaches in the sub-catchments of Deep Creek Lower, Jacksons Creek, Werribee River Upper, Werribee River Middle and Werribee River Lower.

The 'difference' maps highlight the particular areas within the PPWP region where WTD predicts habitat suitability increases or decreases relative to CURR (middle-right, Figure 10), and likewise, for 10-year planned works (bottom-right, Figure 10). For WTD, there declines in predicted habitat suitability in reaches of the sub-catchments of Emu Creek, Werribee River Middle, Merri Creek Upper, Woori Yallock Creek, Cardinia, Toomuc, Deep and Ararat Creeks, Tarago River, King Parrot and Musk Creeks and Lang Lang River (middle-right, Figure 10). There are also a small number of reaches with increased predicted habitat suitability in reaches within the Lang Lang River management unit. For 10-year planned works, the changes are predominantly small to moderate increases in predicted habitat suitability in reaches within the sub-catchments of Werribee River Upper, Jacksons Creek, Deep Creek Upper, Deep Creek Lower, Boyd Creek, Yarra River Middle, Cardinia, Toomuc, Deep and Ararat Creeks, Bunyip River Middle and Upper and Lang Lang River (bottom-right, Figure 10).

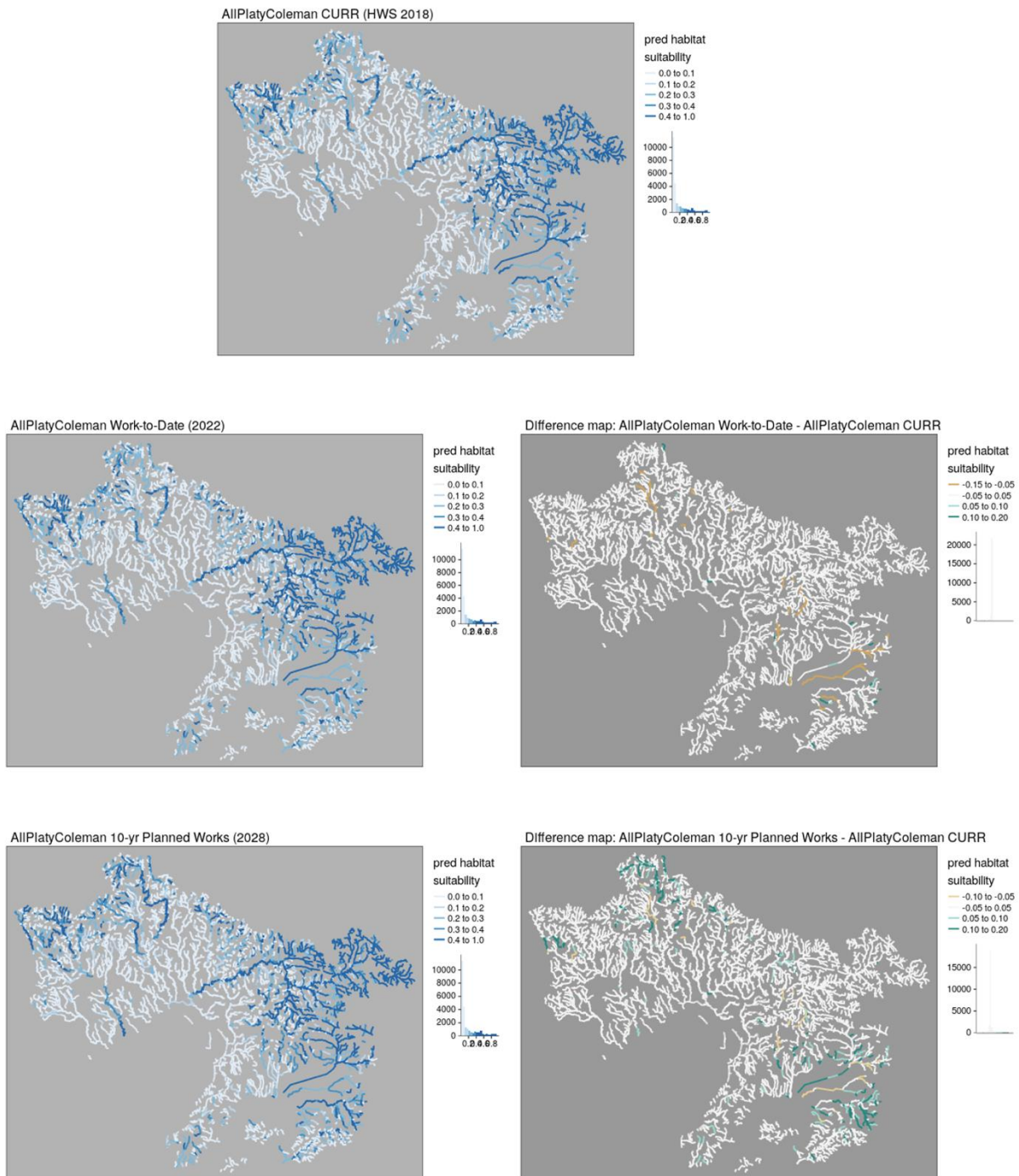


Figure 10 Mapped predictions of 'AllPlatyColeman' model male-female platypus habitat suitability across the PPWP region under the CURR scenario used in HWS 2018 (top), the works-to-date (WTD) scenario (middle-left) and the 10-year planned works scenario (bottom-left). Deeper blues indicate higher predicted habitat suitability. 'Difference' maps show where predicted habitat suitability under WTD (middle-right) and under 10-year planned works (bottom-right) differs from that of the CURR scenario used in HWS 2018. On this diverging colour scale darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and deeper blue-greens indicate higher predicted habitat suitability relative to CURR.

6 Native Fish

We explore predicted habitat suitability for 13 native fish species, for the five scenarios of interest described in Table 3. The 11 native fish species we were able to develop (boosted regression tree, BRT) habitat suitability models (HSMs) for are:

1. Short-finned Eel (ANGUAUST)
2. River Blackfish (GADOMARM)
3. Broad-finned Galaxias (GALABREV)
4. Common Galaxias (GALAMACU)
5. Ornate Galaxias (GALAORNA)
6. Spotted Galaxias (GALATRUT)
7. Pouched lamprey & Short-headed lamprey (LAMPREYS)
8. Southern Pygmy Perch (NANNAUST)
9. Flatheaded Gudgeon (PHILGRAN)
10. Tupong (PSEUURVI) and
11. Australian Smelt (RETRSEMO)
12. *Yarra Pygmy Perch (NANNOBSC)
13. *Australian Grayling (PROTMARA)

As noted in Chee *et al.* (2020), two freshwater fish species of conservation concern, namely, the Yarra Pygmy Perch (*Nannoperca obscura*) and the Australian Grayling (*Prototroctes maraena*), both of which are listed as ‘threatened’ under Victoria’s Flora and Fauna Guarantee Act 1988 and as ‘vulnerable’ under the Federal Government’s Environment Protection and Biodiversity Conservation Act 1999 were not explicitly modelled due to a lack of adequate data. But given their conservation importance, we felt it was important that they be represented in the HWS 2018 development process in order to inform the prioritisation of management interventions. Our workaround for the HWS 2018 development process, and for the current report, was to use predictions from ‘surrogate’ species deemed to be sufficiently similar in their habitat requirements (Dr Tarmo Raadik, Arthur Rylah Institute for Environmental Research, *pers. comm.*). Specifically, Southern Pygmy Perch (*Nannoperca australis*) was used as the surrogate for Yarra Pygmy Perch and Common Galaxias (*Galaxias maculatus*) was the surrogate for Australian Grayling. Guided by the expert knowledge of Dr Tarmo Raadik (*pers. comm.*) we applied predictions from each respective surrogate in just the catchments and river reaches Yarra Pygmy Perch and Australian Grayling were known to occur in. For Yarra Pygmy Perch, that meant Deep Creek in the Maribyrnong catchment, and for Australian Grayling, that meant just the mainstems of the Werribee, Maribyrnong, Yarra, Cardinia, Bunyip and Lang Lang rivers, downstream of major instream barriers.

The fitted response curves for predictors in each of the native fish species HSMs are provided in the Appendix and they are an important aid to understanding and interpreting the predicted habitat suitability of individual native fish species in the five scenarios of interest described in Table 3. Some relevant points of note are as follows:

1. There are a total of 9 potential predictors that can feature in a native fish HSM (e.g. meanTemp, meanAnnQ, AttFor, AttImperv, FullBarrierDS, PartBarrierDS, see Table 1).

None of the native fish HSMs include all 9 predictors — the number of predictors included in each native fish species HSM ranges from 6 to 8. And included predictors differ in their relative percentage contribution (a measure of ‘importance’) depending on species.

2. Habitat suitability has a consistently negative association with increasing attenuated imperviousness (AttImperv), and increasing number of full and partial barriers (along the downstream flowpath). But the direction and strength of association with other predictors varies species-by-species.
3. While most fish species have a positive association with increasing attenuated forest cover (AttFor), Common Galaxias and Southern Pygmy Perch have a negative association with increasing attenuated forest cover. As Common Galaxias is the surrogate model for Australian Grayling, and Southern Pygmy Perch is the surrogate model for Yarra Pygmy Perch, these associations transfer to Australian Grayling and Yarra Pygmy Perch. In other words, for these 4 species, revegetation to 20 metre riparian buffer reduces predicted habitat suitability. This is an important trade-off to bear in mind with respect to revegetation as a management action.
4. In our HSMs, when full or partial barriers feature in a model, they do not tend to feature in the top three contributing predictors (see Appendix). The relative percentage contribution of full or partial barriers in most fish HSMs is less than or approximately 5% (e.g. Short-finned Eel, Broad-finned Galaxias, Common Galaxias (and by extension, Australian Grayling), Lampreys, Southern Pygmy Perch (and by extension, Yarra Pygmy Perch), Flatheaded Gudgeon, Australian Smelt). The two exceptions to this are Spotted Galaxias and Tupong. Number of partial and full barriers along the downstream flowpath are the third and fifth most influential predictors in the Spotted Galaxias HSM with relative percentage contributions of 12.9% and 11.4% respectively. For Tupong, full and partial barriers are the third and eighth most influential predictors in the its HSM with relative percentage contributions of 15.5% and 4.4% respectively.

In the following sections, we provide the following 10-year planned works results for *each* of the 13 native fish species:

- a) Stacked barplots summarising the lengths of stream in each predicted habitat suitability category by scenario
- b) Mapped predictions across the Port Philip Western Port (PPWP) region by scenario
- c) ‘Difference’ maps showing where and how scenarios differ relative to the CURR scenario used in the HWS 2018

Finally, we also provide results based on native fish species stacked probabilities which is calculated by summing predicted habitat suitability probabilities across all 13 species by stream reach.

Note that for the works-to-date (WTD), we did *not* produce stacked barplots, mapped predictions or ‘difference’ maps for individual native fish species. For WTD, we only produced results based on native fish species stacked probabilities.

6.1 Short-finned Eel

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 11). For the Short-finned Eel, revegetation action on its own produced increases in lengths of streams mainly in the 0.45-0.60, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories (top image, Figure 11). Stormwater works on its own produced negligible changes in predicted habitat suitability. Fishways action on its own produced small increases in lengths of streams mainly in the 0.45-0.60 category. All actions in combination produced predicted increases in the length of streams in the three highest predicted habitat suitability categories (top image, Figure 11).

The mapped habitat suitability of Short-finned Eel under the CURR scenario shows a wide distribution across the PPWP region with predicted occurrences in just about all major river systems and indeed tributaries of the major rivers (bottom image, Figure 11).

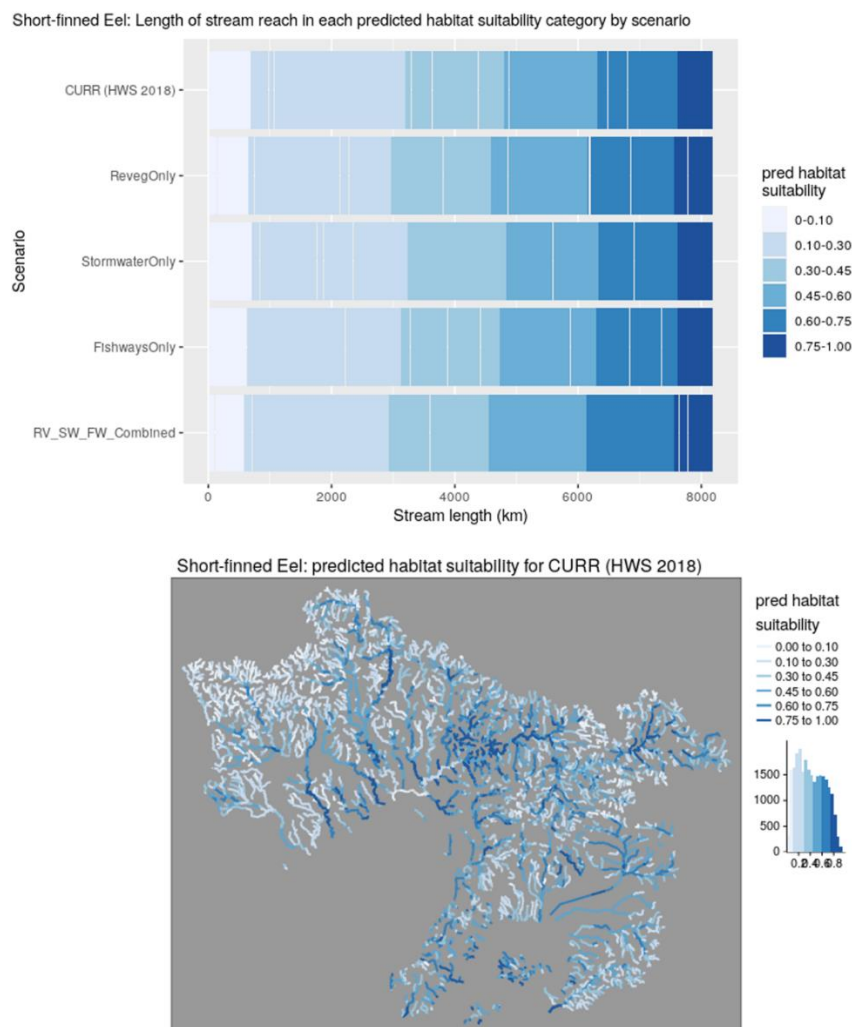
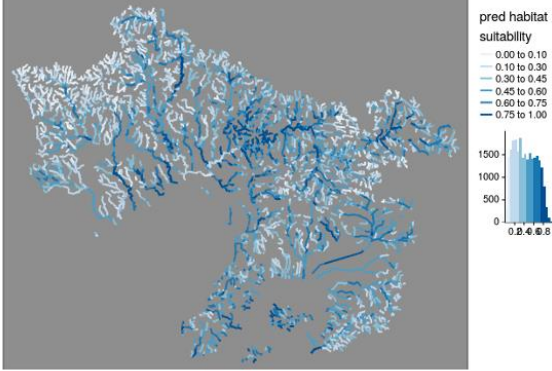


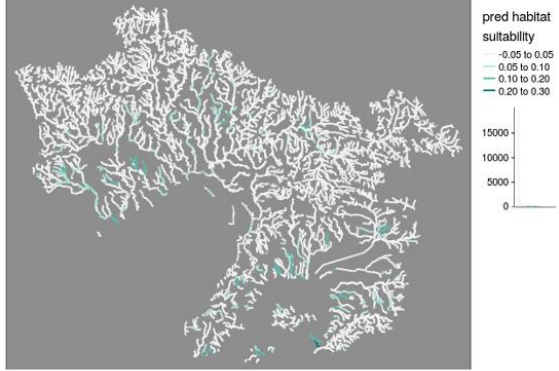
Figure 11 Top: Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Short-finned Eel. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURR scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

The mapped habitat suitability of Short-finned Eel under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 12. The corresponding 'difference' map for each action type is shown in the right-hand column of images in Figure 12. These 'difference' maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURR scenario used in HWS 2018. As we can see, revegetation-only works produced predicted habitat suitability benefits in stream reaches across a wider range of localities such as stream reaches in the sub-catchments of Little River Lower, Little River Upper, Lollypop Creek, Skeleton Creek, Moonee Ponds Creek, Merri Creek Upper, Darebin Creek, Yarra River Middle, Woori Yallock Creek, Bunyip Middle and Upper, Lang Lang River, Bass River, Cardinia, Toomuc, Deep and Ararat Creeks, Dalmore Outfalls, Mornington Peninsula Western Creeks, Mornington Peninsula South-Eastern Creeks and French and Phillip Islands (Figure 12). Stormwater works produced decreases in predicted habitat suitability in a small number of reaches in the sub-catchments of Werribee River Lower, Kororoit Creek Lower, Emu Creek, Woori Yallock Creek, Cardinia, Toomuc, Deep and Ararat Creeks and King Parrot and Mush Creeks (Figure 12). Fishways works produced increases in predicted habitat suitability mainly in reaches of the sub-catchments of Werribee River Lower, Werribee River Middle and Parwan Creek) (Figure 12).

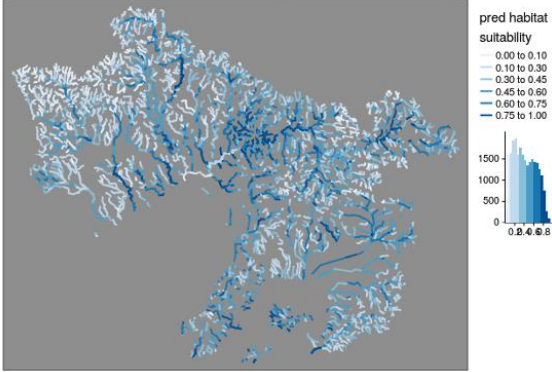
Short-finned Eel: predicted habitat suitability for 10yr planned Reveg Only



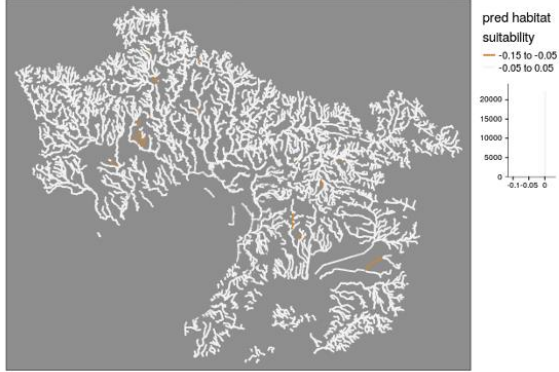
Short-finned Eel Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



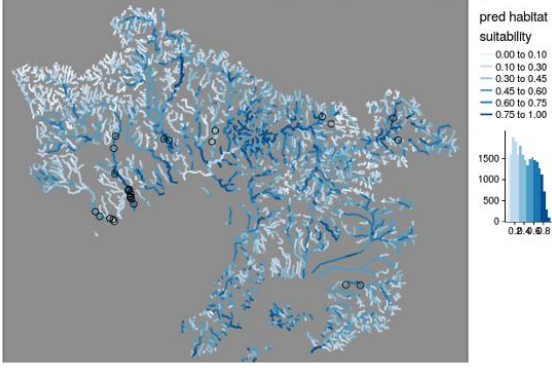
Short-finned Eel: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



Short-finned Eel Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)



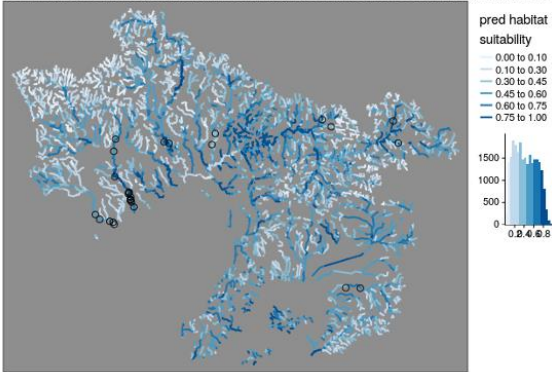
Short-finned Eel: predicted habitat suitability for 10yr planned Fishways Only



Short-finned Eel Difference Map: 10yr planned Fishway works Only - CURR (HWS 2018)



Short-finned Eel: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Short-finned Eel Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

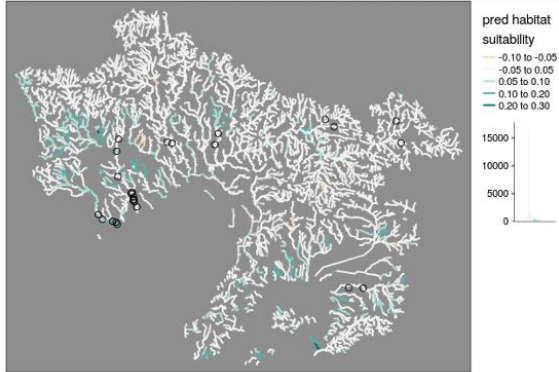


Figure 12 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Short-finned Eel under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned

stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.2 River Blackfish

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 13). For the River Blackfish, revegetation action on its own is what drives predicted increases in length of streams mainly in the 0.10-0.30 and 0.75-1.0 predicted habitat suitability categories; the stormwater works and fishways action on their own produce negligible and no changes, respectively, in predicted habitat suitability (top image, Figure 13).

The mapped habitat suitability of River Blackfish under the CURR scenario shows a relatively restricted distribution within the PPWP region with predicted occurrences concentrated in reaches in the sub-catchments of Lerderderg River, Woori Yallock Creek, Little Yarra River and Hoddles Creek, Watts River (Rural), Watts River (Source), Yarra Rver Upper (Rural), Yarra River Upper (Source) and Bunyip River Middle and Upper (bottom image, Figure 13).

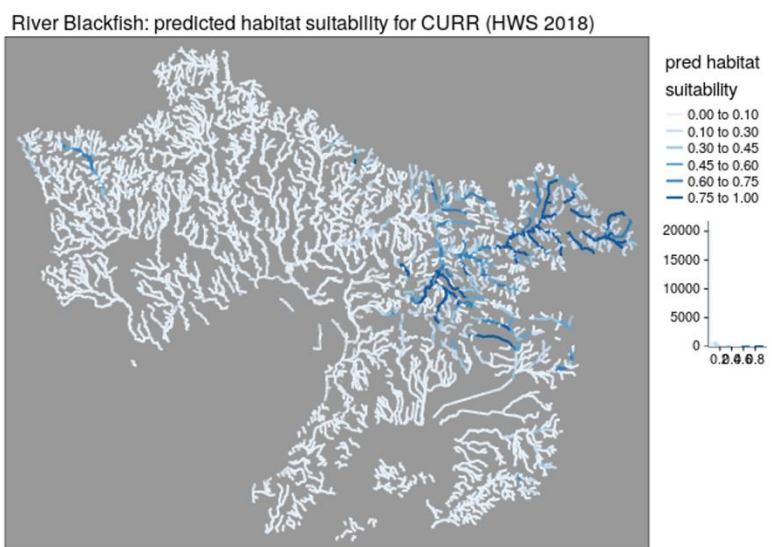
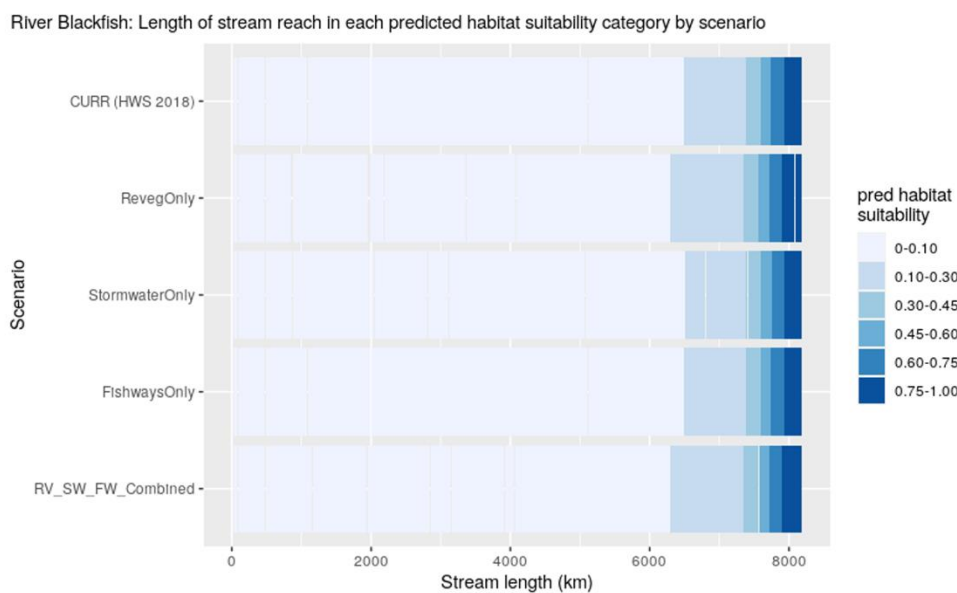
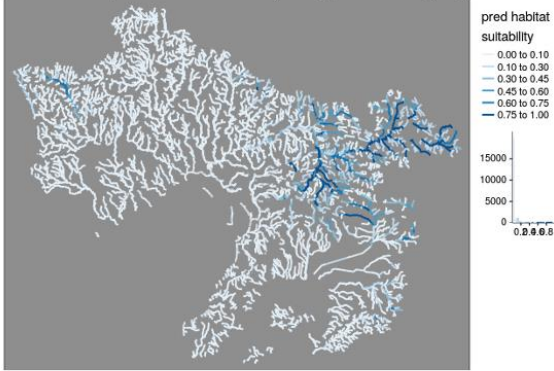


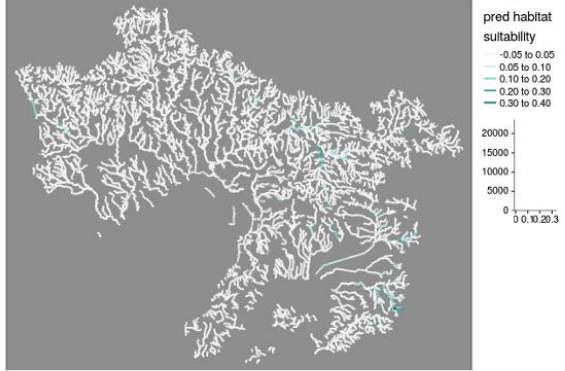
Figure 13 Top: Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the River Blackfish. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURRE scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

The mapped habitat suitability of River Blackfish under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 14. The corresponding 'difference' map for each action type is shown in the right-hand column of images in Figure 14. These 'difference' maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURRE scenario used in HWS 2018. As we can see, revegetation-only works produces predicted habitat suitability benefits in a small number of localities, namely in stream reaches of the sub-catchments of Yarra River Middle, Yarra River Upper (Rural) and Lang Lang River (Figure 14). Stormwater works and fishway works make negligible and no difference respectively to predicted habitat suitability of River Blackfish (Figure 14).

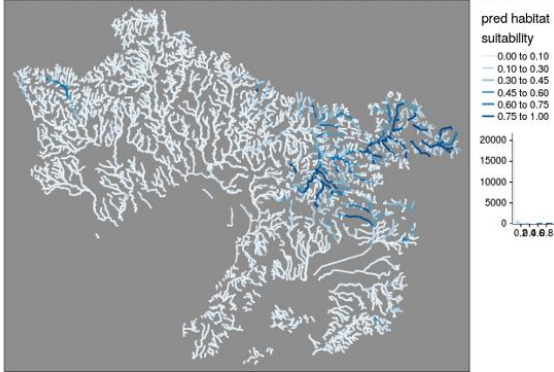
River Blackfish: predicted habitat suitability for 10yr planned Reveg Only



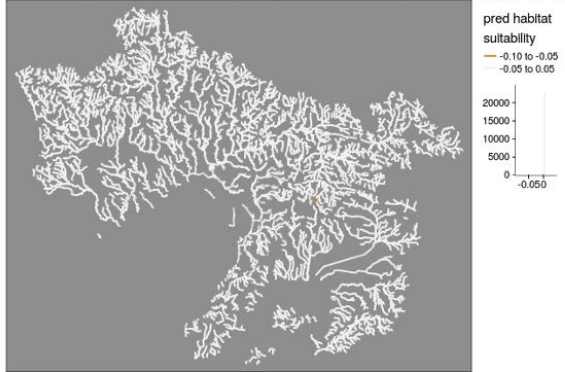
River Blackfish Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



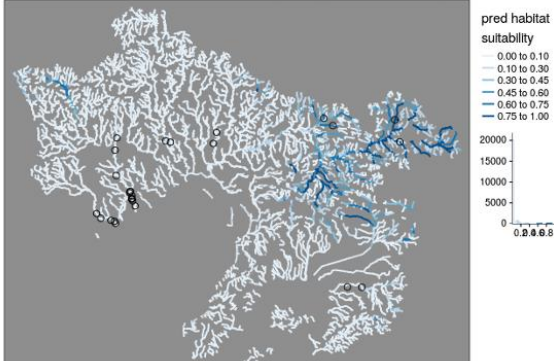
River Blackfish: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



River Blackfish Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)

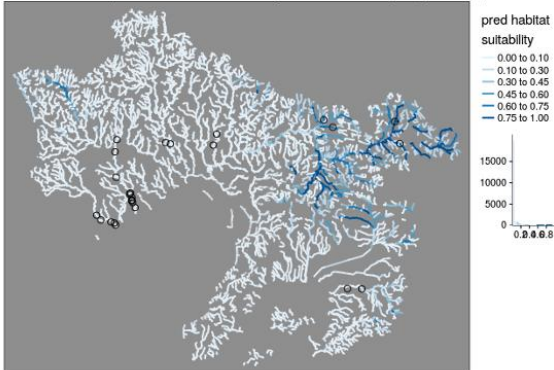


River Blackfish: predicted habitat suitability for 10yr planned Fishways Only



For River Blackfish, there is NO difference in predicted habitat suitability for 10yr planned Fishway works Only - CURR (HWS 2018). Neither FullBarrierDS nor PartBarrierDS feature in the fitted HSM for River Blackfish (see fitted response curves for the species in the Appendix), so it's unsurprising that fishway works make no difference to predicted habitat suitability for River Blackfish.

River Blackfish: predicted habitat suitability for combined RV, SW, FW 10yr planned works



River Blackfish Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

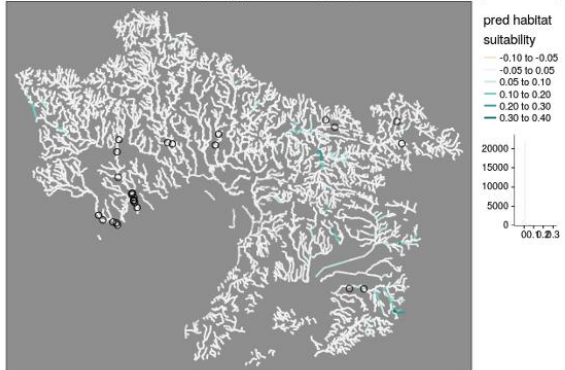


Figure 14 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the River Blackfish under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned

stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.3 Broad-finned Galaxias

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 13). For the Broad-finned Galaxias, both revegetation action and fishways action on their own can drive predicted increases in lengths of streams in the 0.10-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories; the stormwater works action on its own produced no improvement in predicted habitat suitability (top image, Figure 15). All three actions combined produced strong increases in lengths of streams in the 0.10-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories.

The mapped habitat suitability of Broad-finned Galaxias under the CURR scenario shows a broad but very patchy distribution within the PPWP region with predicted occurrences concentrated in reaches in the sub-catchments of Little River Upper, Lollypop Creek, Werribee River Lower, Deep Creek Lower, Merri Creek Upper, Moonee Ponds Creek, Diamond Creek (Rural), Corhanwarrabul, Monbulk and Ferny Creeks, Watts River (Source), Bunyip River Middle and Upper, Tarago River, Cardinia, Toomuc, Deep and Ararat Creeks, Mornington Peninsular Western Creeks, Mornington Peninsula North-Eastern Creeks and Mornington Peninsula South-Eastern Creeks (bottom image, Figure 15).

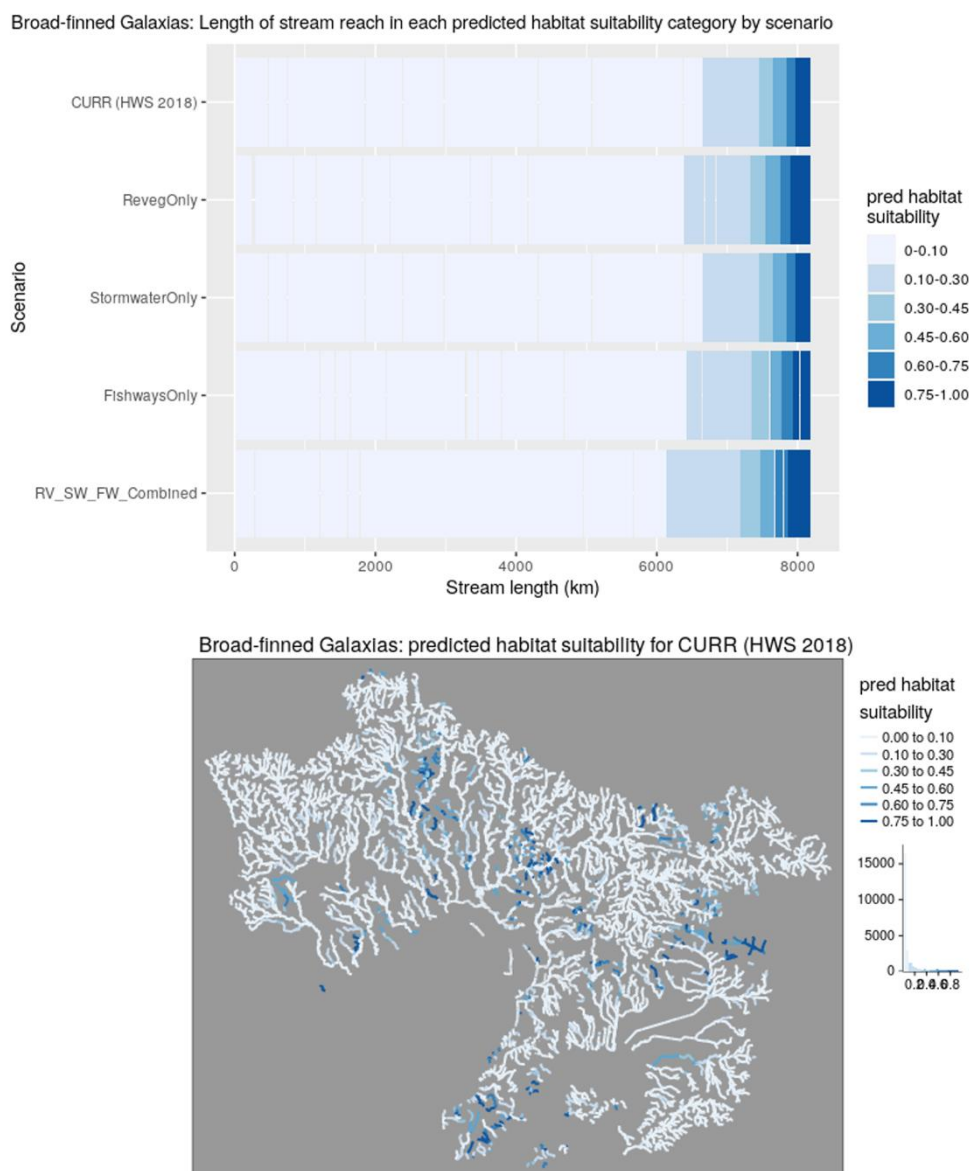
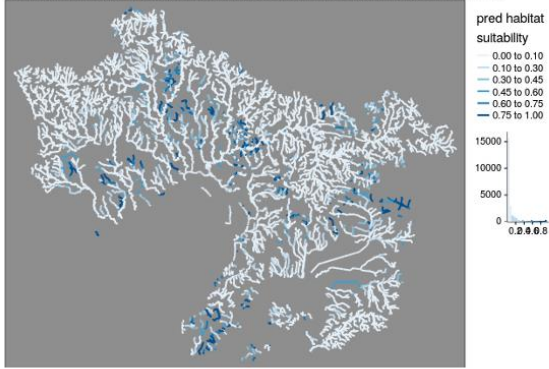


Figure 15 Top: Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Broad-finned Galaxias. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURR scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

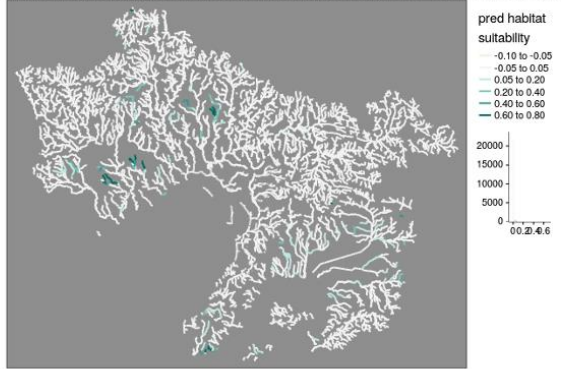
The mapped habitat suitability of Broad-finned Galaxias under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 16. The corresponding ‘difference’ map for each action type is shown in the right-hand column of images in Figure 16. These ‘difference’ maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURR scenario used in HWS 2018. As we can see, revegetation-only works produces predicted habitat suitability benefits in a small number of localities, namely in stream reaches of the sub-catchments of Lollypop Creek, Skeleton Creek, Jacksons Creek, Kororoit Creek Upper, Merri Creek Upper, Darebin Creek and Mornington Peninsula South-Eastern Creeks (Figure 16). Stormwater works make no difference to predicted habitat suitability of Broad-finned Galaxias (Figure 16). And fishway works on their own

produced predicted habitat suitability benefits mainly in the west, in stream reaches of the sub-catchments of Little River Upper, Parwan Creek, Werribee River Lower, Werribee River Middle and Toolern Creek (Figure 16).

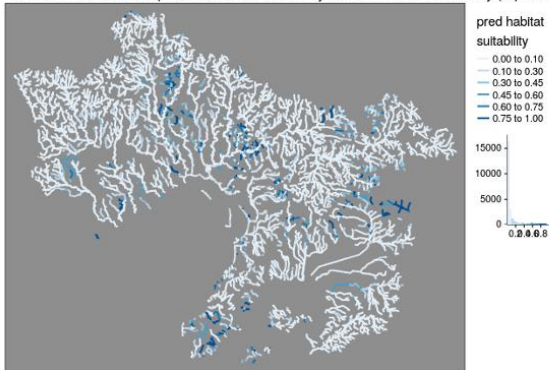
Broad-finned Galaxias: predicted habitat suitability for 10yr planned Reveg Only



Broad-finned Galaxias Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)

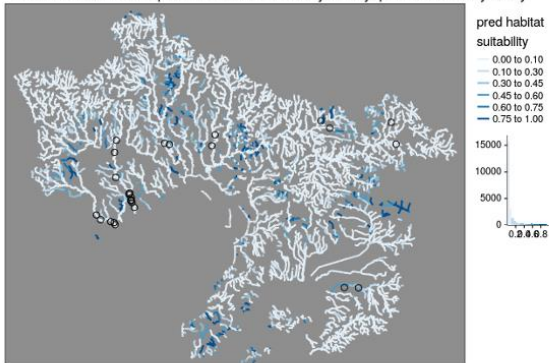


Broad-finned Galaxias: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)

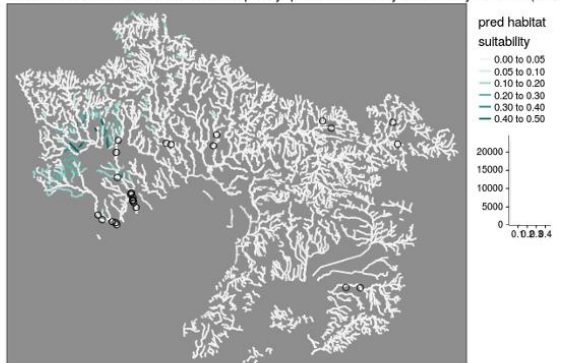


For Broad-finned Galaxias, there is NO difference in predicted habitat suitability for 10yr planned Stormwater works Only - CURR (HWS 2018). AttImperv does not feature in the fitted HSM for Broad-finned Galaxias (see fitted response curves for the species in the Appendix), so it's unsurprising that stormwater works make no difference to predicted habitat suitability for Broad-finned Galaxias.

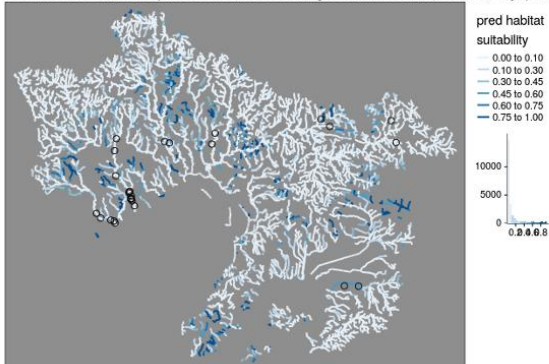
Broad-finned Galaxias: predicted habitat suitability for 10yr planned Fishways Only



Broad-finned Galaxias Difference Map: 10yr planned Fishway works Only - CURR (HWS 2018)



Broad-finned Galaxias: predicted habitat suitability for combined RV, SW, FW 10yr planned



Broad-finned Galaxias Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

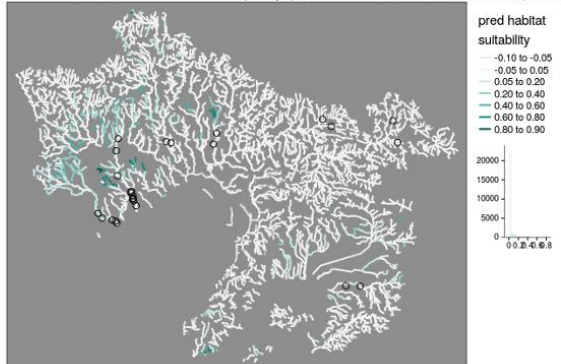


Figure 16 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Broad-finned Galaxias under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year

planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.4 Common Galaxias

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 17). For the Common Galaxias, fishway actions are what drives predicted increases in habitat suitability (mainly in the 0.45-0.60, 0.60-0.75 and 0.75-1.0 categories). Revegetation on its own produced decreases in lengths of streams mainly in the 0.45-0.60, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories. Stormwater works on its own produced slight increases in stream lengths in the 0-0.10, 0.10-0.30, 0.30-0.45 and 0.45-0.60 categories and slight decreases of stream lengths in 0.60-0.75 and 0.75-1.0 categories of predicted habitat suitability (top image, Figure 17). All three actions in combination produced slight increases in stream lengths in the predicted habitat suitability categories of 0-0.10, 0.30-0.45, 0.45-0.60, and decreases in the categories of 0.10-0.30, 0.60-0.75 and 0.75-1.0 (top image, Figure 17).

The mapped habitat suitability of Common Galaxias under the CURR scenario shows a broad distribution right across the PPWP region but it does not seem to favour stream reaches in highly forested catchments such as in the sub-catchments of Werribee River Upper, Lerderderg River, upper sections of Werribee River Middle and Jacksons Creek, Watts River (Source), Yarra River Upper (Rural), Yarra River Upper (Source) and Little Yarra River and Hoddles Creek (bottom image, Figure 17).

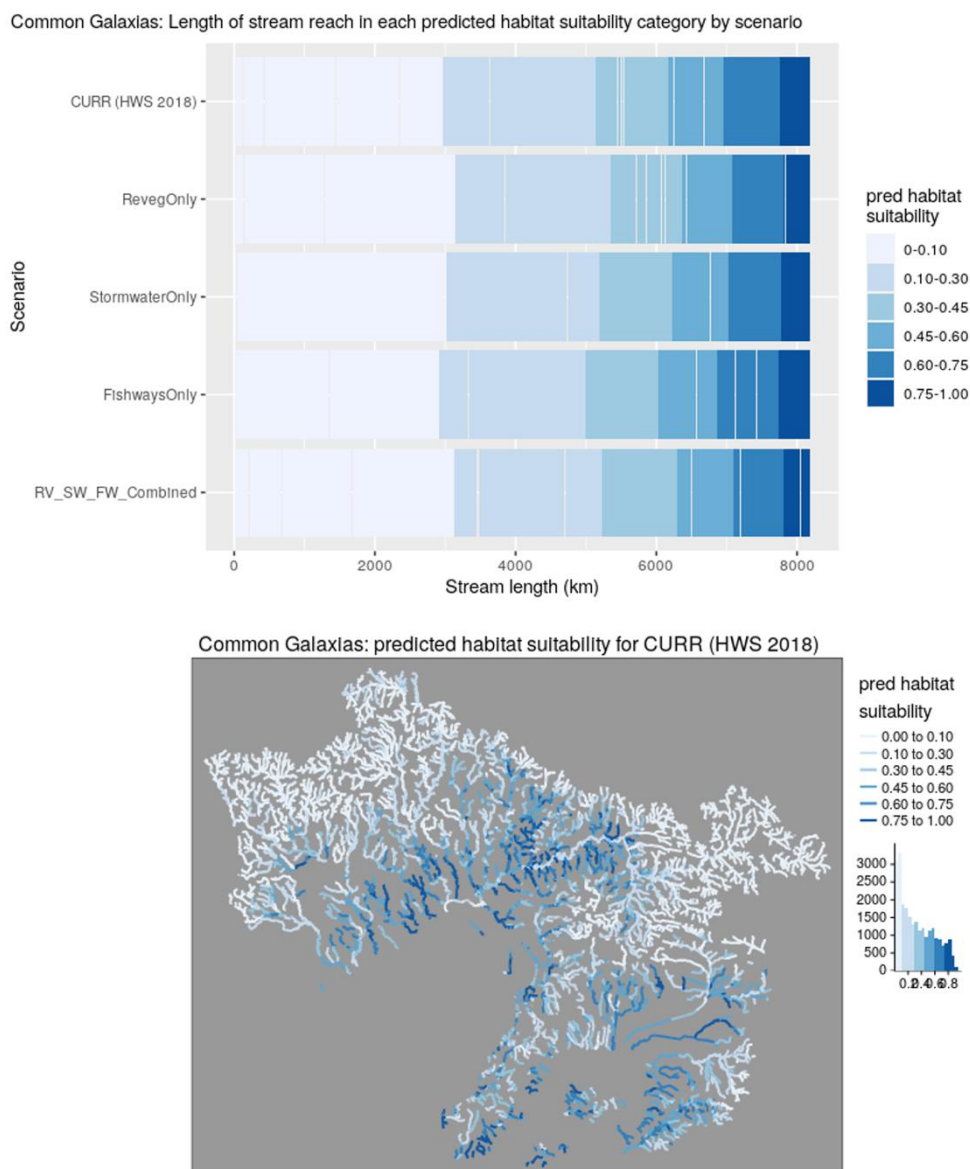
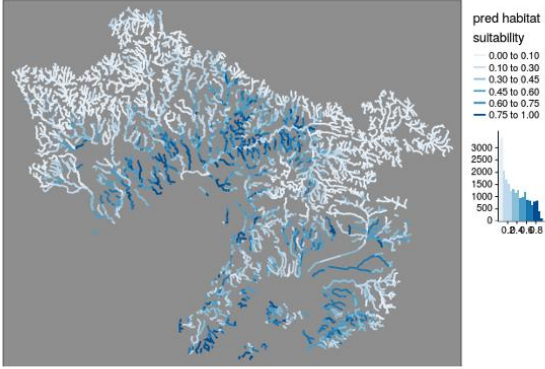


Figure 17 Top: Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Common Galaxias. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURR scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

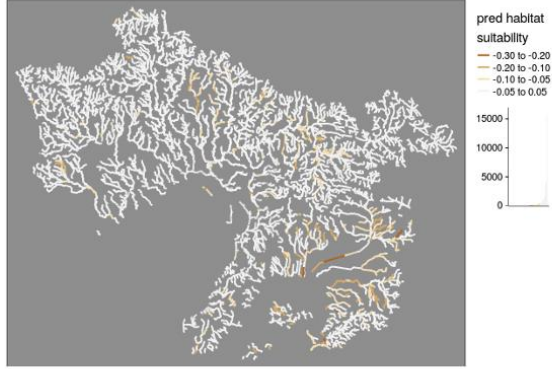
The mapped habitat suitability of Common Galaxias under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 18. The corresponding 'difference' map for each action type is shown in the right-hand column of images in Figure 18. These 'difference' maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURR scenario used in HWS 2018. As we can see, revegetation-only works produces slight decreases in predicted habitat suitability in a number of locations, such as in stream reaches of the sub-catchments of Merri Creek Upper, Bunyip River Middle and Upper, Cardinia, Toomuc, Deep and Ararat Creeks and Lang Lang River (Figure 18). Stormwater works also produced slight decreases in predicted habitat suitability in stream reaches in the sub-catchments of Skeleton Creek, Kororoit Creek Lower, Darebin Creek,

Tarago River and King Parrot and Musk Creeks. Fishway works produced increases in predicted habitat suitability of Common Galaxias in the sub-catchments of Werribee River Lower, Darebin Creek and Lang Lang River (Figure 18).

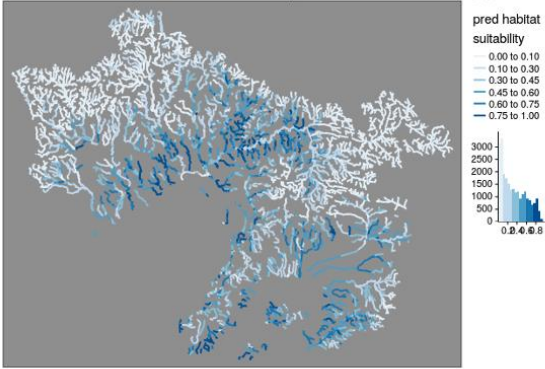
Common Galaxias: predicted habitat suitability for 10yr planned Reveg Only



Common Galaxias Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



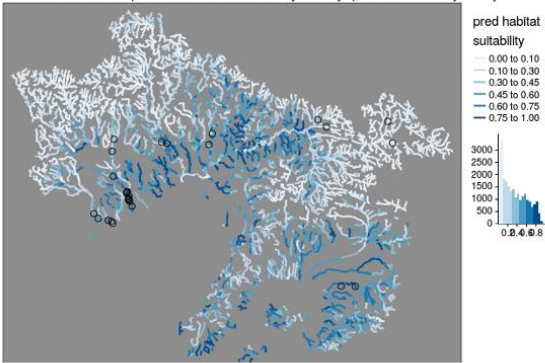
Common Galaxias: predicted habitat suitability for Stormwater works Only (equiv to WTD 20;



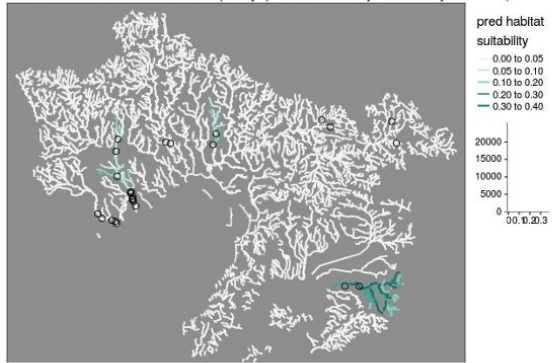
Common Galaxias Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)



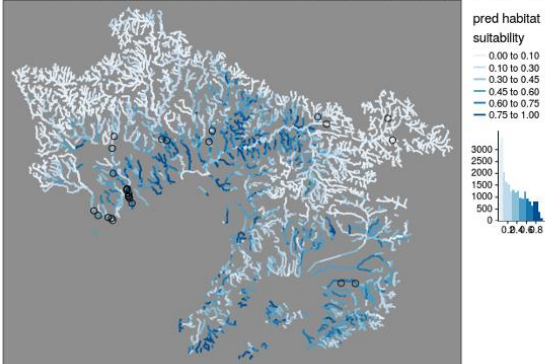
Common Galaxias: predicted habitat suitability for 10yr planned Fishways Only



Common Galaxias Difference Map: 10yr planned Fishway works Only - CURR (HWS 2018)



Common Galaxias: predicted habitat suitability for combined RV, SW, FW 10yr planned work



Common Galaxias Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

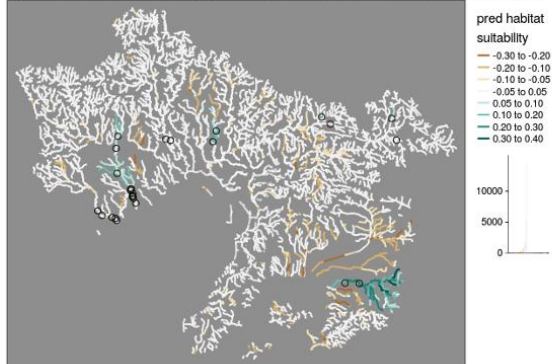


Figure 18 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Common Galaxias under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year

planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.5 Ornate Galaxias

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 19). For the Ornate Galaxias, revegetation action on its own is what drives predicted increases in length of streams mainly in the 0.10-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories. Stormwater works and fishways action on their own produce slight deterioration and no improvement predicted habitat suitability, respectively (top image, Figure 19). All three actions in combination produced increases in lengths of stream in the 0.10-0.30, 0.45-0.60, 0.60-0.75 and 0.75-1.0 categories of predicted habitat suitability, though the performance of all three actions in combination delivers slightly less benefit than revegetation action on its own (top image, Figure 19).

The mapped habitat suitability of Ornate Galaxias under the CURR scenario shows a relatively broad distribution right across the PPWP region. Interestingly, Ornate Galaxias appears to have almost the opposite spatial distribution pattern in the PPWP as the Common Galaxias. Ornate Galaxias predicted occurrences are concentrated in stream reaches where the predicted occurrence of Common Galaxias is low, in the sub-catchments of Werribee River Upper, Lerderderg River, Jacksons Creek, Emu Creek, Deep Creek Upper, Boyd Creek, Plenty River Upper, Plenty River (Source), Diamond Creek (Source), Steels and Pauls Creek (Source), Watts River (Rural), Watts River (Source), Yarra River Upper (Source), Yarra River Upper (Rural), Little Yarra River and Hoddles Creek, Woori Yallock Creek, Bunyip River Middle and Upper and Tarago River (bottom image, Figure 19).

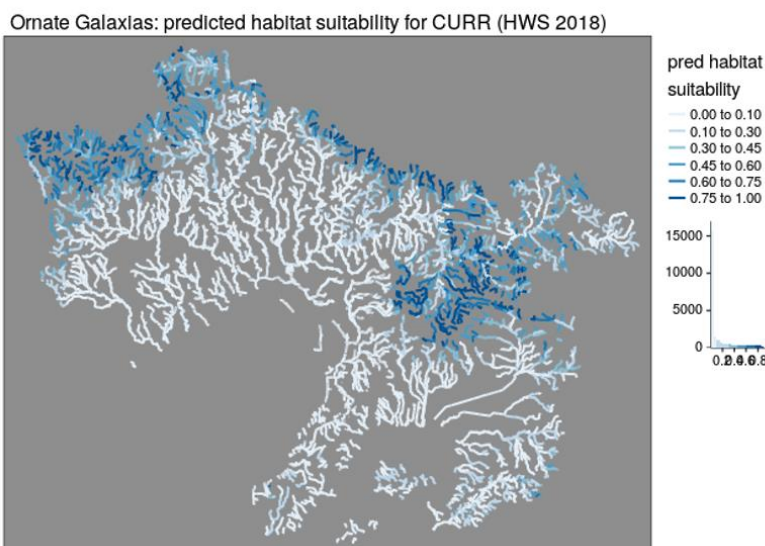
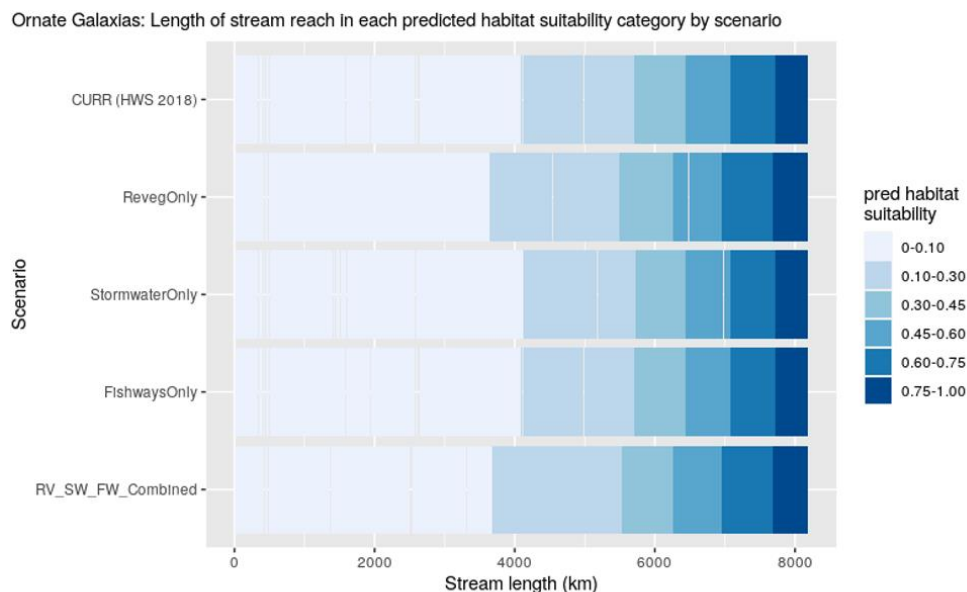
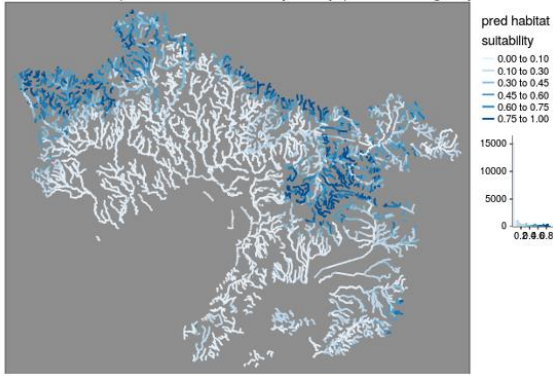


Figure 19 Top: Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Ornate Galaxias. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURRE scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

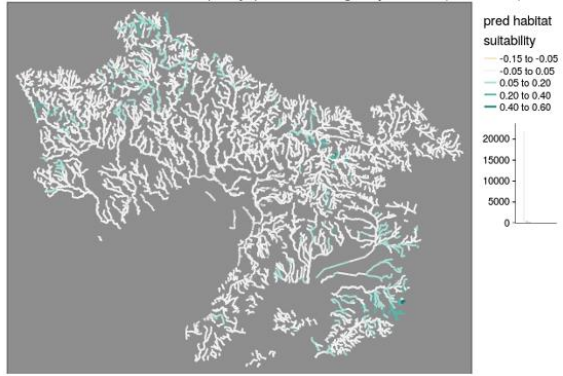
The mapped habitat suitability of Ornate Galaxias under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 20. The corresponding ‘difference’ map for each action type is shown in the right-hand column of images in Figure 20. These ‘difference’ maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURRE scenario used in HWS 2018. As we can see, revegetation-only works produces predicted habitat suitability benefits in a number of localities, namely in stream reaches of the sub-catchments of Werribee River Upper, Toolern Creek, Jacksons Creek, Deep Creek Upper, Yarra River Middle, Yarra River Upper (Rural), Bunyip River Middle and Upper, Tarago River, King Parrot and Musk Creeks and Lang Lang River

(Figure 20). Stormwater works and fishway works make a very slight negative and no difference, respectively, to predicted habitat suitability of Ornate Galaxias (Figure 20).

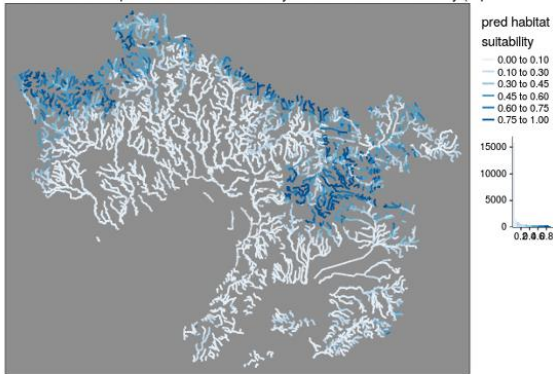
Ornate Galaxias: predicted habitat suitability for 10yr planned Reveg Only



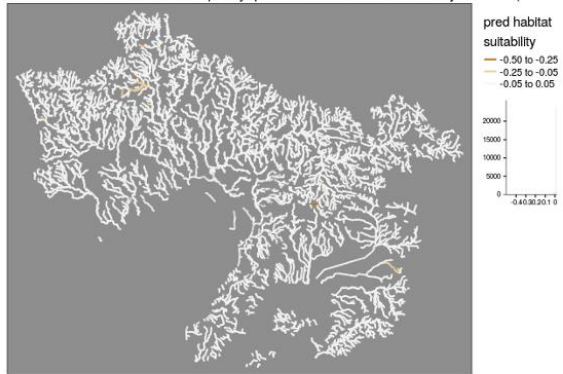
Ornate Galaxias Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



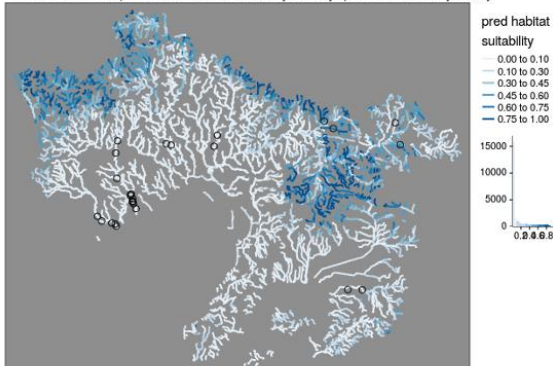
Ornate Galaxias: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



Ornate Galaxias Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)

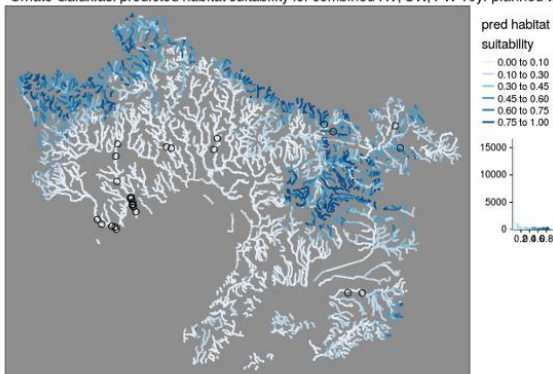


Ornate Galaxias: predicted habitat suitability for 10yr planned Fishways Only



For Ornate Galaxias, there is NO difference in predicted habitat suitability for 10yr planned Fishway works Only - CURR (HWS 2018). Neither FullBarrierDS nor PartBarrierDS feature in the fitted HSM for Ornate Galaxias (see fitted response curves for the species in the Appendix), so it's unsurprising that fishway works make no difference to predicted habitat suitability for Ornate Galaxias.

Ornate Galaxias: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Ornate Galaxias Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

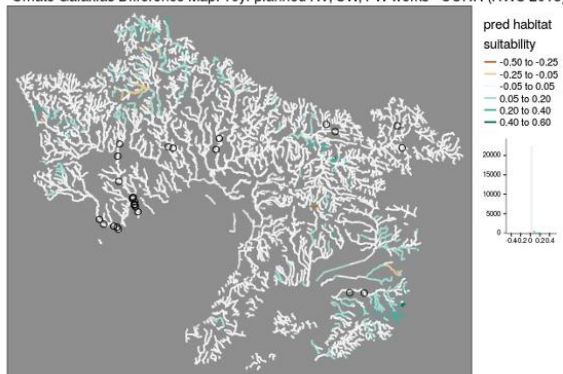


Figure 20 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Ornate Galaxias under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned

stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.6 Spotted Galaxias

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 21). For the Spotted Galaxias, both revegetation action and fishways on their own can drive predicted increases in lengths of stream mainly in the 0.10-0.30, 0.30-0.45, 0.45-0.60 and 0.60-0.75 predicted habitat suitability categories. Stormwater works action on its own produces no improvement in predicted habitat suitability (top image, Figure 21). All three actions in combination produce strong increases in lengths of stream in the 0.10-0.30, 0.30-0.45, 0.45-0.60 and 0.60-0.75 categories of predicted habitat suitability (top image, Figure 21).

The mapped habitat suitability of Spotted Galaxias under the CURR scenario shows a relatively broad but patchy distribution within the PPWP region. Areas with very high predicted habitat suitability (0.75-1.0) are restricted to stream reaches in the sub-catchments of Little Yarra River and Hoddles Creek and Bunyip River Middle and Upper. Areas of moderate predicted habitat suitability are in reaches in the sub-catchments of Lollypop Creek, Kororoit Creek Lower, Watsons Creek and French and Phillip Islands (bottom image, Figure 21).

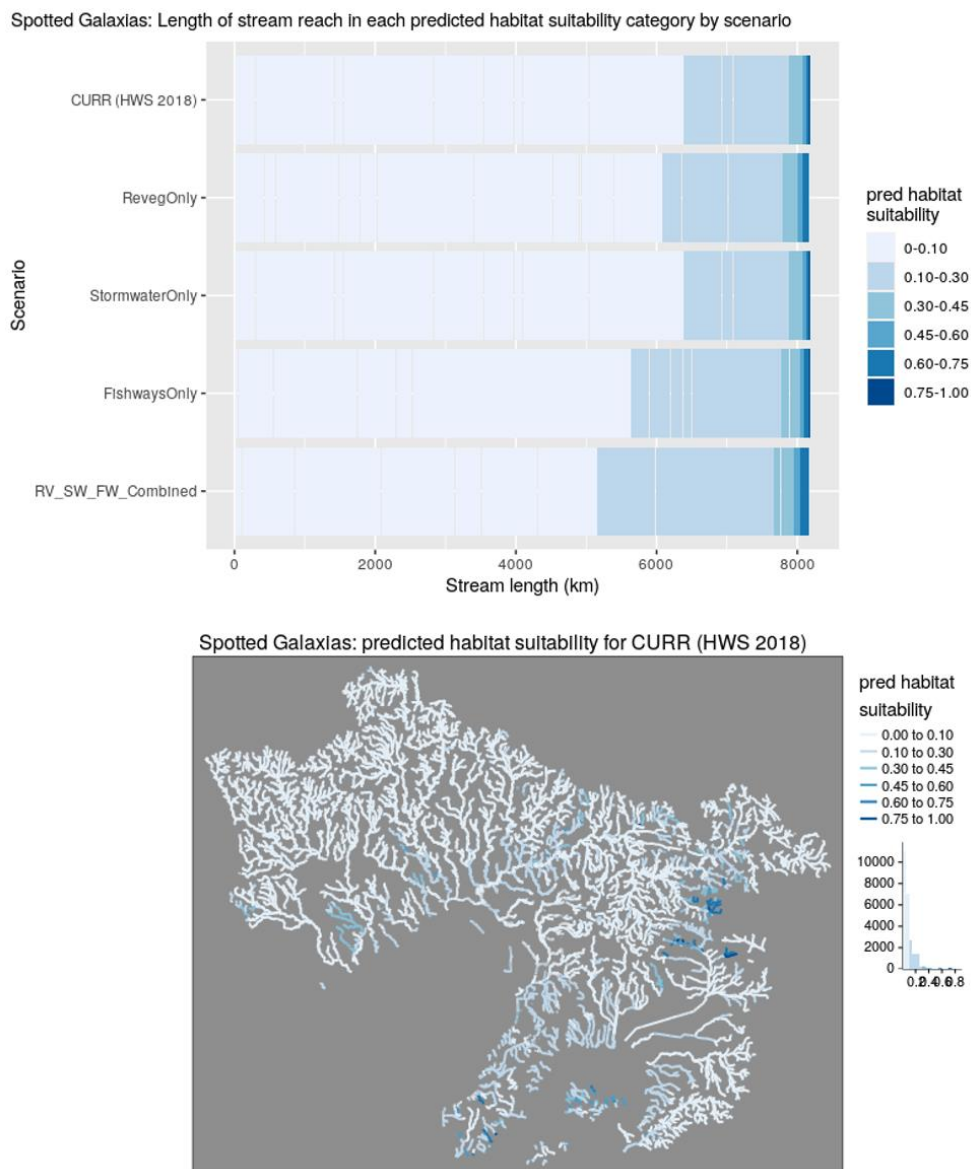
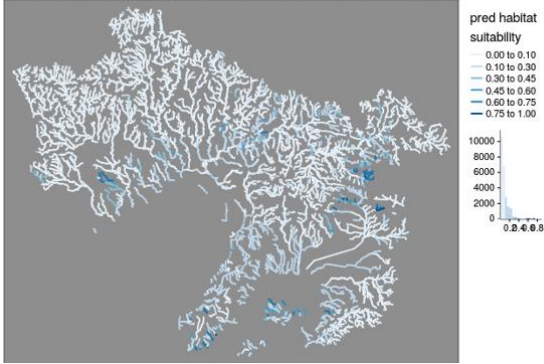


Figure 21 Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Spotted Galaxias. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURRE scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

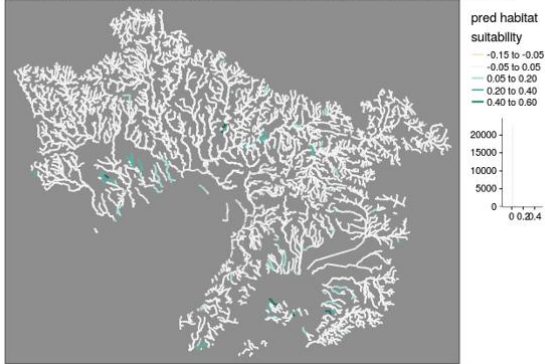
The mapped habitat suitability of Spotted Galaxias under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 22. The corresponding ‘difference’ map for each action type is shown in the right-hand column of images in Figure 22. These ‘difference’ maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURRE scenario used in HWS 2018. As we can see, revegetation-only works produces predicted habitat suitability benefits in a small number of localities, namely in stream reaches of the sub-catchments of Lollypop Creek, Skeleton Creek, Laverton Creek, Kororoit Creek Lower, Watsons Creek, Lang Lang River, Dalmore Outfalls, Mornington Peninsula South-Eastern Creeks and French and Phillip Islands (Figure 22).

Stormwater works make no difference to predicted habitat suitability of Spotted Galaxias (Figure 22). Fishway works produced increases in predicted habitat suitability of Spotted Galaxias in the sub-catchments of Little River Lower, Little River Upper, Werribee River Lower, Toolern Creek, Watts River (Source) and Yarra River Upper (Source) (Figure 22).

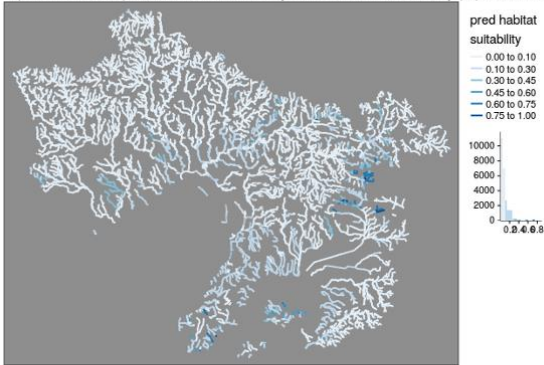
Spotted Galaxias: predicted habitat suitability for 10yr planned Reveg Only



Spotted Galaxias Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



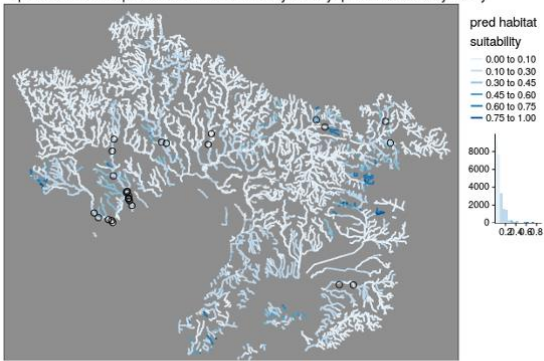
Spotted Galaxias: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



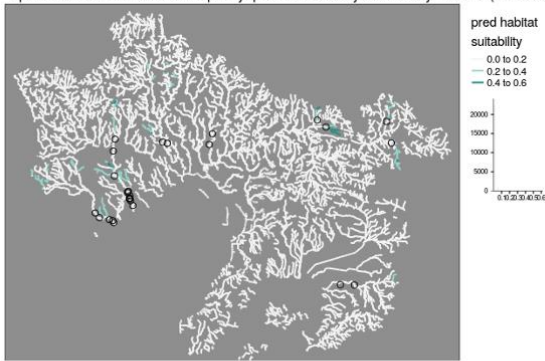
For Spotted Galaxias, there is NO difference in predicted habitat suitability for 10yr planned Stormwater works Only - CURR (HWS 2018).

Attimpery does not feature in the fitted HSM for Spotted Galaxias (see fitted response curves for the species in the Appendix), so it's unsurprising that stormwater works make no difference to predicted habitat suitability for Spotted Galaxias.

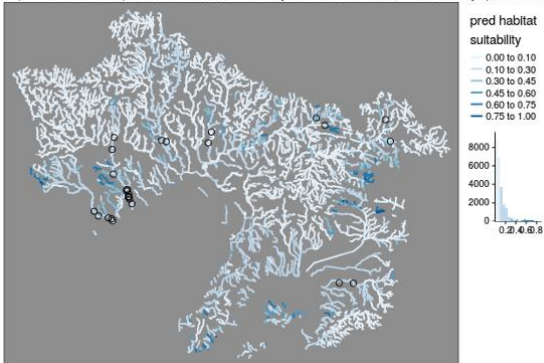
Spotted Galaxias: predicted habitat suitability for 10yr planned Fishways Only



Spotted Galaxias Difference Map: 10yr planned Fishway works Only - CURR (HWS 2018)



Spotted Galaxias: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Spotted Galaxias Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

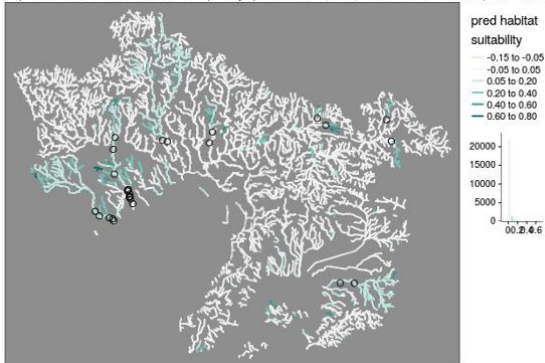


Figure 22 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Spotted Galaxias under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned

revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.7 Pouched Lamprey & Short-headed Lamprey

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 23). For the Lampreys, none of the actions of revegetation, stormwater works or fishways on their own or in combination seems to make little difference to predicted habitat suitability (top image, Figure 23).

The mapped habitat suitability of Lampreys under the CURR scenario shows a relatively restricted distribution within the PPWP region. The spatial distribution pattern of Lampreys is quite similar to that of River Blackfish, with predicted occurrences concentrated in the mainstem reaches in the sub-catchments of Yarra River Lower, Yarra River Middle, Yarra River Upper (Rural), Watts River (Rural), Watts River (Source), Woori Yallock Creek, Bunyip River Middle and Upper and Lang Lang River (bottom image, Figure 23).

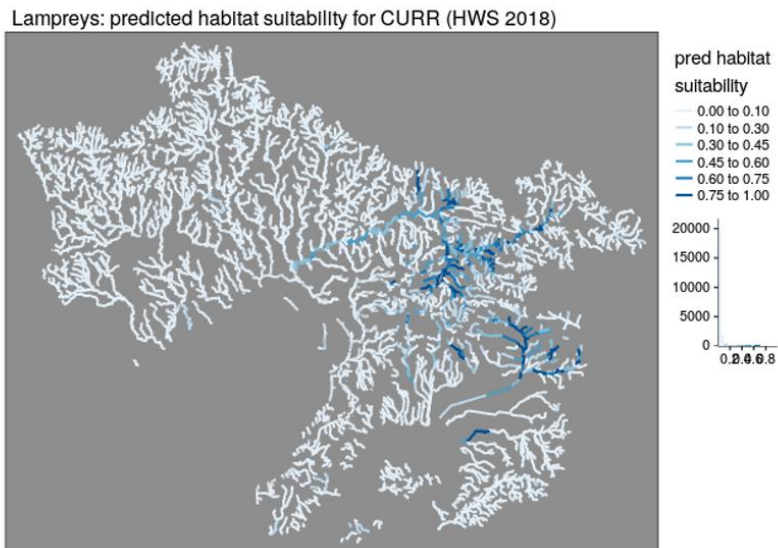
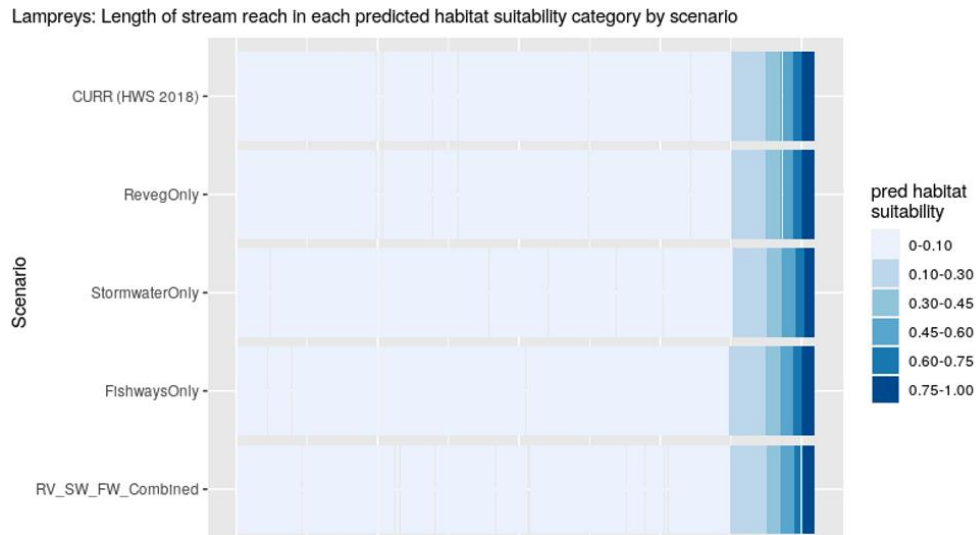
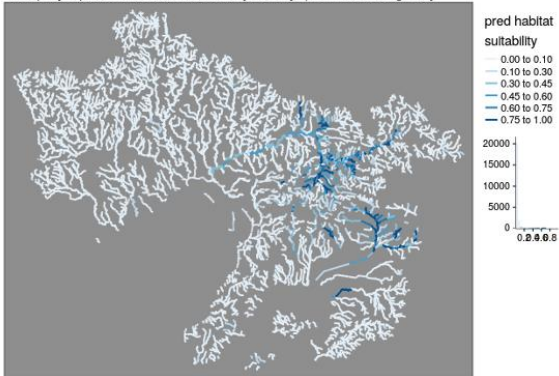


Figure 23 Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Lampreys. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURR scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

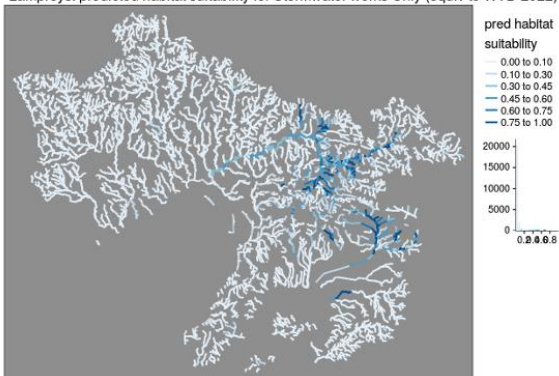
The mapped habitat suitability of Lampreys under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 24. The corresponding ‘difference’ map for each action type is shown in the right-hand column of images in Figure 24. These ‘difference’ maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURR scenario used in HWS 2018. As we can see, revegetation-only works makes no difference to predicted habitat suitability (Figure 24). Stormwater works on its own makes a slight negative difference in small pockets of stream reaches of the sub-catchments of Woori Yallock Creek and Tarago River. And fishway works makes negligible difference to predicted habitat suitability of Lampreys (Figure 24).

Lampreys: predicted habitat suitability for 10yr planned Reveg Only

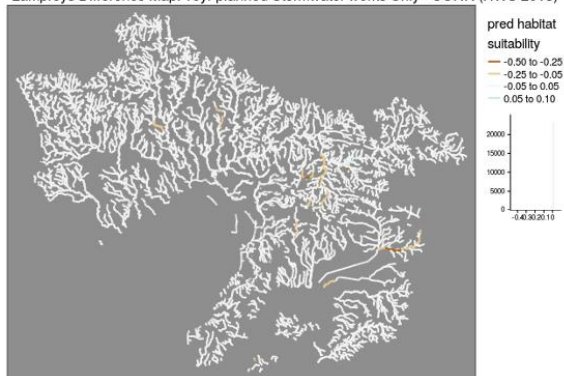


For Lampreys, there is NO difference in predicted habitat suitability for 10yr planned Reveg works Only - CURR (HWS 2018). AttForest does not feature in the fitted HSM for Lampreys (see fitted response curves for the species in the Appendix), so it's unsurprising that revegetation works make no difference to predicted habitat suitability for Lampreys.

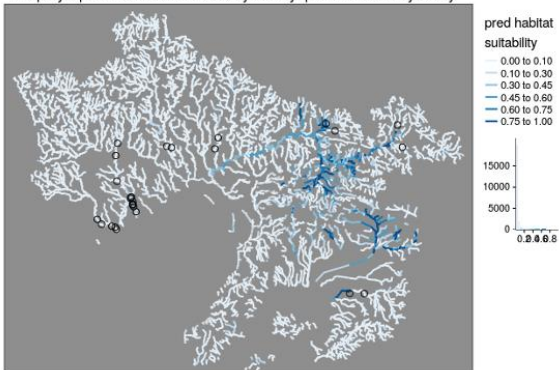
Lampreys: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



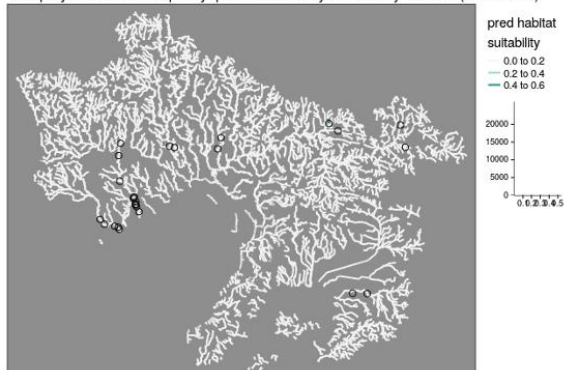
Lampreys Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)



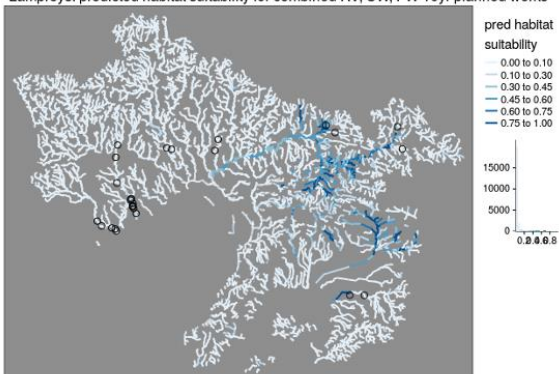
Lampreys: predicted habitat suitability for 10yr planned Fishways Only



Lampreys Difference Map: 10yr planned Fishway works Only - CURR (HWS 2018)



Lampreys: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Lampreys Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

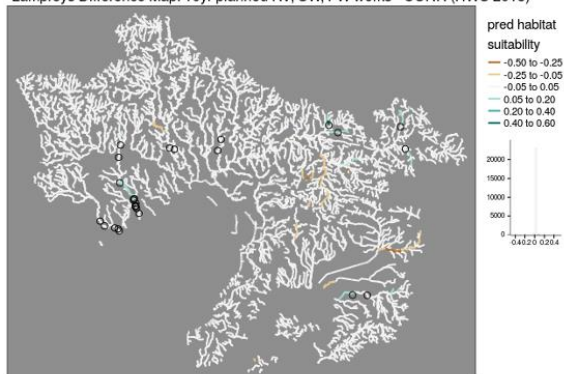


Figure 24 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Lampreys under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: stormwater works only (upper-middle), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.8 Southern Pygmy Perch

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 25). For the Southern Pygmy Perch, revegetation action that is "implemented" in the HSM by assuming a 20 m forest buffer along revegetated reaches (see Section 3.1), actually strongly decreases lengths of stream in the 0.10-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 categories of predicted habitat suitability (top image, Figure 25). Stormwater works on its own makes very little difference to predicted habitat suitability. Fishways are the only action that produce some improvement in predicted habitat suitability, but it is only very slight improvement in the lengths of stream in the 0.30-0.45, 0.45-0.60 and 0.60-0.75 categories (top image, Figure 25). All three actions in combination produce rather large decreases in lengths of stream in the 0.10-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 categories (top image, Figure 25).

The mapped habitat suitability of Southern Pygmy Perch under the CURR scenario shows a broad but very patchy distribution within the PPWP region with higher predicted occurrences concentrated in reaches in the sub-catchments of Werribee River Upper, Deep Creek Upper, Plenty River Upper, Diamond Creek (Rural), Steels and Pauls Creek (Rural), Olinda Creek, Woori Yallock Creek, Cardinia, Toomuc, Deep and Ararat Creeks, Bunyip River Middle and Upper, Tarago River, King Parrot and Musk Creeks, Lang Lang River and Mornington Peninsula Western Creeks (bottom image, Figure 25).

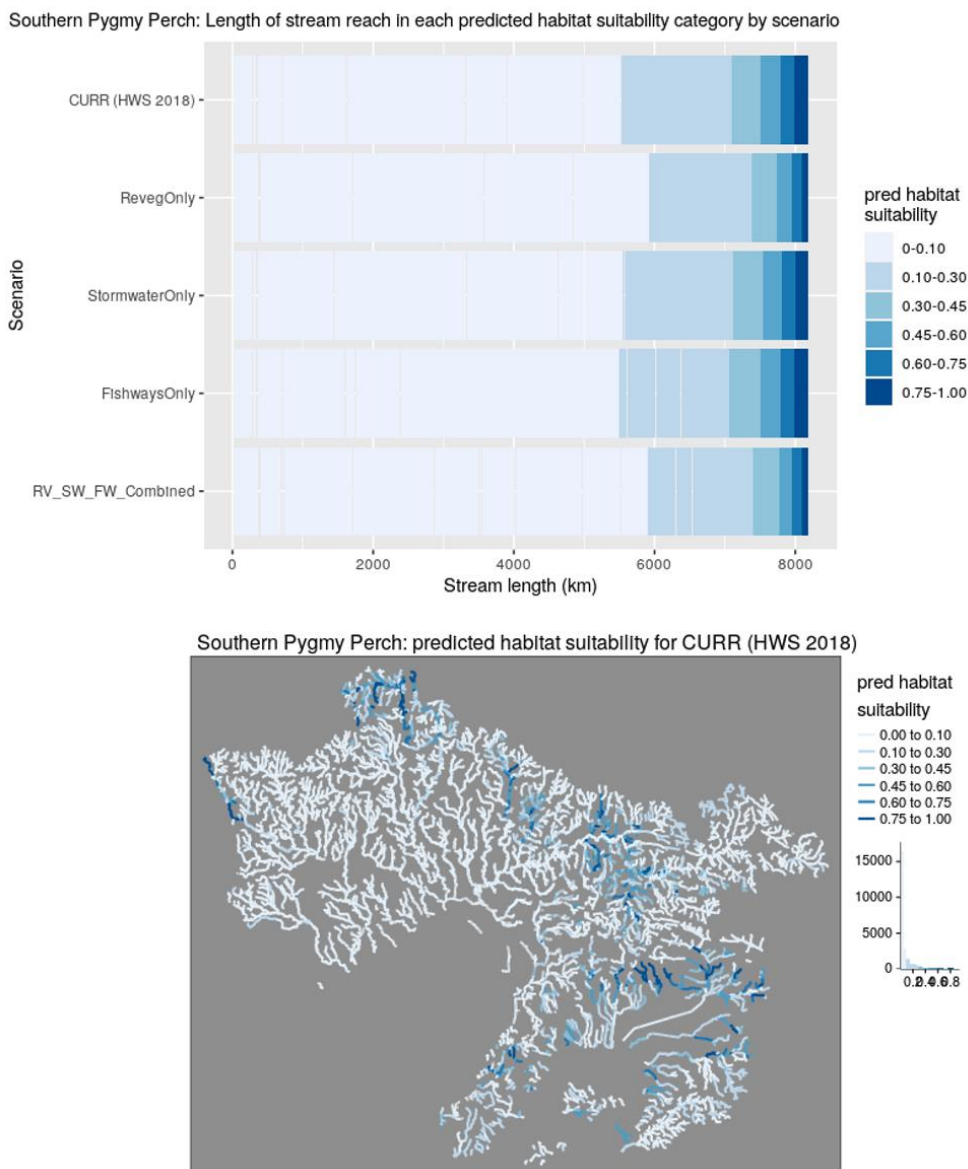


Figure 25 Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Southern Pygmy Perch. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURRE scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

The mapped habitat suitability of Southern Pygmy Perch under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 26. The corresponding ‘difference’ map for each action type is shown in the right-hand column of images in Figure 26. These ‘difference’ maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURRE scenario used in HWS 2018. As we can see, revegetation action that is “implemented” in the HSM by assuming a 20 m forest buffer along revegetated reaches (see Section 3.1), actually decreases predicted habitat suitability in a number of localities, most notably in stream reaches of the sub-catchments of Werribee River Upper, Deep Creek Upper and Woori Yallock Creek (Figure 26). Stormwater works

makes barely any difference to the predicted habitat suitability of Southern Pygmy Perch except for small decreases in isolated reaches in the sub-catchments of Deep Creek Upper, Cardinia, Toomuc, Deep and Ararat Creeks and King Parrot and Musk Creeks. Fishway works make a positive difference to predicted habitat suitability in a small number of localities, namely in stream reaches in the sub-catchments Werribee River Upper, Watts River (Source) (very small improvement) and Lang Lang River (upper reaches) (Figure 26). Interestingly, fishways also slightly decrease predicted habitat suitability of Southern Pygmy Perch in some of the lower reaches in the Lang Lang River management unit (Figure 26). The three actions in combination predominantly produced decreases in predicted habitat suitability across the distribution of the Southern Pygmy Perch (Figure 26).

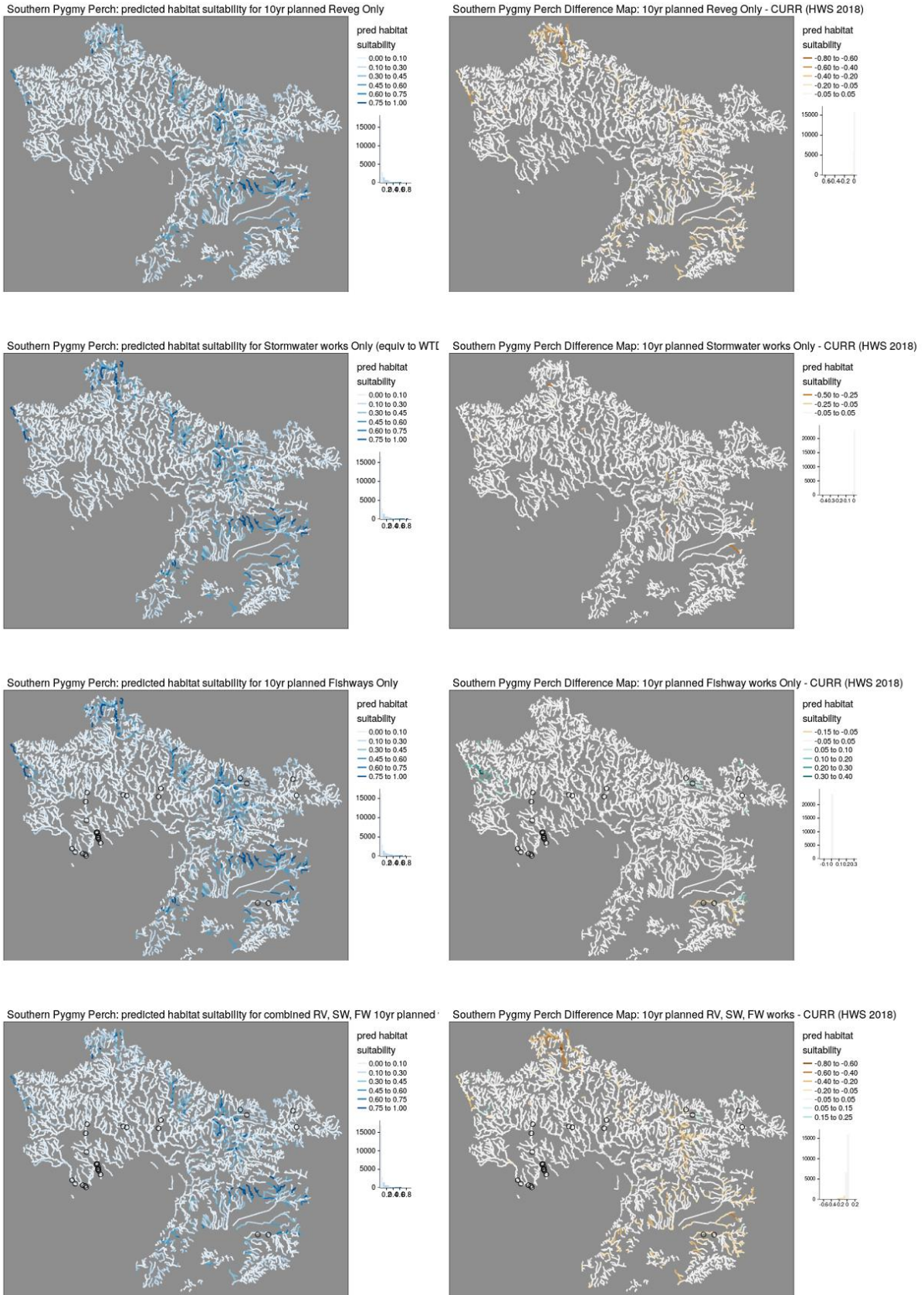


Figure 26 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Southern Pygmy Perch under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat

suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.9 Flatheaded Gudgeon

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 27). For the Flatheaded Gudgeon, revegetation action on its own increased lengths of stream in the 0.60-0.75 and 0.75-1.0 categories of predicted habitat suitability. Stormwater works on its own made no difference to predicted habitat suitability and fishways action on its own produced slight improvements in lengths of stream in the 0.30-0.45 and 0.75-1.0 categories, but also slight declines in lengths of streams in the 0.45-0.60 and 0.60-0.75 categories (top image, Figure 27).

The mapped habitat suitability of Flatheaded Gudgeon under the CURR scenario shows a distribution mostly within the western half of the PPWP region (bottom image, Figure 27). High predicted occurrences are concentrated in stream reaches in the sub-catchments of Little River Lower, Little River Upper, Lollypop Creek, Werribee River Lower, Skeleton Creek, Kororoit Creek Lower, Maribyrnong River, Deep Creek Upper, Merri Creek Lower, Merri Creek Upper, Plenty River Lower and Kananook Creek (bottom image, Figure 27)

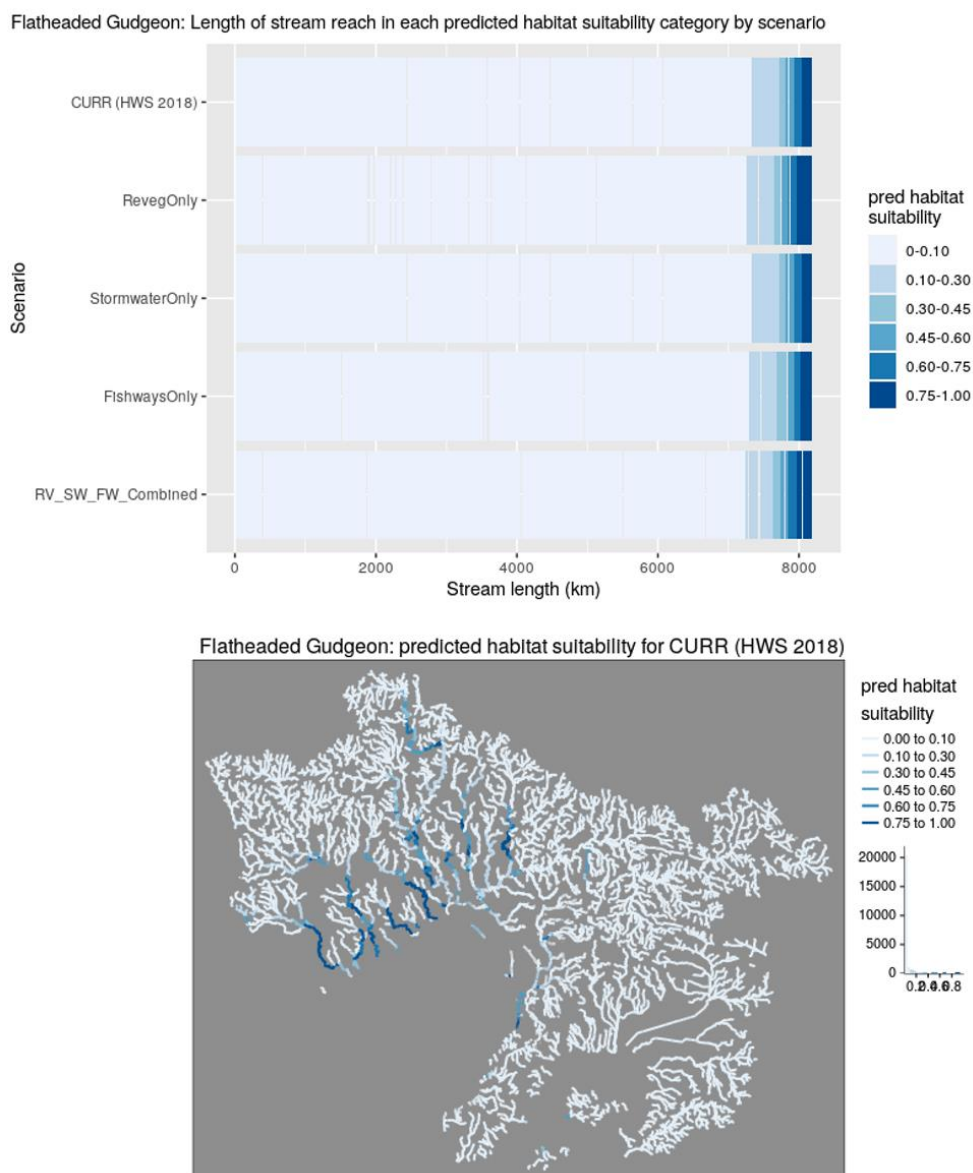
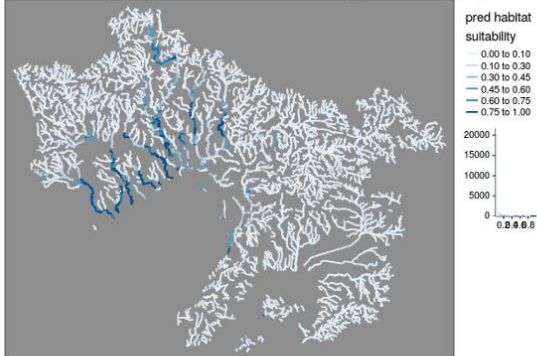


Figure 27 Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Flatheaded Gudgeon. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURRE scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

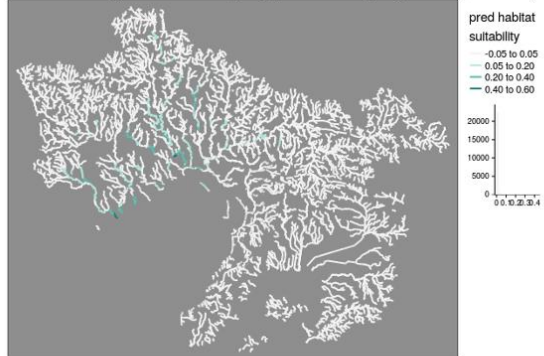
The mapped habitat suitability of Flatheaded Gudgeon under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 28. The corresponding 'difference' map for each action type is shown in the right-hand column of images in Figure 28. These 'difference' maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURRE scenario used in HWS 2018. As we can see, revegetation-only works produces predicted habitat suitability benefits in a number of localities, namely in stream reaches of the sub-catchments of Little River Lower, Little River Upper, Werribee River Lower, Kororoit Creek Lower, Maribyrnong River, Merri Creek Upper and Merri Creek Lower (Figure 28). Stormwater works made no difference to predicted habitat

suitability and fishway works made slight improvements in predicted habitat suitability of Flatheaded Gudgeon mainly in reaches in the sub-catchments of Werribee River Lower, Werribee River Middle, Parwan Creek and Darebin Creek (Figure 28).

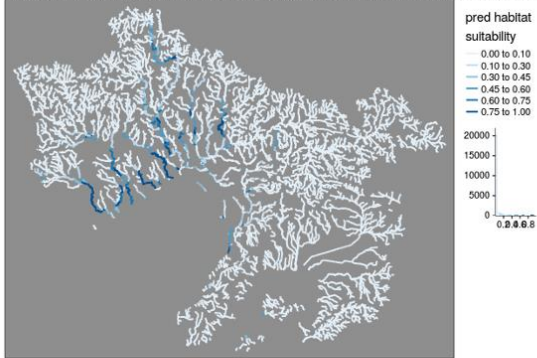
Flatheaded Gudgeon: predicted habitat suitability for 10yr planned Reveg Only



Flatheaded Gudgeon Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



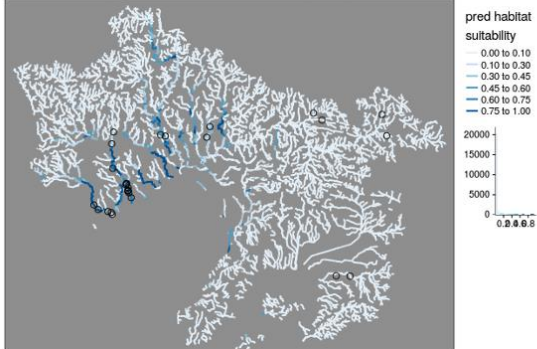
Flatheaded Gudgeon: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



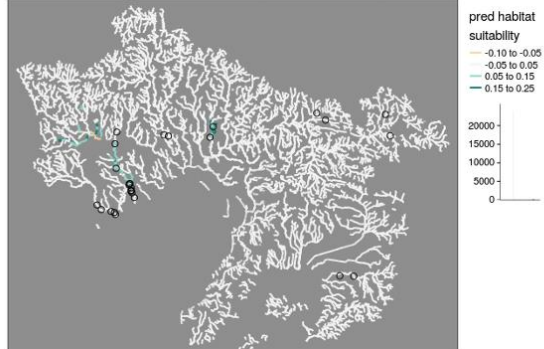
For Flatheaded Gudgeon, there is NO difference in predicted habitat suitability for 10yr planned Stormwater works Only - CURR (HWS 2018).

AttImperv does not feature in the fitted HSM for Flatheaded Gudgeon(see fitted response curves for the species in the Appendix), so it's unsurprising that stormwater works make no difference to predicted habitat suitability for Flatheaded Gudgeon.

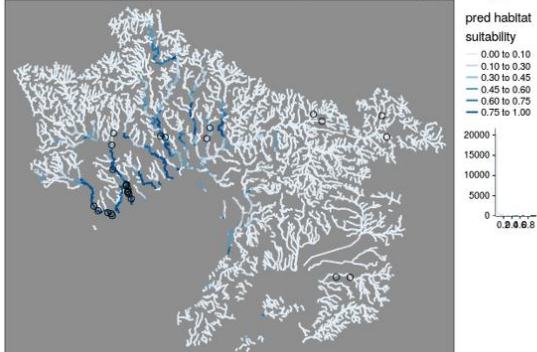
Flatheaded Gudgeon: predicted habitat suitability for 10yr planned Fishways Only



Flatheaded Gudgeon Difference Map: 10yr planned Fishway works Only - CURR (HWS 2018)



Flatheaded Gudgeon: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Flatheaded Gudgeon Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

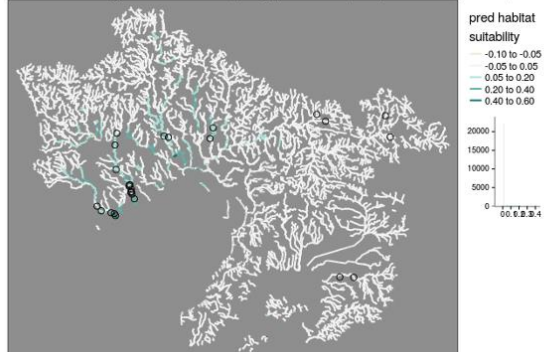


Figure 28 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Flatheaded Gudgeon under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.10 Tupong

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 29). For the Tupong, revegetation action on its own produced sizeable increases in lengths of stream in the 0.10-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories. Stormwater works on its own produced negligible improvement in predicted habitat suitability. Fishways action on its own made slight improvements in lengths of stream in the 0.10-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 categories (top image, Figure 29). All three actions in combination produced notable increases in lengths of stream in the 0.10-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 categories (top image, Figure 29).

The mapped habitat suitability of Tupong under the CURR scenario shows a distribution largely within the eastern half of the PPWP region within the PPWP region. High predicted occurrences are concentrated in stream reaches in the sub-catchments of Moonee Ponds Creek, Yarra River Lower, Diamond Creek (Rural), Diamond Creek (Source), Yarra River Middle, Watsons Creek, Pauls and Steels Creek (Rural), Watts River (Rural), Yarra River Upper (Rural), Woori Yallock Creek, Bunyip River Middle and Upper, Bunyip River Lower, Lang Lang River, Bass River, French and Phillip Islands and Mornington Peninsula South-Eastern Creeks (bottom image, Figure 29).

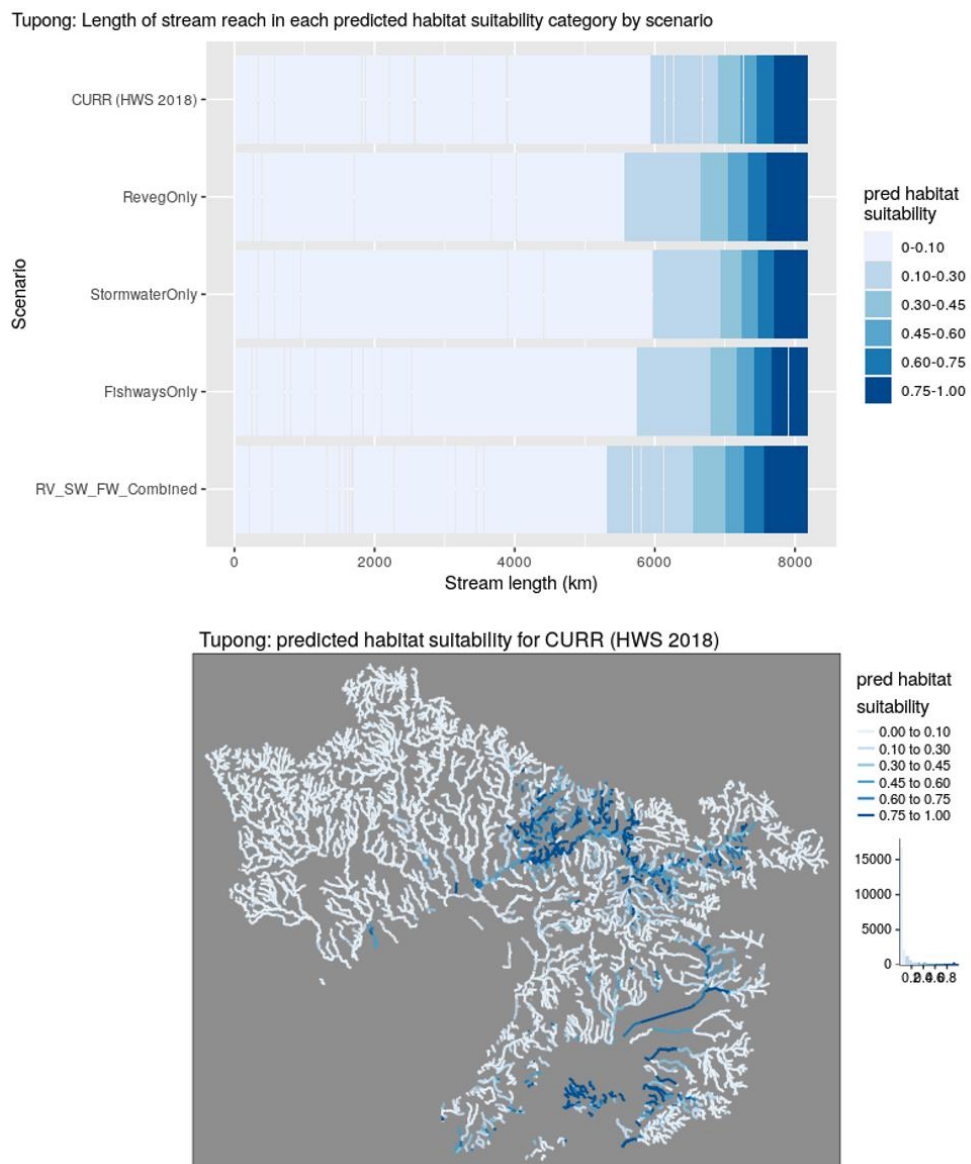
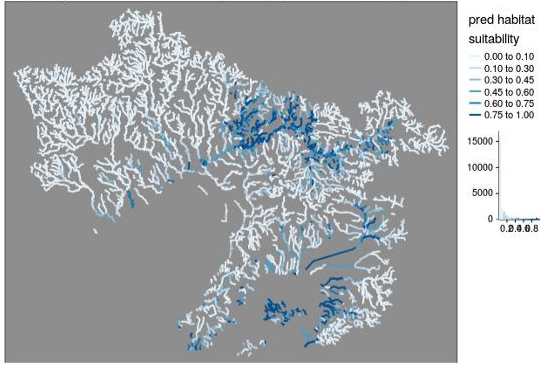


Figure 29 Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Tupong. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURR scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

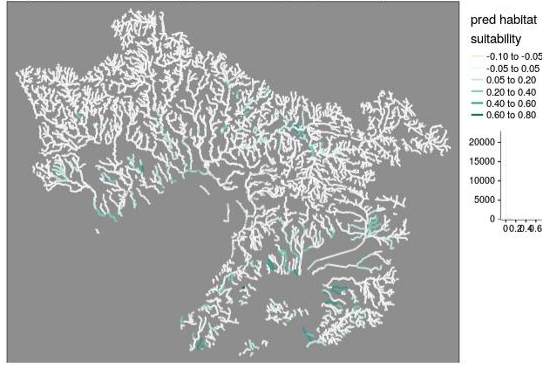
The mapped habitat suitability of Tupong under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 30. The corresponding ‘difference’ map for each action type is shown in the right-hand column of images in Figure 30. These ‘difference’ maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURR scenario used in HWS 2018. As we can see, revegetation-only works produced predicted habitat suitability benefits in a number of localities, including in streams in the western half of the PPWP region such as Little River and Skeleton Creek (even though as noted above, the CURR distribution of Tupong is predominantly in the eastern half of the region). Other areas of improved predicted habitat suitability from

revegetation included stream reaches of the sub-catchments of Yarra River Middle, Dalmore Outfalls, Bunyip River Middle and Upper, Lang Lang River, Bass River and Mornington Peninsula South-Eastern Creeks (Figure 30). Stormwater works make negligible difference to predicted habitat suitability. Fishway works made mostly small to moderate improvements in predicted habitat suitability in reaches in the sub-catchments of Little River Lower, Skeleton Creek, Watts River Source), Yarra River Upper (Source) and Lang Lang River (Figure 30).

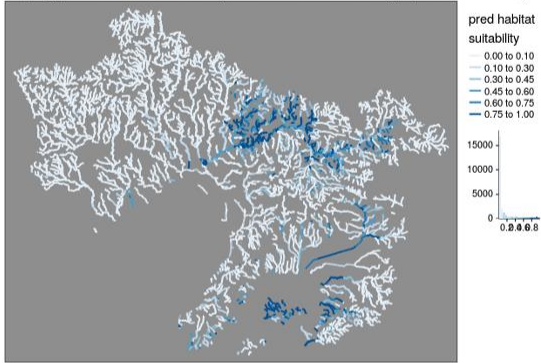
Tupong: predicted habitat suitability for 10yr planned Reveg Only



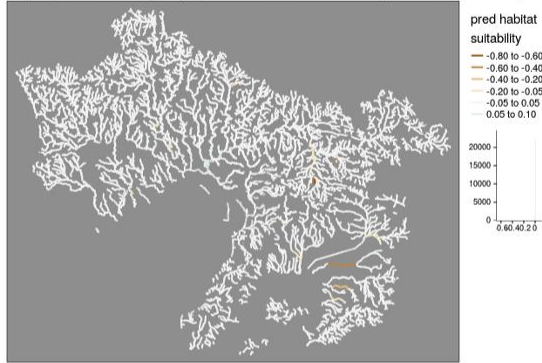
Tupong Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



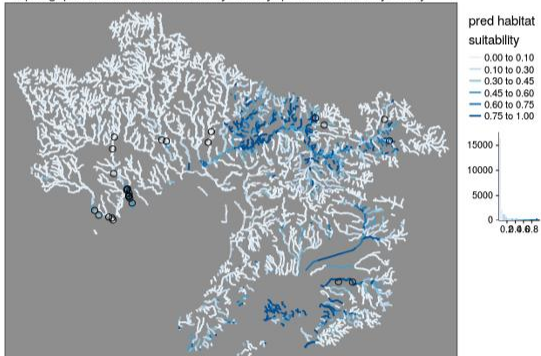
Tupong: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



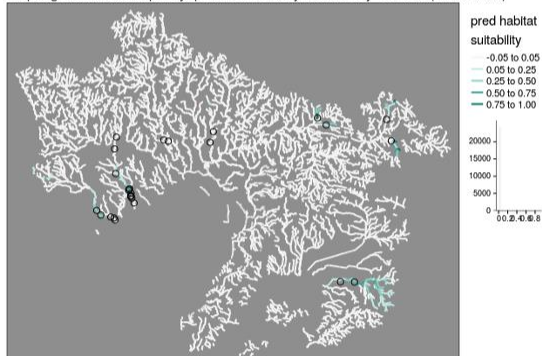
Tupong Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)



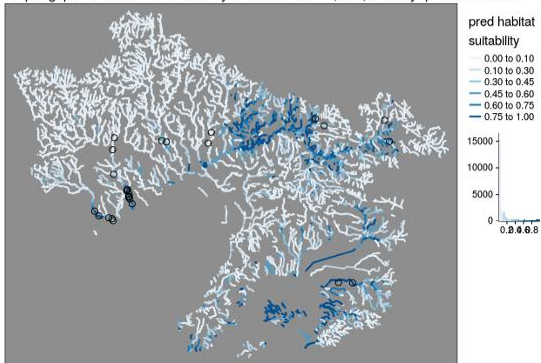
Tupong: predicted habitat suitability for 10yr planned Fishways Only



Tupong Difference Map: 10yr planned Fishway works Only - CURR (HWS 2018)



Tupong: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Tupong Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

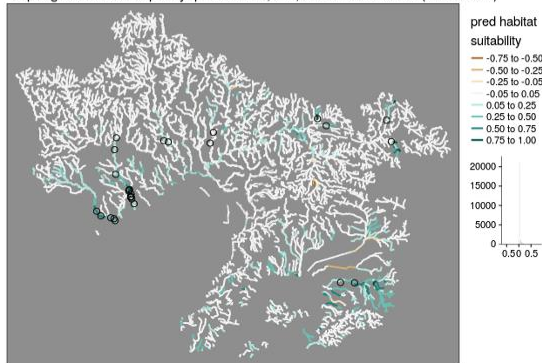


Figure 30 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Tupong under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation,

stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.11 Australian Smelt

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 31). For the Australian Smelt, revegetation action on its own is what drives predicted increases of lengths of stream mainly in the 0.10-0.30, 0.30-0.45, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories. Stormwater works and fishways action on their own produced negligible and no improvement respectively, in predicted habitat suitability (top image, Figure 31). All three actions in combination produced an increase in lengths of stream in the 0.10-0.30, 0.30-0.45, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories (top image, Figure 31).

The mapped habitat suitability of Australian Smelt under the CURR scenario shows a rather specific distribution primarily in selected river mainstems within the PPWP region. High predicted occurrences are concentrated in mainstem reaches in the sub-catchments of Werribee River Middle, Kororoit Creek, Deep Creek Lower, Deep Creek Upper, Yarra River Middle, Yarra River Upper (Rural) and Woori Yallock Creek (bottom image, Figure 31).

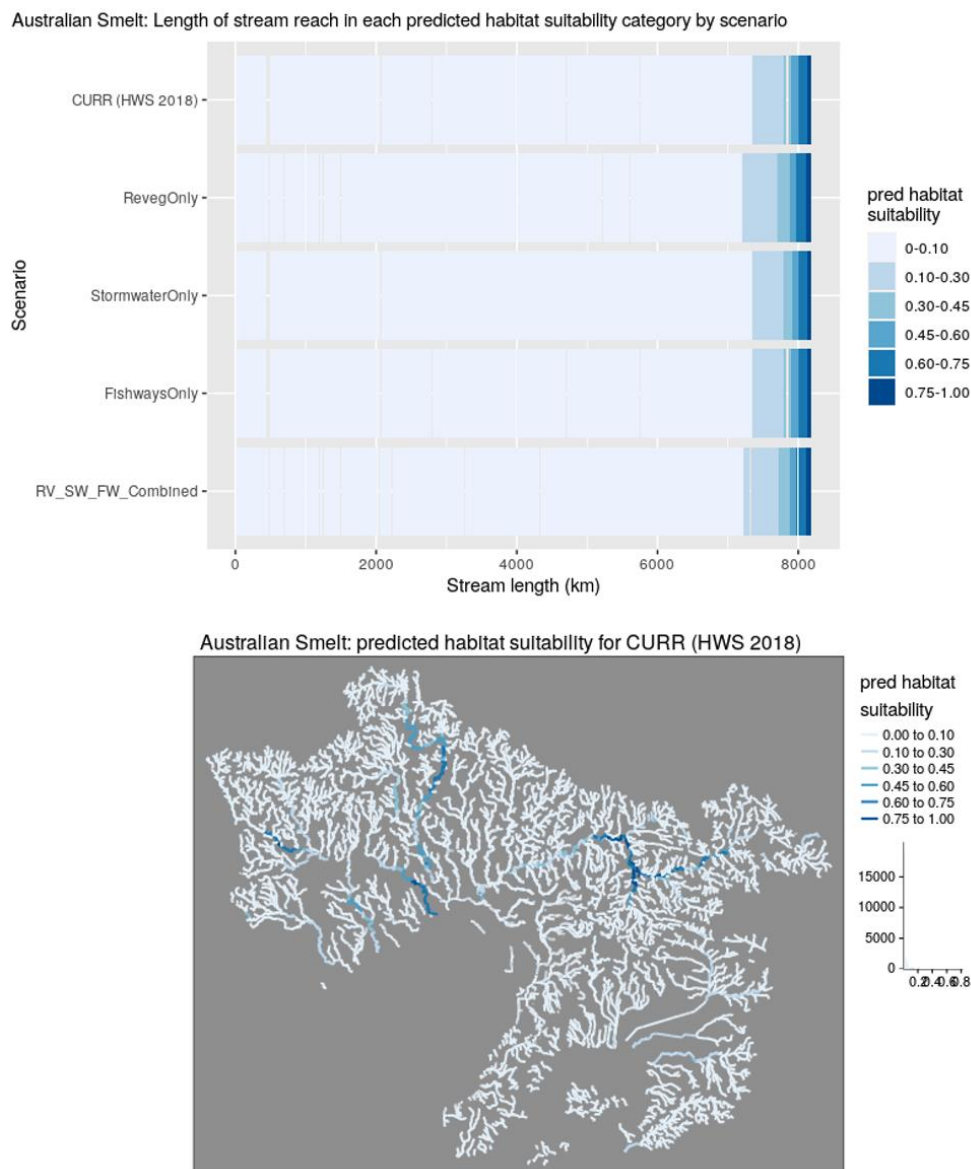
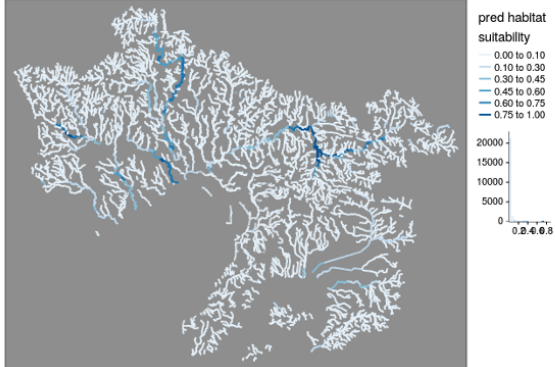


Figure 31 Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Australian Smelt. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURR scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

The mapped habitat suitability of Australian Smelt under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 32. The corresponding 'difference' map for each action type is shown in the right-hand column of images in Figure 32. These 'difference' maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURR scenario used in HWS 2018. As we can see, revegetation-only works produces predicted habitat suitability benefits in a number of localities, namely in stream reaches of the sub-catchments of Little River Lower, Werribee River Lower, Werribee River Middle, Jacksons Creek, Deep Creek Upper, Yarra River Lower, Yarra River Middle, Woori Yallock Creek and Bunyip Lower (Figure 32). Stormwater works and

fishway works make negligible and no difference respectively to predicted habitat suitability of Australian Smelt (Figure 32).

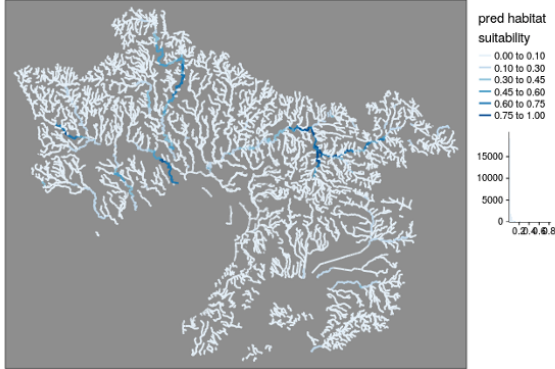
Australian Smelt: predicted habitat suitability for 10yr planned Reveg Only



Australian Smelt Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



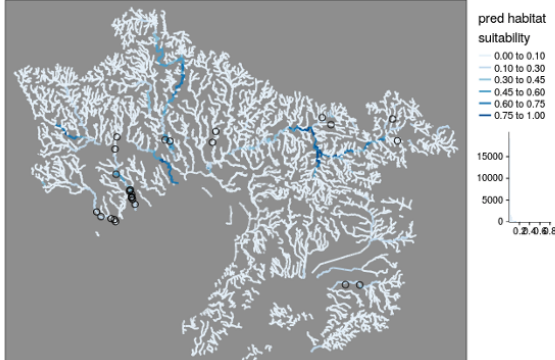
Australian Smelt: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



Australian Smelt Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)

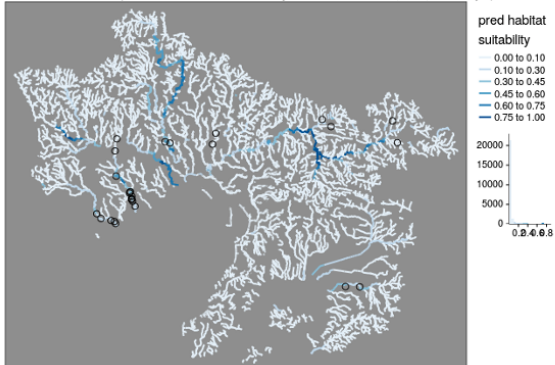


Australian Smelt: predicted habitat suitability for 10yr planned Fishways Only



For Australian Smelt, there is NEGLIGIBLE difference in predicted habitat suitability for 10yr planned Fishway works Only - CURR (HWS 2018). PartBarrierDS does not feature in the fitted HSM for Australian Smelt and while FullBarriersDS is in its HSM, its relative percentage contribution in the model is only ~0.1% (see fitted response curves for the species in the Appendix), so it's unsurprising that fishway works make no difference to predicted habitat suitability for Australian Smelt.

Australian Smelt: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Australian Smelt Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)



Figure 32 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Australian Smelt under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.12 Yarra Pygmy Perch

Recall that we were not able to develop a HSM for Yarra Pygmy Perch (insufficient data), but given its importance as a listed threatened species, we're using Southern Pygmy Perch (*Nannoperca australis*) as the surrogate for Yarra Pygmy Perch. Guided by the expert knowledge of Dr Tarmo Raadik (*pers. comm.*) we applied predictions from Southern Pygmy Perch in just the catchments and river reaches where Yarra Pygmy Perch are known to occur in, namely, Deep Creek in the Maribyrnong catchment.

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 33). For the Yarra Pygmy Perch, revegetation action that is "implemented" in the HSM by assuming a 20 m forest buffer along revegetated reaches (see section 3.1), actually substantially decreases stream lengths in the 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories (top image, Figure 33). Stormwater works and fishways action on their own makes very little and no difference respectively, to predicted habitat suitability of Yarra Pygmy Perch (top image, Figure 33). All three actions in combination substantially decreases stream lengths in the 0.30-0.45, 0.45-0.60, 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories (top image, Figure 33).

The mapped habitat suitability of Yarra Pygmy Perch under the CURR scenario shows a very restricted distribution within the PPWP region with the species primarily occurring in the stream reaches of the Deep Creek Upper and Boyd Creek sub-catchments (bottom image, Figure 33).

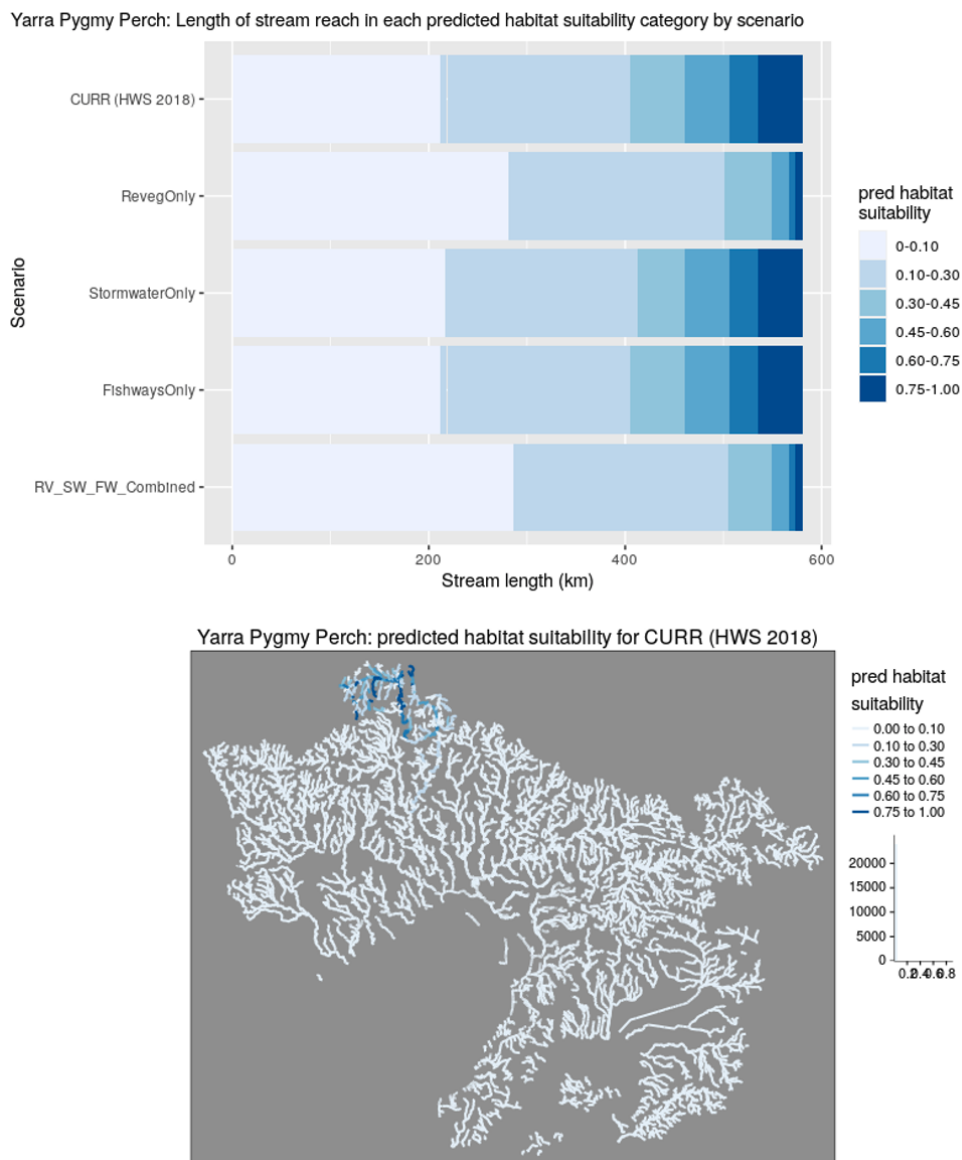
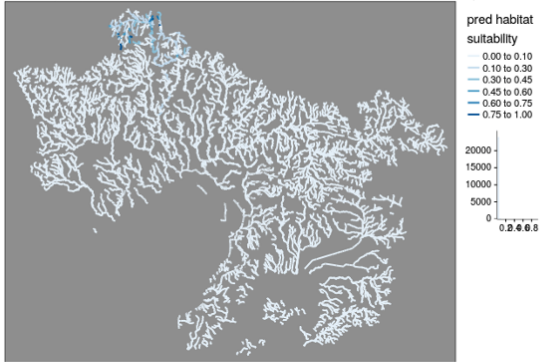


Figure 33 Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Yarra Pygmy Perch. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURRE scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

The mapped habitat suitability of Yarra Pygmy Perch under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 34. The corresponding ‘difference’ map for each action type is shown in the right-hand column of images in Figure 34. These ‘difference’ maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURRE scenario used in HWS 2018. As we can see, revegetation action that is “implemented” in the HSM by assuming a 20 m forest buffer along revegetated reaches (see Section 3.1), actually decreases predicted habitat suitability in the species’ already restricted distribution. Stormwater works and fishways works makes very little and no difference respectively, to predicted habitat suitability of Yarra Pygmy Perch (Figure 34).

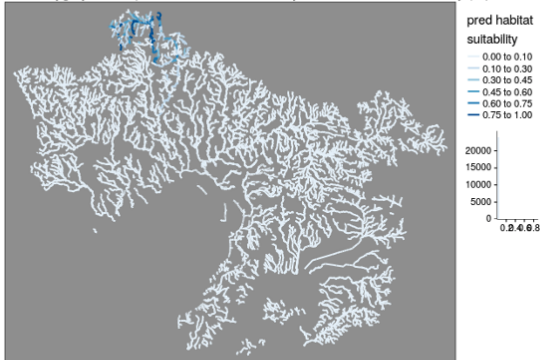
Yarra Pygmy Perch: predicted habitat suitability for 10yr planned Reveg Only



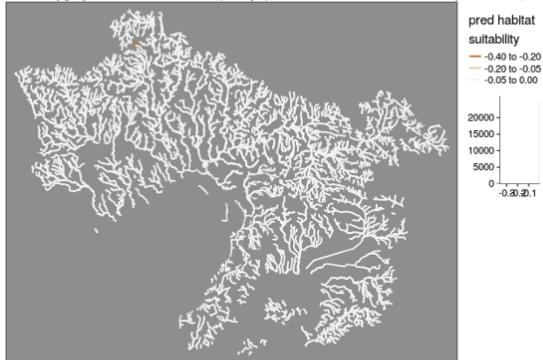
Yarra Pygmy Perch Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



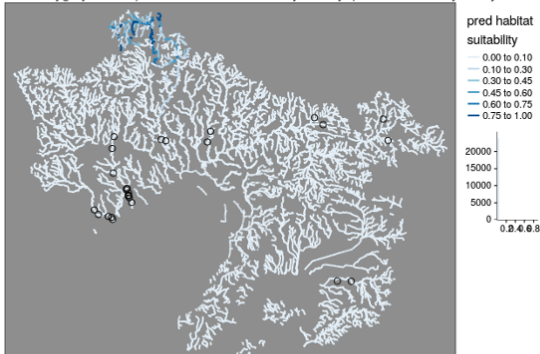
Yarra Pygmy Perch: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



Yarra Pygmy Perch Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)

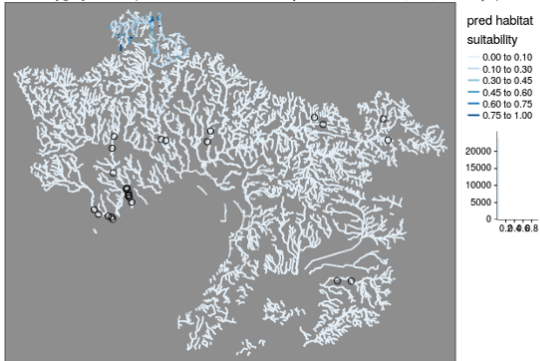


Yarra Pygmy Perch: predicted habitat suitability for 10yr planned Fishways Only



For Yarra Pygmy Perch, there is NEGLIGIBLE difference in predicted habitat suitability for 10yr planned Fishway works Only - CURR (HWS 2018). PartBarrierDS does not feature in its surrogate Southern Pygmy Perch HSM and while FullBarriersDS is in the HSM, its relative percentage contribution in the model is only ~3.9% (see fitted response curves for Southern Pygmy Perch in the Appendix), so it's unsurprising that fishway works make no difference to predicted habitat suitability for Yarra Pygmy Perch.

Yarra Pygmy Perch: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Yarra Pygmy Perch Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

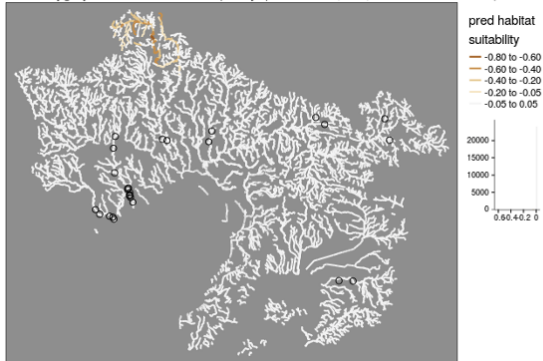


Figure 34 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Yarra Pygmy Perch under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned

revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.13 Australian Grayling

Recall that we were not able to develop a HSM for Australian Grayling (insufficient data), but given its importance as a listed threatened species, we're using Common Galaxias (*Galaxias maculata*) as the surrogate for Australian Grayling. Guided by the expert knowledge of Dr Tarmo Raadik (*pers. comm.*) we applied predictions from Common Galaxias in just the catchments and river reaches where Australian Grayling are known to occur in, namely, the mainstems of the Werribee, Maribyrnong, Yarra, Cardinia, Bunyip and Lang Lang rivers, downstream of major instream barriers.

The stacked barplots of stream lengths in each predicted habitat suitability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 35). For the Australian Grayling, fishways are what drives predicted increases in lengths of stream mainly in the 0.60-0.75 and 0.75-1.0 predicted habitat suitability categories. Revegetation action on its own produced increases in lengths of stream in the 0.0-0.10, 0.10-0.30, and 0.30-0.45 predicted habitat suitability categories, but undesirably, also produced decreases in lengths of stream in the 0.45-0.60 and 0.60-0.75 categories (top image, Figure 35). Stormwater works on its own produced negligible changes in predicted habitat suitability (top image, Figure 35). All three actions in combination produced slight positive increases of lengths of stream in the 0.30-0.45, 0.60-0.75 and 0.75-1.0 categories but these benefits are lower than fishway action on its own (top image, Figure 35).

The mapped habitat suitability of Australian Grayling under the CURR scenario shows a rather specific distribution primarily in selected river mainstems within the PPWP region. High predicted occurrences are concentrated in mainstem reaches in the sub-catchments of Werribee River Lower, Maribyrnong River, Yarra River Lower, Cardinia, Toomuc, Deep and Ararat Creeks, Tarago River, Bunyip Lower and Lang Lang River (bottom image, Figure 35).

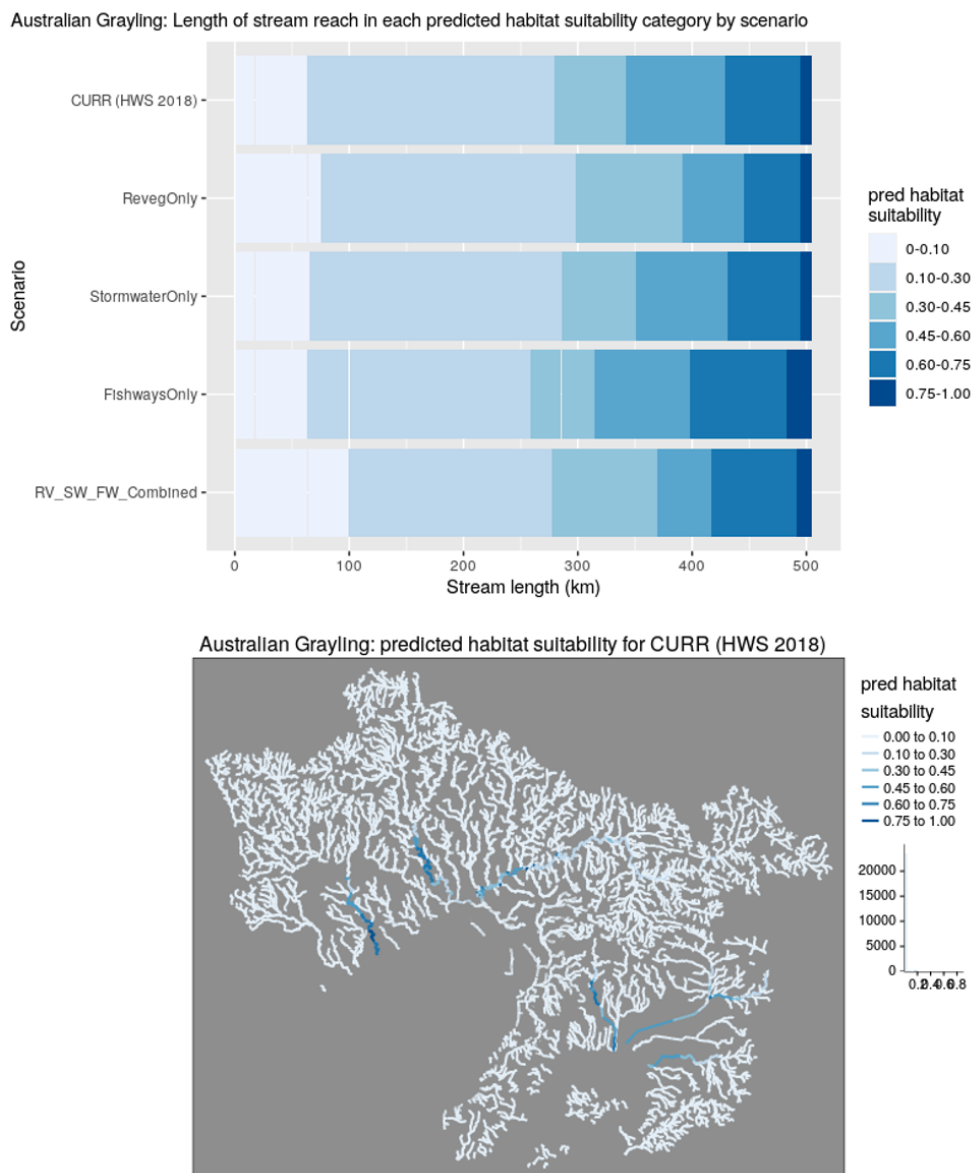
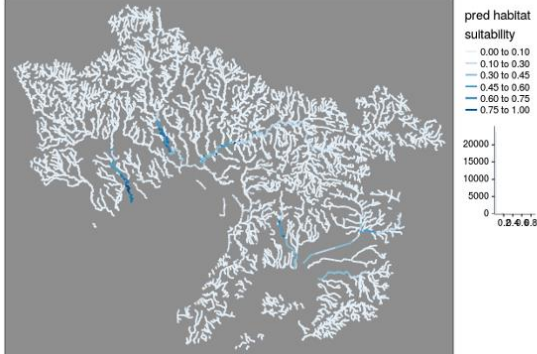


Figure 35 Stacked barplot of stream lengths in each habitat suitability category by scenario (see Table 2 and Table 3 for details) for the Australian Grayling. The intervals for the predicted habitat suitability categories are: 0 - 0.10, 0.10 - 0.30, 0.30 - 0.45, 0.45 - 0.60, 0.60 - 0.75 and 0.75 - 1.0. Bottom: Mapped predictions of habitat suitability across the PPWP region under the CURR scenario used in HWS 2018. Deeper blues indicate higher predicted habitat suitability.

The mapped habitat suitability of Australian Grayling under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 36. The corresponding 'difference' map for each action type is shown in the right-hand column of images in Figure 36. These 'difference' maps highlight the particular areas within the PPWP region where predicted habitat suitability of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURR scenario used in HWS 2018. As we can see, revegetation-only works produces slight to moderate decreases in predicted habitat suitability in a small number of locations, such as in stream reaches of the sub-catchments of Cardinia, Toomuc, Deep and Ararat Creeks, Tarago River, Bunyip Lower and Lang Lang River (Figure 36). Stormwater works also produced small to moderate decreases in predicted habitat

suitability in the stream reaches in the sub-catchments of Cardinia, Toomuc, Deep and Ararat Creeks and Tarago River. Fishway works produced small to sizeable increases in predicted habitat suitability of Australian Grayling in the mainstems of Werribee River Lower and Lang Lang River (Figure 36).

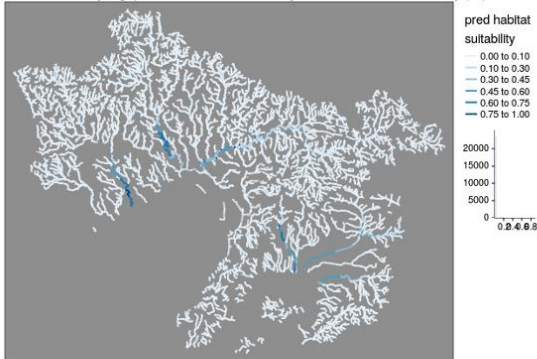
Australian Grayling: predicted habitat suitability for 10yr planned Reveg Only



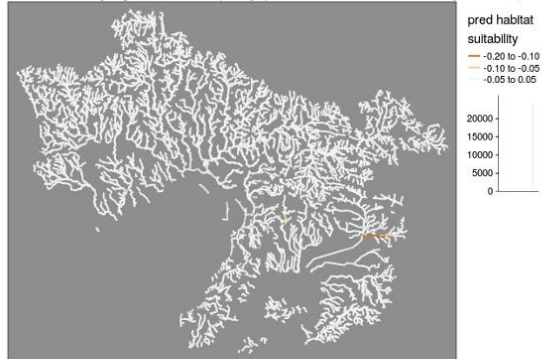
Australian Grayling Difference Map: 10yr planned Reveg Only - CURR (HWS 2018)



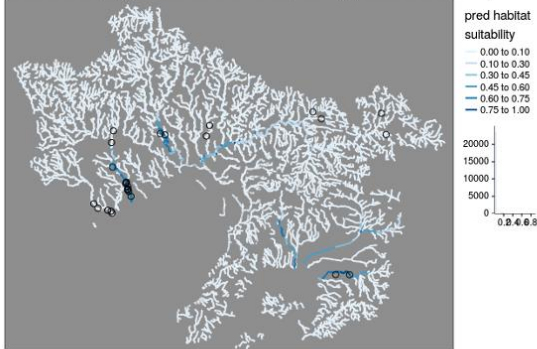
Australian Grayling: predicted habitat suitability for Stormwater works Only (equiv to WTD 2022)



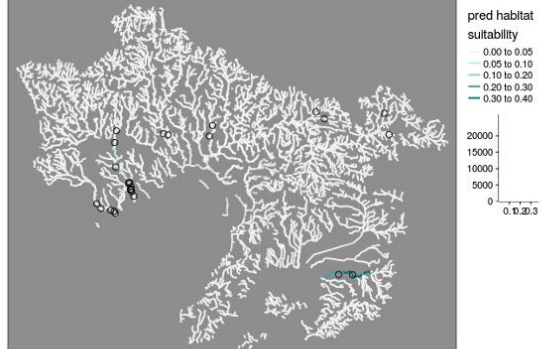
Australian Grayling Difference Map: 10yr planned Stormwater works Only - CURR (HWS 2018)



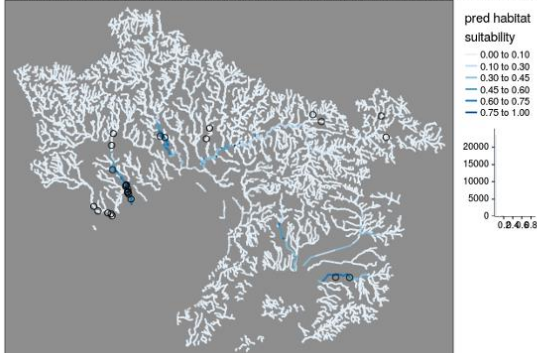
Australian Grayling: predicted habitat suitability for 10yr planned Fishways Only



Australian Grayling Difference Map: 10yr planned Fishway works Only - CURR (HWS 2018)



Australian Grayling: predicted habitat suitability for combined RV, SW, FW 10yr planned works



Australian Grayling Difference Map: 10yr planned RV, SW, FW works - CURR (HWS 2018)

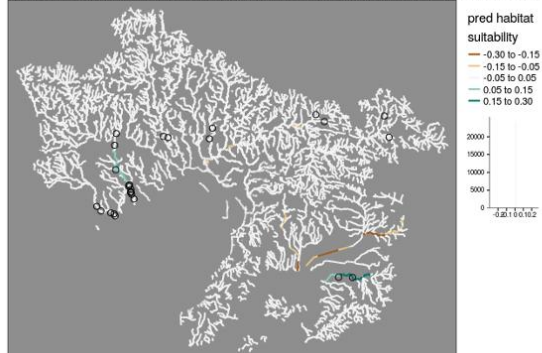


Figure 36 Left-hand column shows mapped predictions of habitat suitability across the PPWP region for the Australian Grayling under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where predicted habitat suitability differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower predicted habitat suitability relative to CURR, white indicates little difference and blue-greens indicate higher predicted habitat suitability relative to CURR.

6.14 Native Fish Individual Species Response to Actions Summary

In Table 5, we summarise the individual fish species responses to revegetation, stormwater works and fishways on their own and in combination. Looking across the cells in the table, we can see that there can be considerable variation in individual species' responses to each action. Of the three actions on their own, revegetation seems to drive the strongest positive increase in habitat suitability for species like Short-finned Eel, Broad-finned Galaxias, Ornate Galaxias, Spotted Galaxias, Flatheaded Gudgeon, Tupong and Australian Smelt. But for three fish species: Common Galaxias, Southern Pygmy Perch and Yarra Pygmy Perch, revegetation in the form of a 20 m forest-like buffer produced a decrease in predicted habitat suitability (Table 5).

Stormwater works was not relevant with respect to three fish species (Broad-finned Galaxias, Spotted Galaxias and Flatheaded Gudgeon) but it largely had an equivocal effect, increasing the lengths of streams in some habitat suitability categories while decreasing the lengths of streams in other habitat suitability categories such that positive and negative changes mostly cancelled out (Table 5). It is however, important to bear in mind that the 10-year planned stormwater works scenario essentially represents a 'no worsening' of the slight deterioration in attenuated imperviousness conditions represented by WTD. As highlighted in Section 3.2, with no available spatially-explicit data on the distribution and location of near-future development, there was no real basis on which to generate 10-year attenuated imperviousness estimates, hence the assumed "no worsening but also no improvement" scenario for 10-year planned stormwater works.

Fishways action on its own drove very strong positive increases in habitat suitability for Australian Grayling, substantial increases for Broad-finned Galaxias, Common Galaxias, Spotted Galaxias, and some increases for Short-finned Eel, Southern Pygmy Perch and Tupong. Fishways produced equivocal predicted benefits for Lampreys and Flatheaded Gudgeon (Table 5).

The 'Combination' column in Table 5 gives an indication of the overall impact of applying all three actions together, and the outcomes are largely positive, though there are also equivocal outcomes (Common Galaxias and Lampreys) and negative outcomes (Southern Pygmy Perch and Yarra Pygmy Perch). Australian Grayling would also have been better off with just the single action of fishways rather than all three actions in combination. Where there are trade-offs between actions, some are more severe (e.g. Common Galaxias, Australian Grayling) than others (e.g. Ornate Galaxias, Southern Pygmy Perch). In the case of Spotted Galaxias, revegetation and fishways together, boosted the beneficial effects (Table 5).

Table 5 Summary of individual fish species predicted responses to revegetation, stormwater works and fishways actions, on their own and in combination. Plus (+) symbol indicates a positive response and minus (-) symbol represents a negative response as judged by the lengths of streams in the predicted habitat suitability categories. The number of + and – symbols is indicative of the magnitude of response. The vertical bar (|) symbol denotes an equivocal response overall given increases in lengths of stream in some predicted habitat suitability categories and decreases in other categories. NA denotes when the predictor linked to the action does not feature in a species’ HSM (see Section 6 and Appendix).

Species	Revegetation	Stormwater works	Fishways	Combination
Short-finned Eel	++		+	++
River Blackfish	+		NA	+
Broad-finned Galaxias	+++	NA	++	+++
Common Galaxias	--		++	
Ornate Galaxias	+++	-	NA	+++
Spotted Galaxias	++	NA	++	+++
Pouched Lamprey & Short-headed Lamprey	NA			
Southern Pygmy Perch	---		+	---
Flatheaded Gudgeon	++	NA		++
Tupong	+++		+	+++
Australian Smelt	++		NA	++
Yarra Pygmy Perch	---		NA	---
Australian Grayling			+++	+

6.15 Native Fish Species Stacked

As a way of summarising across all 13 native species, we present native fish species stacked probabilities which is calculated by summing predicted habitat suitability probabilities across all 13 species by stream reach. This provides an index of native fish “species richness”. We first present results for the WTD scenario followed by results for the 10-year planned works scenario (see Table 3 for scenario details).

Works-to-date (WTD)

The stacked barplots of stream lengths in each stacked probability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top-left image, Figure 37). Relative to CURR, the WTD scenario shows slight decreases in lengths of streams in the 2.0-3.0, 3.0-4.0 and 4.0-5.5 stacked probability categories, and a slight increase in lengths of stream in the 1.0-1.5 and 1.5-2.0 stacked probability categories.

The mapped stacked probabilities under the CURR scenario gives an indication of the native fish species richness in river systems and stream reaches across the PPWP region (bearing in mind that this is based on the 13 modelled native fish species) (top-right image, Figure 37). The most species-rich waterways are stream reaches in the sub-catchments of Werribee River Lower, Kororoit Creek Lower, Maribyrnong River, Deep Creek Upper, Plenty River Upper, Diamond Creek (Rural), Steels and Pauls Creek, Watts River (Rural), Watts River (Source), Yarra River Middle, Yarra River Upper (Rural), Litte Yarra River and Hoddles Creek, Woori Yallock Creek, Cardinia, Toomuc, Deep and Ararat Creeks, Bunyip River Middle and Upper, Tarago River, Lang Lang River, Bass River, French and Phillip Islands, Mornington Peninsula North-Eastern Creeks and Mornington Peninsula South-Eastern Creeks (top-right image, Figure 37).

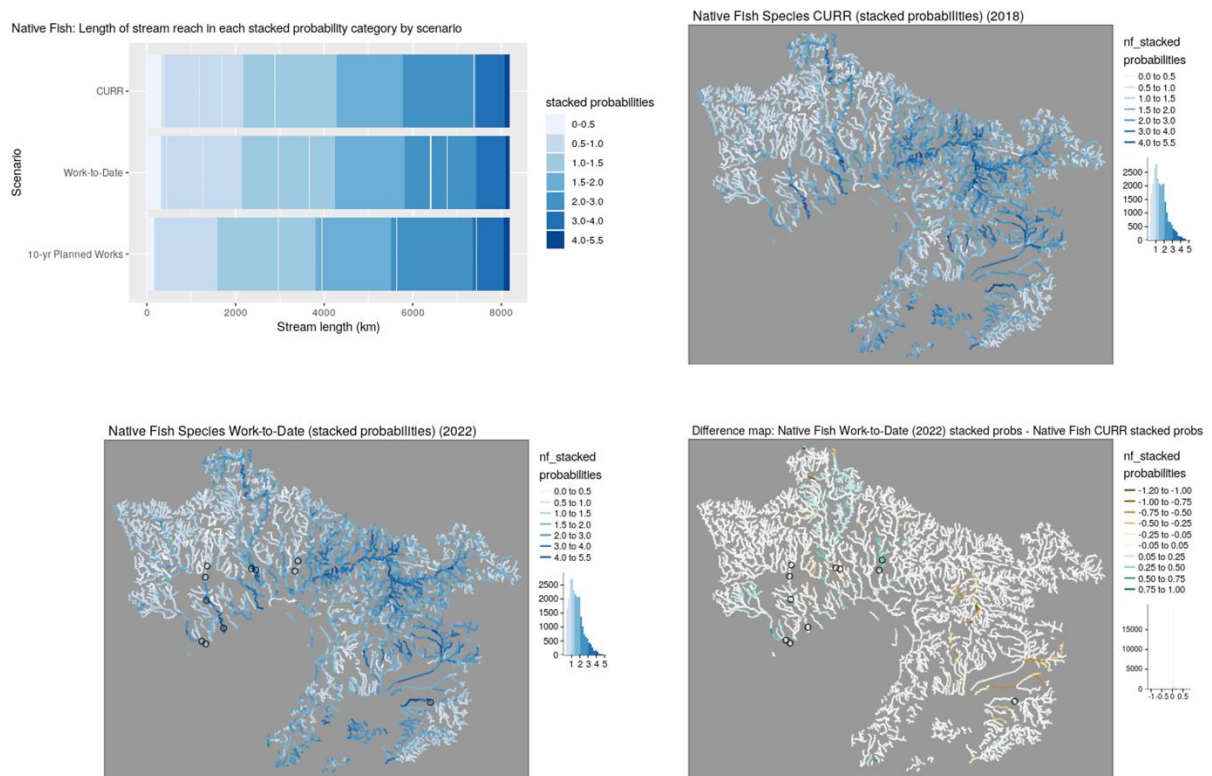


Figure 37 Top-left: Stacked barplot of stream lengths in each native fish species stacked probabilities category by scenario (see Table 2 and Table 3 for details). The intervals for the stacked probabilities categories are: 0 - 0.50, 0.50 - 1.0, 1.0 - 1.5, 1.5 - 2.0, 2.0 - 3.0, 3.0-4.0 and 4.0 - 5.5. Top-right: Mapped predictions of native fish species stacked probabilities across the PPWP region under the CURR scenario used in HWS 2018. Bottom-left: Mapped predictions of native fish species stacked probabilities across the PPWP region under the WTD scenario. Deeper blues indicate higher predicted stacked probability values. Bottom-right: 'Difference' map shows where WTD stacked probabilities differs from that of the CURR scenario used in HWS 2018. On this diverging colour scale, darker browns indicate lower stacked probabilities relative to CURR, white indicates little difference and blue-greens indicate higher stacked probabilities relative to CURR.

The mapped stacked probabilities under the WTD scenario is shown in the bottom-left image of Figure 37. The 'difference' map (bottom-right, Figure 37) highlights where within the PPWP region, WTD stacked probabilities differs from (i.e. is higher or lower than and by how much) that of the CURR scenario used in HWS 2018. As we can see, stacked probability values have improved in stream reaches in the sub-catchments of Little River Lower, Little River Upper, Jacksons Creek, Emu Creek, Deep Creek Lower, Deep Creek Upper and Darebin Creek. On the other hand, stacked probability values have declined in reaches in the sub-catchments of Woori Yallock Creek, Cardinia,

Toomuc, Deep and Ararat Creeks, Tarago River and King Parrot and Musk Creeks (bottom-right, Figure 37).

10-year Planned Works

The stacked barplots of stream lengths in each stacked probability category allows us to compare the predicted impact of scenarios against one another, across an aggregate PPWP region-wide scale (top image, Figure 38). Relative to CURR, revegetation action on its own produced a notable increase in lengths of streams in the 2.0-3.0 stacked probability category. Stormwater works on its own produced a slight decrease in lengths of streams in the 2.0-3.0 and 4.0-5.5 categories, and slight increases mainly in the 0-0.5 and 0.5-1.0 categories. Fishways action on its own produced notable increases in lengths of streams in the 1.0-1.5, 1.5-2.0, 2.0-3.0 and 4.0-5.5 categories. All three actions in combination produced substantial increases in lengths of streams in the 1.0-1.5, 1.5-2.0, 2.0-3.0, 3.0-4.0 and 4.0-5.5 categories (top image, Figure 38).

As noted in the above, the mapped stacked probabilities under the CURR scenario gives an indication of the native fish species richness in river systems and stream reaches across the PPWP region (bearing in mind that this is based on the 13 modelled native fish species) (bottom image, Figure 38). The most species-rich waterways are stream reaches in the sub-catchments of Werribee River Lower, Kororoit Creek Lower, Maribyrnong River, Deep Creek Upper, Plenty River Upper, Diamond Creek (Rural), Steels and Pauls Creek, Watts River (Rural), Watts River (Source), Yarra River Middle, Yarra River Upper (Rural), LITTLE Yarra River and Hoddles Creek, Woori Yallock Creek, Cardinia, Toomuc, Deep and Ararat Creeks, Bunyip River Middle and Upper, Tarago River, Lang Lang River, Bass River, French and Phillip Islands, Mornington Peninsula North-Eastern Creeks and Mornington Peninsula South-Eastern Creeks (bottom image, Figure 38).

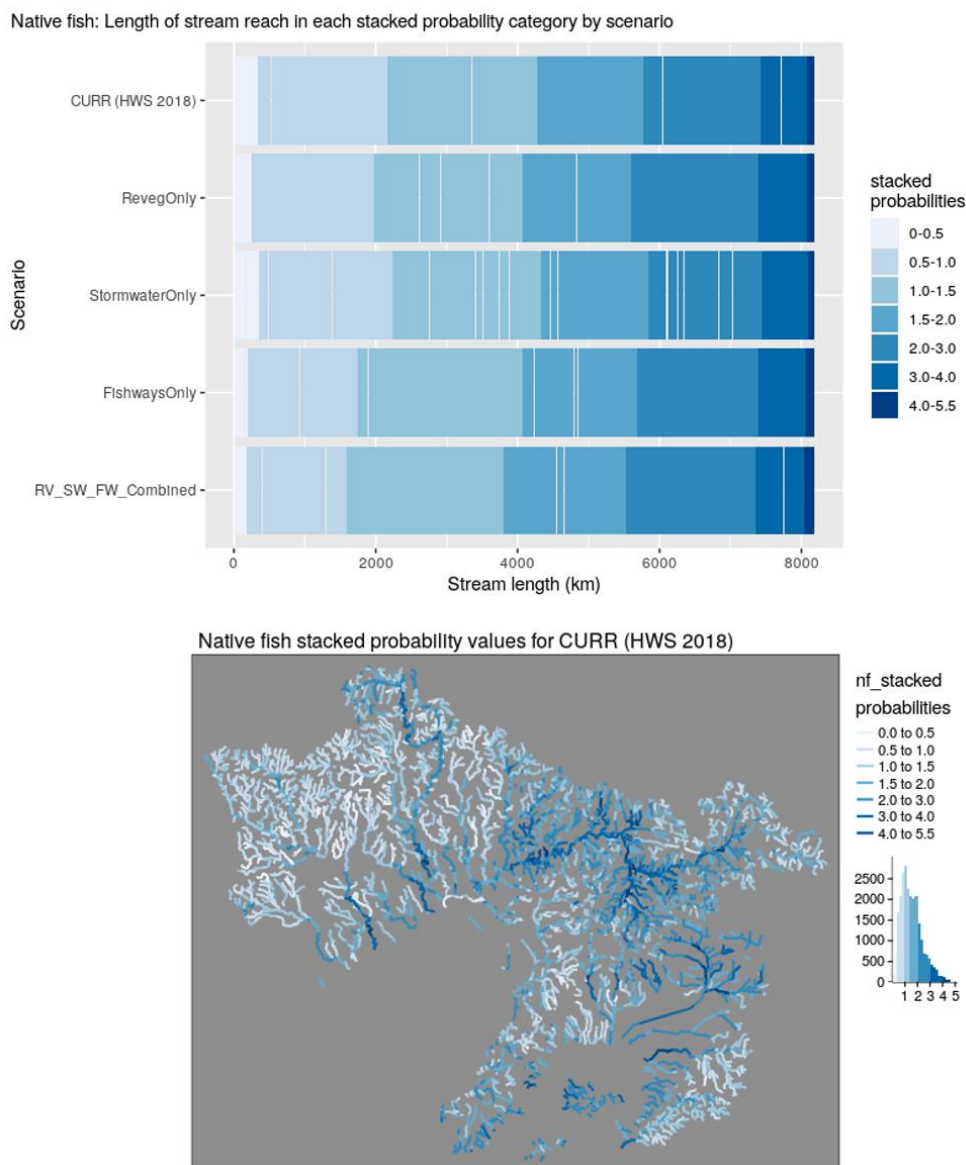


Figure 38 Stacked barplot of stream lengths in each native fish species stacked probabilities category by scenario (see Table 2 and Table 3 for details). The intervals for the stacked probabilities categories are: 0 - 0.50, 0.50 - 1.0, 1.0 - 1.5, 1.5 - 2.0, 2.0 - 3.0, 3.0-4.0 and 4.0 - 5.5. Bottom: Mapped predictions of native fish species stacked probabilities across the PPWP region under the CURRE scenario used in HWS 2018. Deeper blues indicate higher predicted stacked probability values.

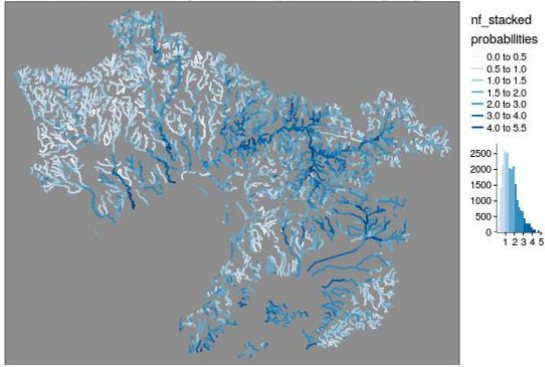
The mapped stacked probabilities under the 10-year planned revegetation-only action, 10-year planned stormwater-only action, 10-year planned fishways-only action and 10-year planned revegetation, stormwater works and fishways action in combination is shown in the left-hand column of images in Figure 39. The corresponding ‘difference’ map for each action type is shown in the right-hand column of images in Figure 39. These ‘difference’ maps highlight the particular areas within the PPWP region where stacked probabilities of the associated action type differs from (i.e. is higher or lower than and by how much) that of the CURRE scenario used in HWS 2018.

As we can see, revegetation-only works produces increases in stacked probabilities in a large number of waterways right across the PPWP region. However, revegetation action on its own, also reduces stacked probabilities relative to CURRE in a small number of localities such as stream reaches of the sub-catchments of Deep Creek Upper, Boyd Creek, Woori Yallock Creek, Tarago River and Lang

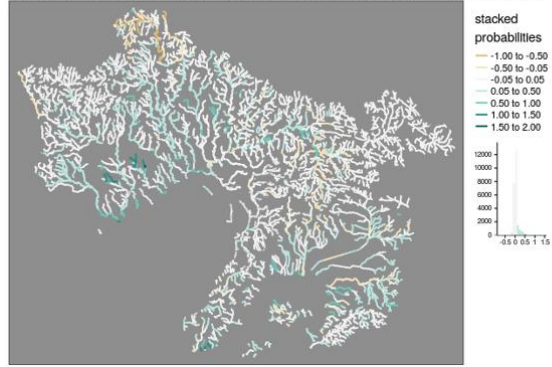
Lang River (Figure 39). The impact of stormwater works (recall that for the 10-year planned works scenario we use WTD attenuated imperviousness estimates, in effect assuming no worsening but also no improvement of attenuated imperviousness throughout the PPWP region) appears to be small to moderate decreases in stacked probabilities in a range of waterways across the PPWP region (Figure 39). However, stormwater works on its own seemed to produce slight increases in stacked probabilities in a small number of reaches in the sub-catchments of Yarra River Lower, Watts River (Rural) and Cardinia, Toomuc, Deep and Ararat Creeks (Figure 39). Fishway works produce increases in stacked probabilities in their target river systems with improvements seen in reaches in the sub-catchments of Little River Lower, Little River Upper, Werribee River Lower, Werribee River Middle, Werribee River Upper, Parwan Creek, Jacksons Creek, Darebin Creek, Watts River (Source), Yarra River Upper (Source) and Lang Lang River (Figure 39).

When all three actions are applied in combination, we see small to large increases in stacked probabilities in waterways across the PPWP region, with the largest increases in reaches in the sub-catchments of Little River Lower, Werribee River Lower and Lang Lang River (Figure 39). There are also some decreases in stacked probabilities in a few localities such as reaches in the sub-catchments of Kororoit Creek Lower, Deep Creek Upper, Merri Creek Upper, Woori Yallock Creek, Tarago River and King Parrot and Musk Creeks (Figure 39).

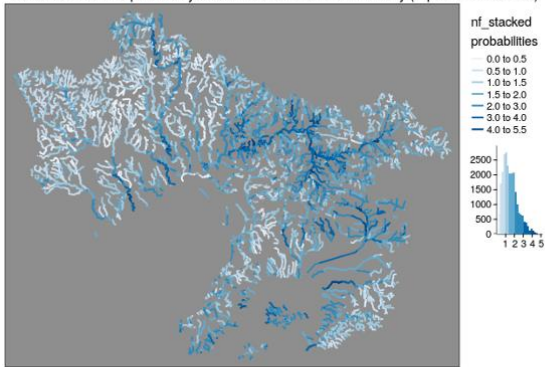
Native fish stacked probability values for 10yr planned Reveg Only



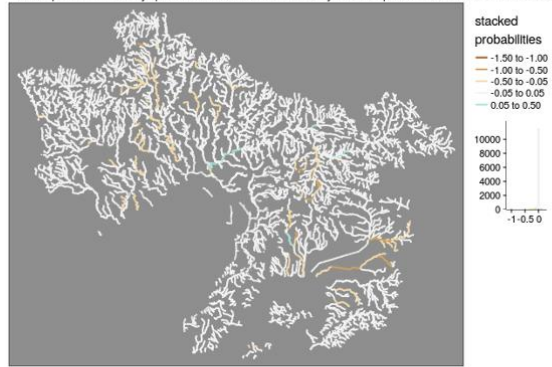
Diff Map: Native fish 10yr planned Reveg Only stacked probs - Native fish CURR stacked probs



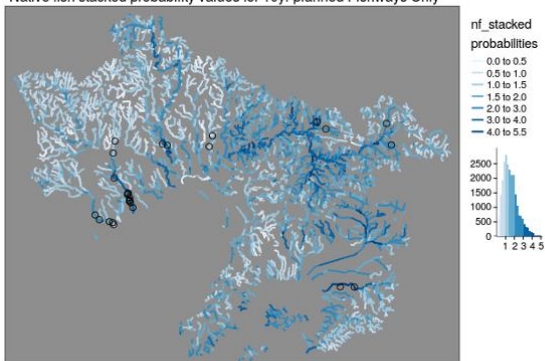
Native fish stacked probability values for Stormwater works Only (equiv to WTD 2022)



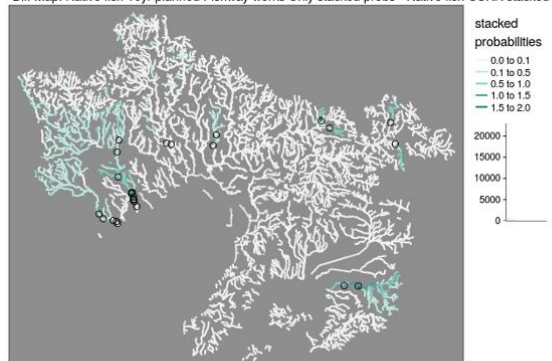
Diff Map: Native fish 10yr planned Stormwater works Only stacked probs - Native fish CURR stacked probs



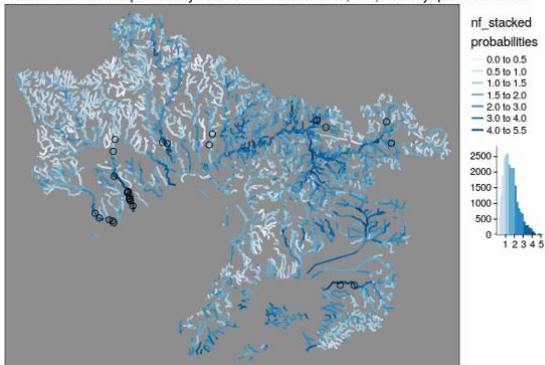
Native fish stacked probability values for 10yr planned Fishways Only



Diff Map: Native fish 10yr planned Fishway works Only stacked probs - Native fish CURR stacked probs



Native fish stacked probability values for combined RV, SW, FW 10yr planned works



Diff Map: Native fish 10yr planned RV, SW, FW works stacked probs - Native fish CURR stacked probs

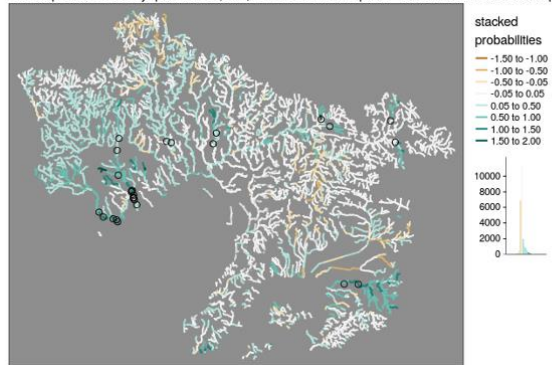


Figure 39 Left-hand column shows mapped predictions of native fish species stacked probabilities across the PPWP region under the following scenarios (detailed in Table 3): 10-year planned revegetation works only (top), 10-year planned stormwater works only (upper-middle), 10-year planned fishway works only (lower-middle) and 10-year planned

revegetation, stormwater and fishway works in combination (bottom). Deeper blues indicate higher predicted habitat suitability. Right-hand column 'difference' maps show where stacked probabilities differs from that of the CURR scenario used in HWS 2018, given: revegetation works only (top), stormwater works only (upper-middle), fishway works only (lower-middle) and revegetation, stormwater and fishway works in combination (bottom). On this diverging colour scale, darker browns indicate lower stacked probabilities relative to CURR, white indicates little difference and blue-greens indicate higher stacked probabilities relative to CURR.

7 Application for values synthesis

The information presented in this report was applied in two ways to support the Science Inquiry Report (Melbourne Water, 2023a) for the Mid-Term Evaluation of the 2018 Healthy Waterways Strategy.

First, the impacts of management activities on reach-scale predictions of habitat suitability for macroinvertebrates, platypus, and fish, as outlined above, were summarised and reported.

Second, an assessment of the modelled reach-scale outputs was undertaken to determine 'significant' (determined using a value-specific threshold value) changes in predicted habitat suitability due to management actions since the beginning of the Strategy. This assessment compared predicted habitat suitability under the works-to-date (WTD) scenario (see Table 3) to that developed at the start of the Strategy (CURR; see Table 2) at the reach-scale for platypus, macroinvertebrates as represented by LUMaR, stacked native fish probability, Common galaxias, Ornate galaxias, and River blackfish. Threshold values of change were determined for each of these predictions. The thresholds and the justification for each is available in Table 6. The reach-scale outcome (stable, improvement, decline) for each value was used alongside other criteria (range reduction or expansion, site-specific trends in values) in a rubric to assess whether a key value within a sub-catchment was stable/improving, potentially declining, or declining - see Synthesis Methods document (Melbourne Water, 2023b). This assessment is reported in the value synthesis section of the Science Inquiry Report (Melbourne Water, 2023a).

Table 6. The threshold applied and the justification for its use.

Environmental value (habitat suitability prediction)	Threshold applied (+/-)	Threshold justification
Platypus (AllPlatyHWS)	0.2	A value of 0.2 was thought to represent a meaningful change in platypus habitat suitability. Note: a threshold of 0.1 was also trialled and produced <5% difference in reach-length change compared to a threshold of 0.2.
Macroinvertebrates (LUMaR)	0.15	Expert opinion (Dr Chris Walsh) indicated that a change in LUMaR of 0.15 represents a discernible shift in this macroinvertebrate index.
Fish (stacked native fish)	0.4	~95% of reaches recorded a change less than this threshold of predicted habitat suitability.
Fish (Common galaxias)	0.06	~95% of reaches recorded a change less than this threshold of predicted habitat suitability.

Fish (Ornate galaxias)	0.05	~95% of reaches recorded a change less than this threshold of predicted habitat suitability.
Fish (River blackfish)	0.02	~95% of reaches recorded a change less than this threshold of predicted habitat suitability.

8 Discussion

Broadly speaking, the outcome of works-to-date (WTD) ranged from slight deterioration to no discernible improvement in instream environmental condition as assessed by predicted LUMaR rating for macroinvertebrates (Figure 5), and predicted habitat suitability for platypus (Figures 7, 9 and 10) and native fish species (Section 6). On the other hand, the expected outcome for 10-year planned works is reversal of environmental decline and substantial increase in lengths of streams with desirable LUMaR ratings (Figure 5) and higher predicted habitat suitability for platypus and many native fish species (Figures 7, 9, 10 and Section 6). The challenge is that the 10-year planned program of works is very ambitious, particularly as compared to what has been achieved with WTD (see Section 3 for full description of each set of works).

The various scenario outputs showed that different taxa have variable responses to individual mitigating actions of revegetation, stormwater management and fishways, and to the three actions applied in combination. This is seen most clearly with the results for the 13 native fish species (Section 6). We did not investigate responses to mitigating actions individually and in combination for the 52 non-weedy macroinvertebrate families but it is likely that we would have seen variable responses for families of this taxonomic group.

We have conducted these scenario analyses to explore the potential effects on instream biota. This exercise is only as sensible as inputs are, so accuracy and appropriateness are paramount. With respect to accuracy, are we capturing all the onground instances of revegetation from actors such as Melbourne Water, local Councils, community projects, private landholders as well as tree cover losses from human disturbances (e.g. clearing) and natural disturbances such as fire, storm and windthrow events? If not, what have we missed and how important is it? How can this be addressed? With respect to appropriateness, we saw that revegetation to 20 m forest-like buffers was detrimental to predicted habitat suitability of Common Galaxias, Southern Pygmy Perch, Yarra Pygmy Perch and possibly, Australian Grayling. It could be that revegetation in the form of more woodlands-like rather than forest-life buffers are more appropriate in the stronghold areas of these three species. As noted in Section 3.2, the 10-year planned stormwater works scenario was essentially equivalent to attenuated imperviousness at WTD. This “no improvement” of attenuated imperviousness differed from the 10-year planned revegetation and fishways actions which represent large improvements over WTD.

The scenario analyses have identified interesting potential trade-offs associated with the three primary interventions and how they affect different native fish species. The “difference” maps for each of the species (Section 6) shows us where these trade-offs occur. One way to use this mapping is to examine the spatial pattern of exactly where these trade-offs occur and how consequential that might be. Do these occur at a species’ high habitat suitability stronghold? Or at some of the species’

more marginal habitat? If it occurs mainly in a species' more marginal habitat and we know that say, revegetation provides benefits for a broad range of other species, then we might accept that trade-off. It provides new information that should be considered both for onground interventions as well as how we "implement" these in our HSM scenario runs as noted in the paragraph above. For instance, it might be more appropriate to compute attenuated forest from a woodland-like vegetation buffer rather than a forest-like vegetation buffer.

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Appendix

Fitted response curves for each of the 11 native fish species.

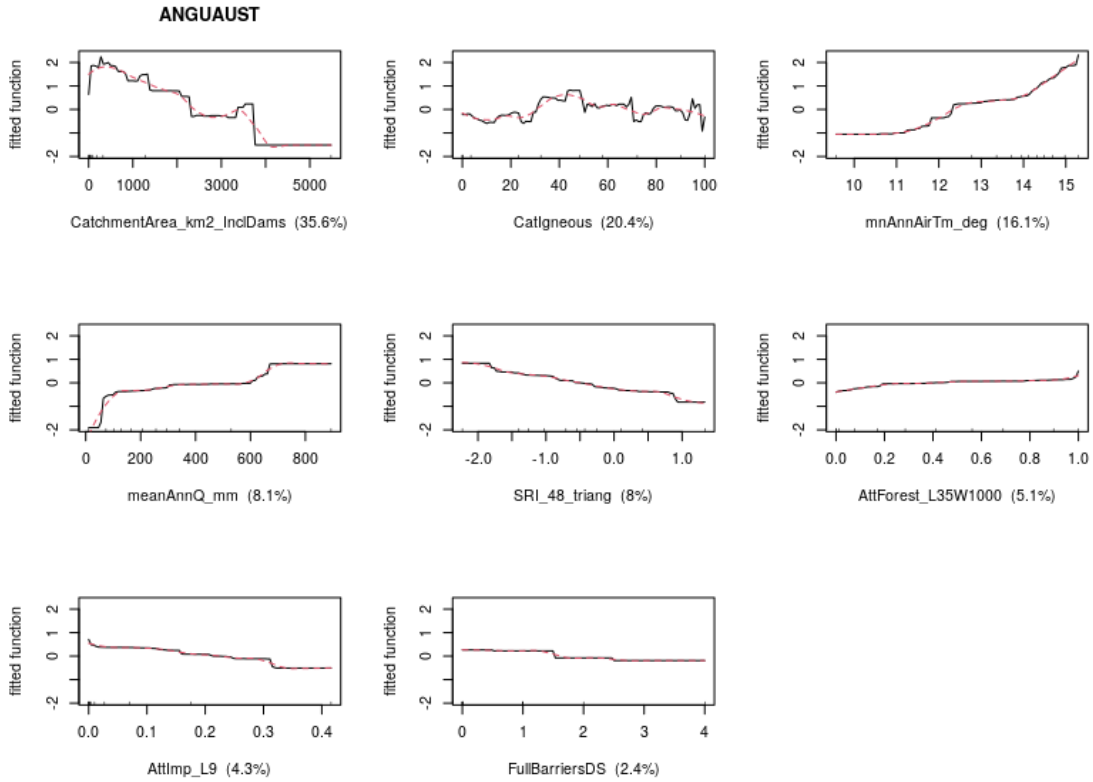


Figure A 1 Short-finned Eel: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

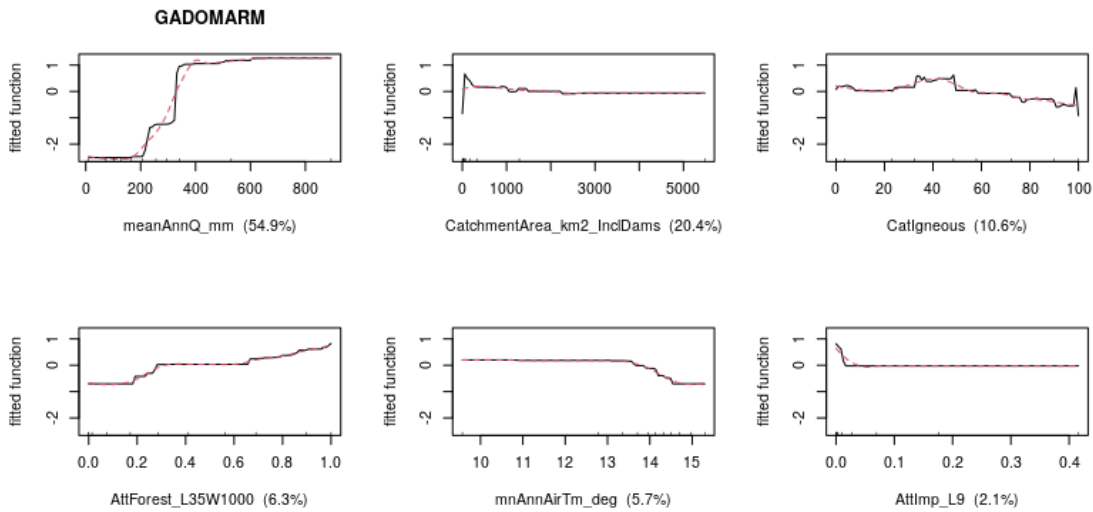


Figure A 2 River Blackfish: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

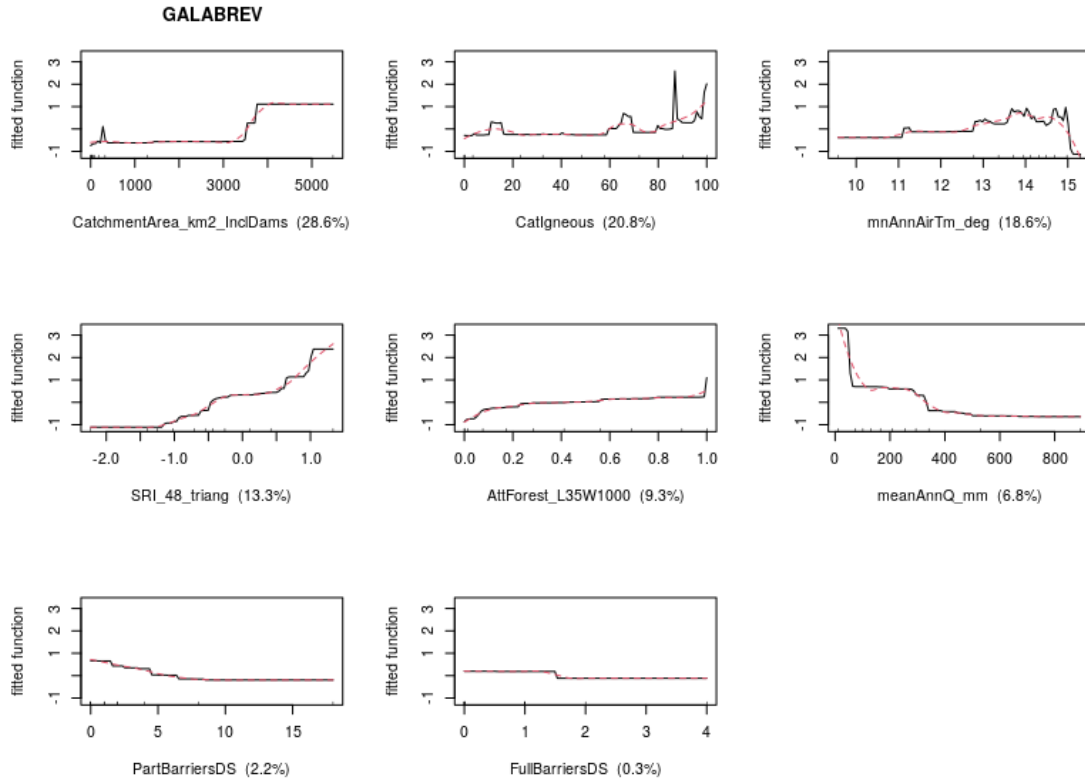


Figure A 3 Broad-finned Galaxias: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

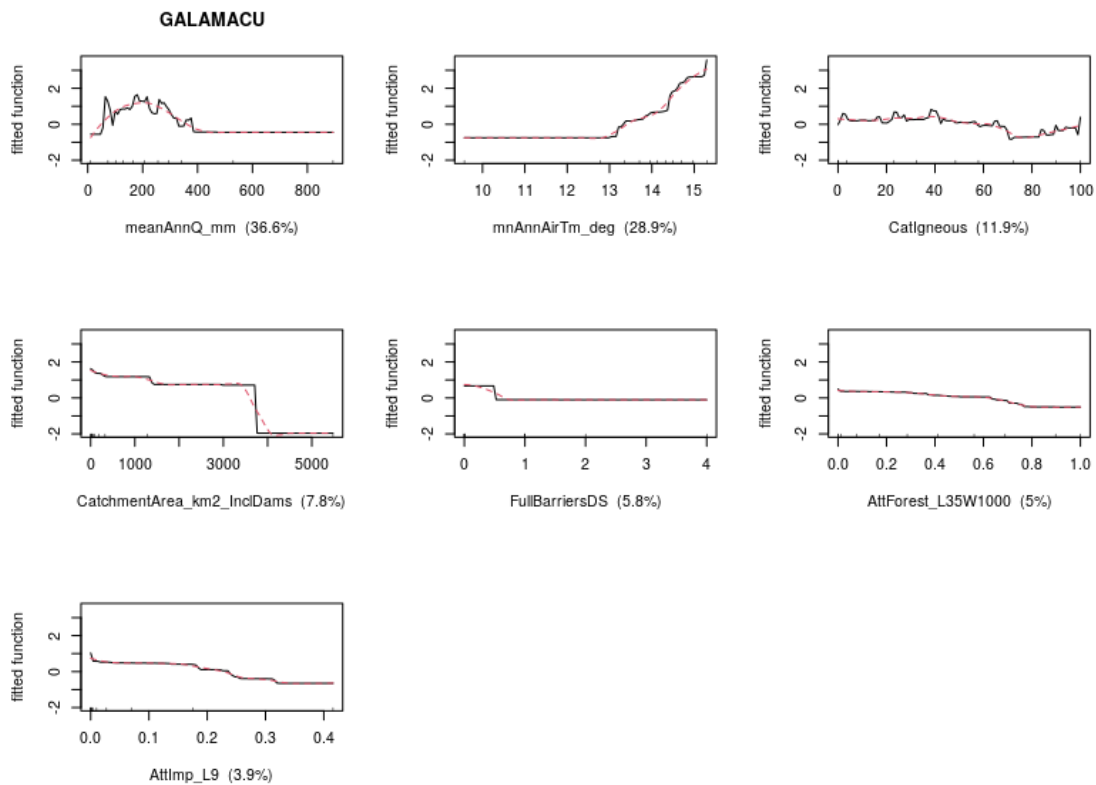


Figure A 4 Common Galaxias: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

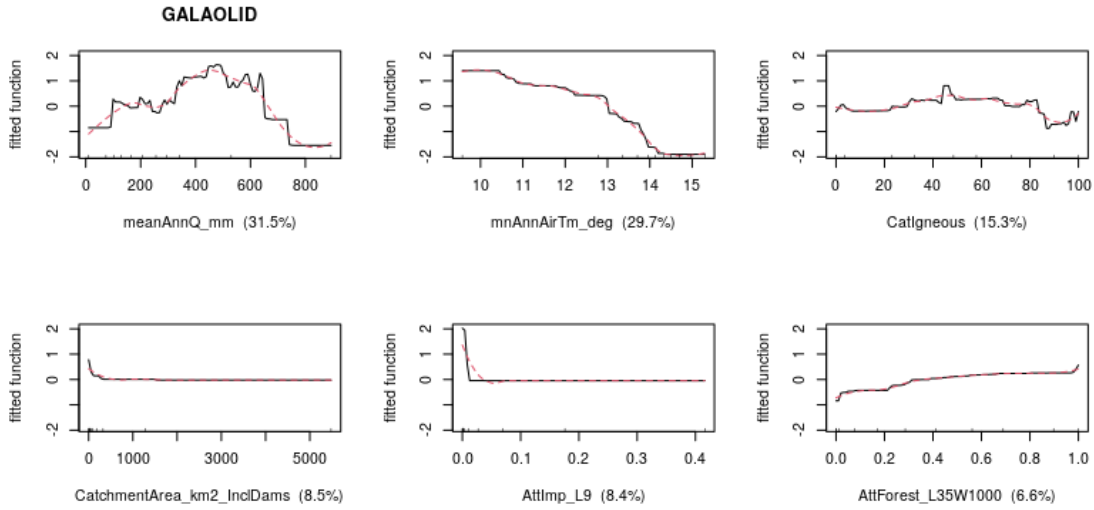


Figure A 5 Ornaté Galaxias: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

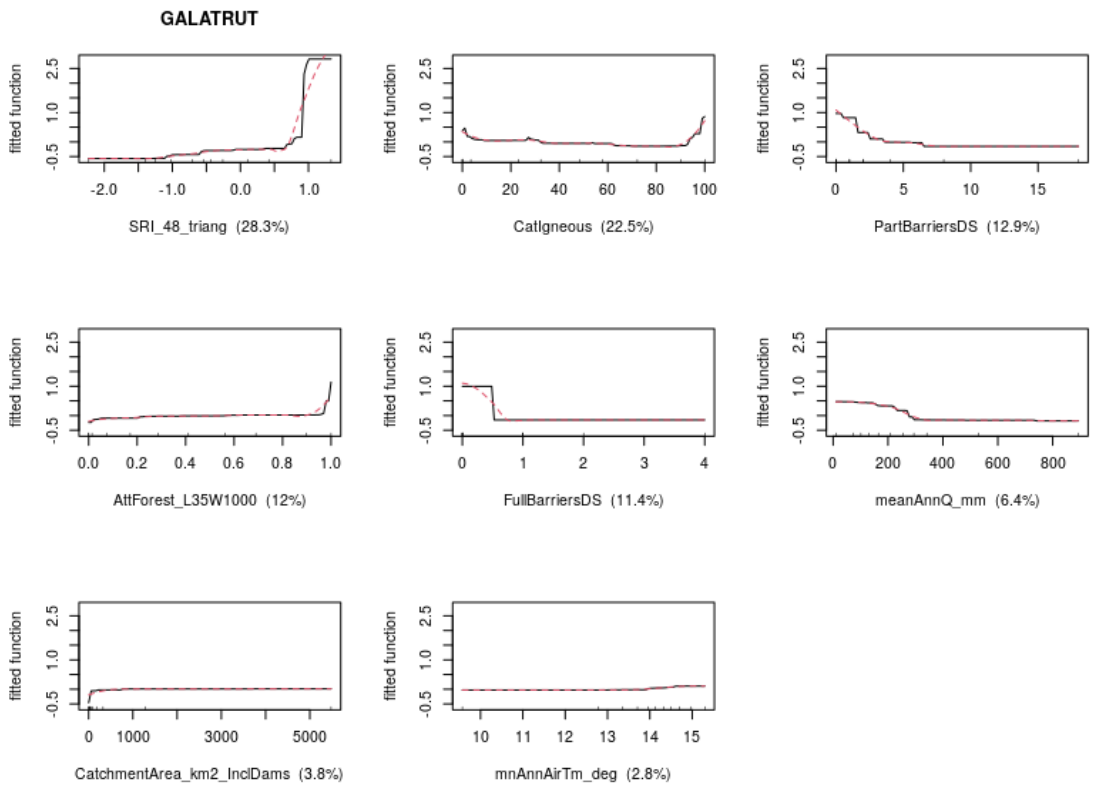


Figure A 6 Spotted Galaxias: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

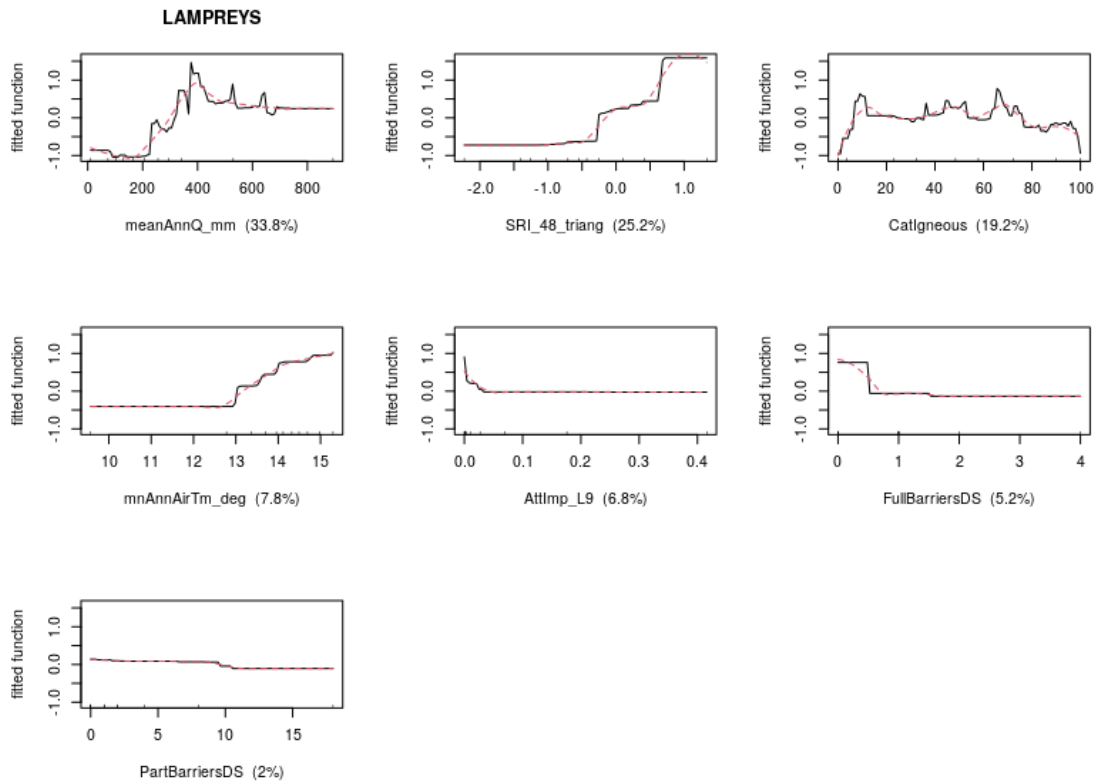


Figure A 7 Lampreys (Pouched Lamprey and Short-headed Lamprey): fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

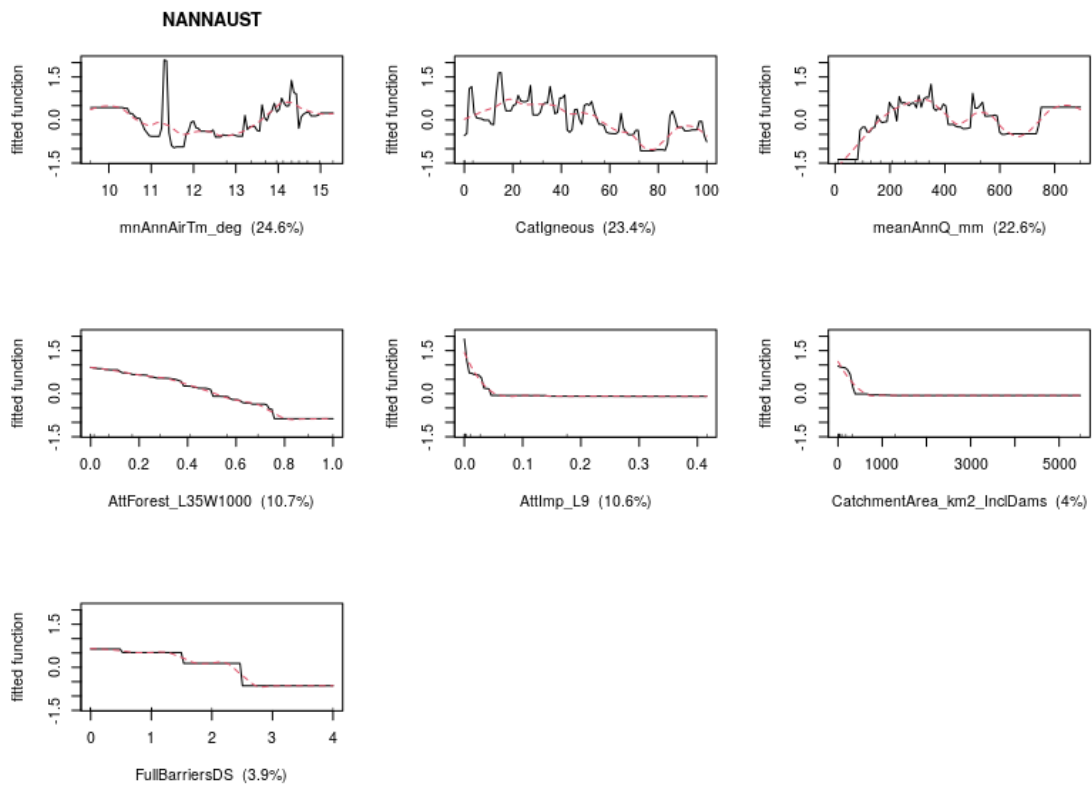


Figure A 8 Southern Pygmy Perch: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

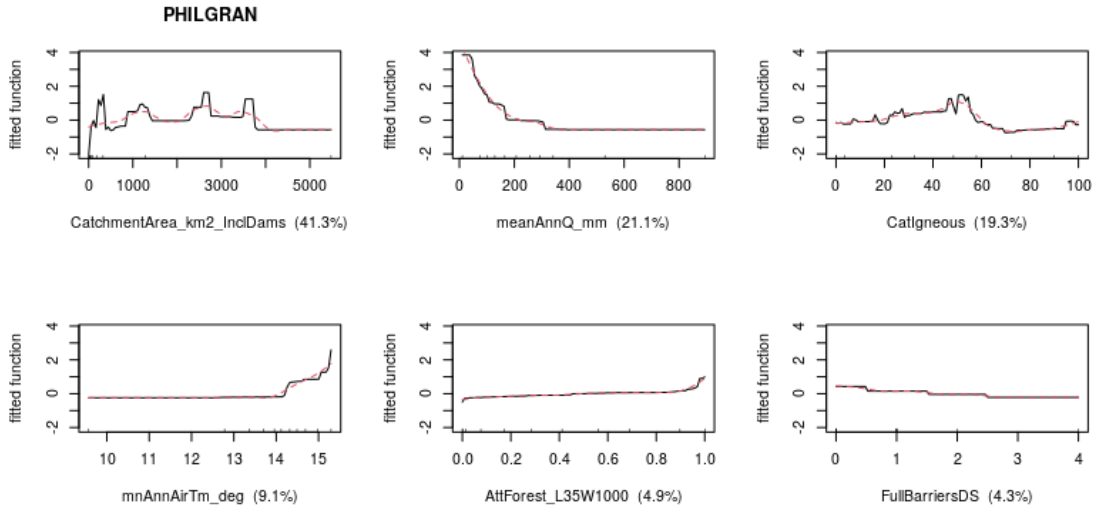


Figure A 9 Flatheaded Gudgeon: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

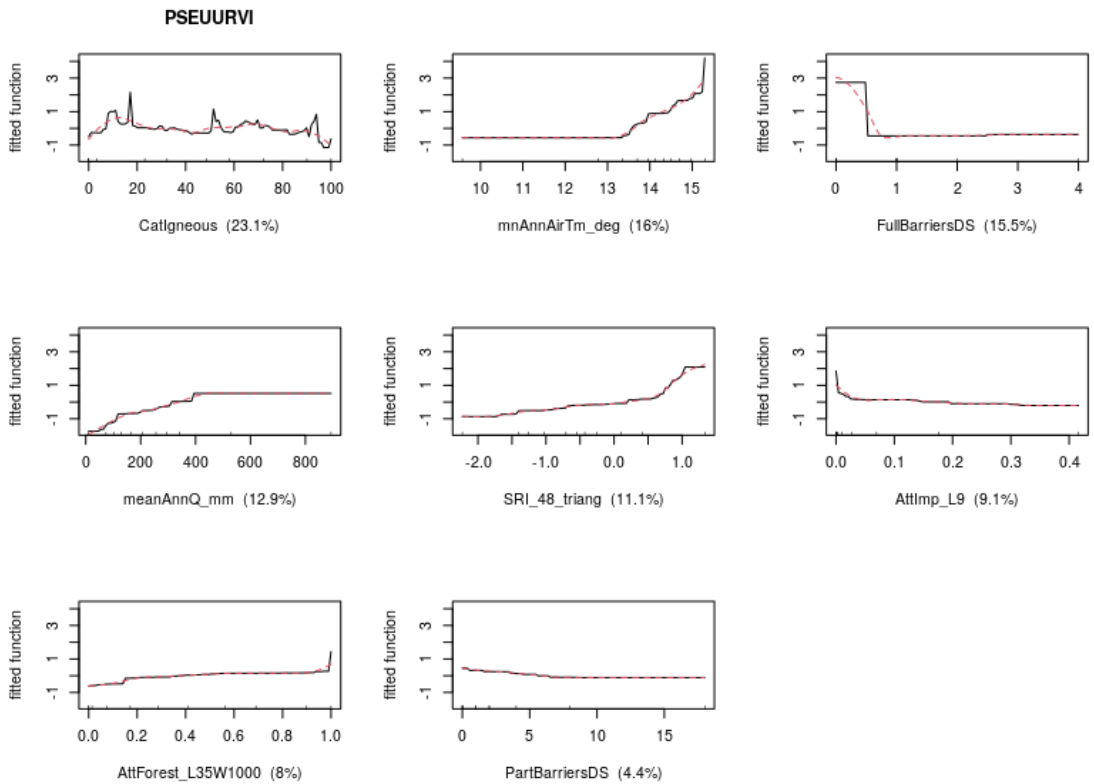


Figure A 10 Tupong: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.

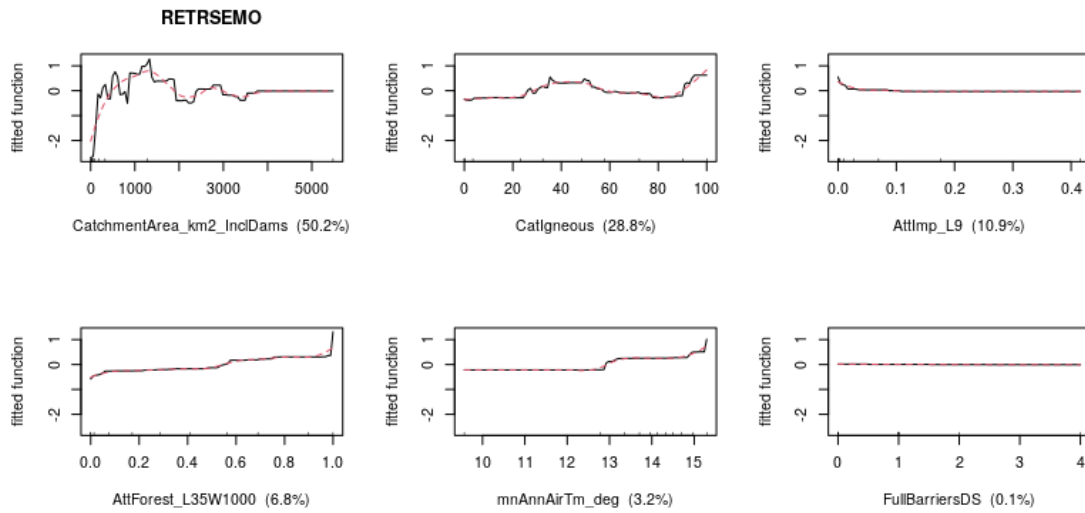


Figure A 11 Australian Smelt: fitted response curves for predictors in the boosted regression tree HSM, in order of relative percentage contribution. See Table 1 for detailed descriptions of each predictor.