Modelling for the Healthy Waterways Strategy mid-term review: risks and opportunities in the face of urban growth and climate change

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Key Points

- Habitat Suitability Models (HSMs) can be a valuable for exploring risks and opportunities for aquatic animals with a range of urban growth, climate and management scenarios
- HSMs indicated benefits from management actions to date and the full 10-year program, however, new climate projections suggest some important environmental values are at greater risk
- HSMs highlighted the need to rethink some strategy priorities and identify innovative solutions that broaden our suite of management options

Abstract

The Healthy Waterways Strategy 2018-2028 for Greater Melbourne includes management actions and 50-year targets to maintain and improve habitat of aquatic macroinvertebrates, native fish and platypus. This is underpinned by spatially explicit, quantitative habitat suitability modelling (HSMs), quantitative prioritisation of cost-effective management actions, and a collaborative process with stakeholders. HSMs enabled predictions of current and future habitat suitability for instream biota across the entire stream network with scenarios of climate change impacts and urban growth, as well as mitigation benefits of management actions (riparian revegetation, stormwater harvesting and treatment, removal of fish barriers) in isolation and in combination. Melbourne Water's mid-term review of the strategy used HSMs to evaluate predicted outcomes for in-stream biota at near-term (works-to-date at the 5-year mark and the proposed 10-year program) and 2070. For 2070, we investigated a range of plausible warming and drying scenarios that became available in 2019 and 2022. The HSMs indicated benefits are still expected from management actions to date and the full 10-year program, however, they also suggest some important environmental values are at greater risk, including platypus, river blackfish and ornate galaxias. HSMs were a valuable tool for exploring risks and opportunities for instream biota with a range of near- and long-term scenarios. This included identification of climate change vulnerable species and reaches where early mitigating actions are most important. It also highlighted the need to rethink some strategy priorities and identify innovative solutions that broaden our suite of management options.

Keywords

Habitat suitability modelling, macroinvertebrates, fish, platypus, future scenarios, strategic planning

Introduction

Melbourne's Healthy Waterways Strategy 2018-2028 (Melbourne Water 2018) is a co-designed strategy with a broad range of stakeholders, including State and local government, Traditional Owners, and community groups. It provides a 50-year 'road map' for protecting and improving the health of ~25,000 km of rivers, creeks, wetlands and estuaries throughout the Port Phillip and Westernport region of Victoria, Australia. Two major, region-wide threats to our waterways are future urban growth and climate change (Melbourne Water 2018). To support our understanding of the likely impacts of these threats, Habitat Suitability Models (HSMs) were developed for aquatic macroinvertebrates, native fish and platypus (Coleman et al. 2018; Chee et al. 2020, Coleman et al. 2022).

HSMs analyse the relationships between the environmental characteristics at sites where a macroinvertebrate family or native aquatic species is, and isn't, detected to develop a quantitative model that predicts how suitable any given stream reach is for the family/species. HSMs were developed using presenceabsence survey data from 1990 to 2009 and a set of environmental predictors to describe instream habitat suitability, such as catchment area, mean annual air temperature, mean annual runoff depth (an indicator of stream flow), attenuated imperviousness (an indicator of catchment urbanisation), attenuated forest cover (an indicator of the extent of upstream streamside vegetation), and instream barriers to fish movement. The selection of environmental predictors enabled direct predictions of changes in aquatic animal habitat suitability to climate and land use, as well as management actions and their interactions. These models allowed us to estimate habitat suitability for 52 macroinvertebrate families, 13 native fish species and platypus at stream reaches throughout the region, make predictions of habitat suitability under projected future scenarios of urban growth and climate change, and quantify expected benefits of specific management actions or combinations of actions. These models helped us identify 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, Moilanen et al. 2011) to rank all reaches showing where we should optimally act first to protect and improve aquatic biodiversity. Model outputs informed multiple co-design workshops with stakeholders where predictions were combined with local knowledge and expertise to agree on priority actions and 50-year targets.

Since the release of the HWS in 2018, there has been substantial investment by Strategy partners to implement the 10-year Performance Objectives towards the 10 and 50-year Management Targets. A Monitoring, Evaluation, Reporting and Improvement (MERI) Framework assesses and reports progress, effectiveness, impact and improvement opportunities (Melbourne Water 2019). A major commitment of the MERI Framework was a mid-term review of the Strategy to determine what's working well and what needs to be improved. The mid-term review brought together multiple lines of evidence from Melbourne Water's monitoring and research program. Here we describe and present the results of using HSMs in the mid-term review for quantifying expected changes from works-to-date and 10-year planned works, and longer-term impacts of updated climate change projections. We discuss the implications of scenario modelling predictions for 10-year progress of HWS 2018 and the robustness of existing Strategy priority management actions and targets in a range of plausible climate-impacted futures.

Modelling Scenarios

Modelling scenarios for HSMs are constructed by selecting input values for 5 predictors: mean annual air temperature (°C), mean annual runoff depth (mm), attenuated forest (0-1), attenuated imperviousness (0-1) and instream barriers (number of full and partial barriers; only applicable to native fish HSMs) (Chee et al. 2020). Basic scenarios during the development of HWS 2018-2028 included:

- *Current conditions* (CURR scenario) – all predictors set to 2016 values;
- *Business-As-Usual Future* (BAUF scenario) – nominally a 50-year outlook with climate change reflected by temperature set at 2016 values + 1.5°C (capped at 15.8°C), runoff depth set equivalent to a 25% reduction in long term mean annual discharge at the mouth of the Yarra River, and modelled future urban growth (details in Chee et al. 2020). Attenuated forest and instream barrier values are set at 2016 values.

To these 'foundation' scenarios, we constructed mid-term review scenarios to explore:

A. In-stream biota habitat condition given ongoing urban development, works-to-date (WTD) management actions at the 5-year mark and what might be expected with fulfilment of the HWS proposed 10-year program

B. In-stream biota habitat condition given updated climate projections for warming and drying at 2070

Urban development, works-to-date (WTD) and 10-year Planned Works

To understand the impact of ongoing urban development, WTD management actions since the Strategy commenced in 2018, and the full 10-year planned works, we focused on three types of management actions – riparian revegetation (which enhances attenuated forest), stormwater management (which reduces attenuated imperviousness) and fishways (which addresses instream barriers). Specifically, the WTD scenario is the CURR scenario, but with WTD attenuated forest, WTD attenuated imperviousness and WTD fishway inputs (only applicable to native fish HSMs) as described below. Similarly, the 10-year Planned Works scenario is the CURR scenario, but with 10-year Planned Works attenuated forest, attenuated imperviousness, and fishways. The attenuated forest, attenuated imperviousness and fishway scenario inputs are described below, with full details in Chee et al. (2023a).

WTD and 10-year Planned Works Attenuated Forest. Our estimate of WTD attenuated forest cover relied solely on data from Melbourne Water revegetation activities (capital works and incentive programs) for 2018-2021 inclusive. This might be an underestimate of revegetation across the region, as unmapped native regrowth and revegetation by entities such as local government, community groups and private landholders were not captured. A caveat is that Melbourne Water incentives programs would partially cover some of these activities. Conversely, we acknowledge that riparian vegetation losses from human and natural disturbances such as vegetation clearing, fire, flood and windthrow was not incorporated into WTD. Revegetation data was integrated with existing lidar-derived estimates of tree cover across the region to estimate WTD attenuated forest cover – which excludes works aimed at improving vegetation quality e.g. infill planting, woody weed removal. To estimate 10-year Planned Works attenuated forest cover, a 20 m vegetation buffer was assumed to be achieved along all stream reaches in the 4,781 HWS priority revegetation reaches. If this level of revegetation works was achieved, many reaches would see an increase in attenuated forest cover of >0.4.

WTD and 10-year Planned Works Attenuated Imperviousness. In the absence of data to fully characterise changes in imperviousness that have occurred since the CURR scenario, we focused on quantifying imperviousness changes in HWS designated stormwater priority areas. We used Statement of compliance (SoC) data for these areas from 2019 to 2022 to estimate increases in directly connected imperviousness since the CURR scenario (Chee et al. 2023a). We acknowledge our estimates of WTD attenuated imperviousness are likely an underestimate. Even with data on approved and registered Precinct Structure Plans it is difficult to estimate exactly where and when greenfield developments will occur in the region out to 2028. For the 10-year planned works scenario, we used WTD attenuated imperviousness estimates, in effect, assuming no worsening (but also no improvement) of attenuated imperviousness throughout the region.

WTD and 10-year Planned Works Fishways. A total of 11 fishways have been completed in WTD. The 10-year Planned Works program includes an additional 17 fishways and that no new barriers will be created. Details of locations in Chee et al. (2023a).

Updated climate projections for warming and drying

The HWS 2018 *Business-As-Usual Future* (BAUF) scenario relied on a single set of temperature increase and runoff depth reduction values. In 2019, updated projections for temperature became available from CSIRO and in 2022, updated projections of runoff became available from the Bureau of Meteorology. To account for a broader range of plausible climate projections, we re-ran the BAUF scenario for HSMs using updated climate-impacted temperature and runoff projections drivers. We particularly wanted to understand if mitigating actions in the Strategy were robust under these projections.

Air temperature. We used application-ready mean annual temperature projections from Victorian Climate Projections 2019 (VCP19, Clarke et al. 2019). These projections consist of a dynamically downscaled set of simulations based on CSIRO's Conformal Cubic Atmospheric Model (CCAM). For these simulations, six global climate models (GCMs) recommended by Climate Change in Australia (i.e. ACCESS-1.0, CNRM-CM5, GFDL-ESM2M, HadGEM2-CC, MIROC5, NorESM1-M) were downscaled to 5 km resolution over Victoria. VCP19 modelling focused on a medium (Representative Concentration Pathway (RCP) 4.5) and a high (RCP8.5) emissions scenario out of a possible set of RCP2.6, RCP4.5, RCP6 and RCP8.5 – with the RCP2.6 greenhouse gas emission scenario closest to that required to meet the Paris Agreement targets (Clarke et al. 2019). We focused on 2070 as that aligns with the 50-year horizon of HWS 2018. Of the six available GCMs, we used ACCESS1.0 RCP 4.5 and HadGEM2_CC RCP 8.5 to represent "book-end" mean annual air temperature inputs for 2070 HSM predictions.

Runoff depth. In 2022, climate-impacted runoff projections driven by the Australian Water Resource Assessment Landscape (AWRA-L v6) model (Frost et al. 2018) using the CSIRO application-ready climate data became available from the Bureau of Meteorology. The AWRA-L model is a daily timestep, gridded, spatially distributed water balance model that simulates the flow of water through the landscape. The AWRA-L model is informed by an ensemble of climate scenarios, which is a combination of RCPs, GCMs, downscaling and bias-correction approaches (Srikanthan et al. 2022). We acquired the historical and climate-impacted projection gridded runoff time-series data that we then used to derive climate-impacted runoff projections for 2070 for every stream reach.

Climate and management action scenarios. Our future climate scenarios explored the impact of temperature and runoff projections under moderate (RCP 4.5) and high (RCP 8.5) emissions pathways for both ACCESS 1.0 and HadGEM2_CC models. For example, ACCESS_RCP4.5 is like the BAUF scenario, but with ACCESS 1.0 projected mean annual temperature *and* mean annual runoff projection under moderate emission pathway RCP 4.5. To explore the potential benefits of management actions like riparian revegetation and stormwater management, on their own and in combination, we constructed the following two scenarios:

1. RV20 – like BAUF (or ACCESS_RCP4.5, HadGEM_RCP8.5 etc) but revegetate riparian zones on both stream sides, to 20m width along all streams (thus attaining attenuated forest = 1)
2. RV20_SW3 – like BAUF (or ACCESS_RCP4.5, HadGEM_RCP8.5 etc) but revegetate riparian zones on both stream sides, to 20m width along all streams (thus attaining attenuated forest = 1), and treat all modelled future and some existing impervious cover such that attenuated imperviousness in existing urban areas is reduced to 75% of 2016 levels.

Results

WTD and 10-year Planned Works

Aquatic macroinvertebrates. Aquatic macroinvertebrate family predictions (LUMaR) indicate that despite the WTD, the length of streams in the 'Very Poor' and 'Poor' categories has increased slightly relative to predicted CURR conditions (in 2016) (**Figure 1**). Decreases in condition are most notable in urban development areas in Melbourne's western, northern, and southeastern growth corridors (not shown due to paper length limitations). If the full 10-year planned works are achieved, however, this is predicted to substantially increase the length of streams in both 'Good' and 'Very Good' condition and decrease the length of streams in 'Poor' and 'Very Poor' condition.

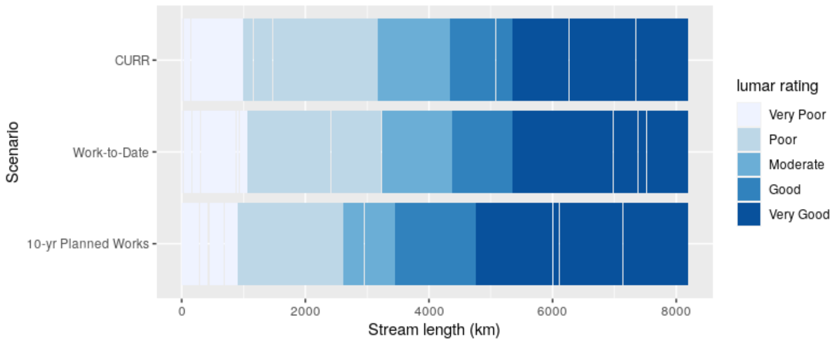

Figure 1. Stream lengths in each aquatic macroinvertebrate family rating (LUMaR) by scenario.

Native fish. HSMs were used to predict habitat suitability for 13 native fish species. At each reach, predicted probabilities were summed across all 13 species to give a 'stacked probabilities' index of native fish 'species richness'. Relative to the CURR scenario, the WTD scenario shows slight decreases in lengths of streams in the better condition (categories 2.0-5.5) and a slight increase in poorer condition (categories 1.0-2.0) (**Figure 2**). For the 10-year planned works scenario, when all three actions are applied in combination, including managing urban stormwater, revegetation and fishways, we generally see small to large increases in habitat suitability across the region.

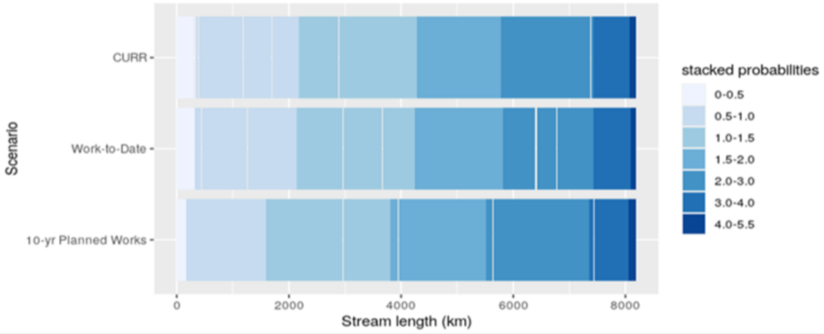

Figure 2. Stream lengths in each native fish species stacked probabilities category by scenario.

Platypus. For the male and female platypus model, the WTD scenario predicts little change in habitat suitability relative to the CURR scenario (**Figure 3)**. On the other hand, if the 10-year planned works are achieved, habitat suitability is predicted to increase the length of streams in 'Moderate' to 'Very High' categories (**Figure 3**).

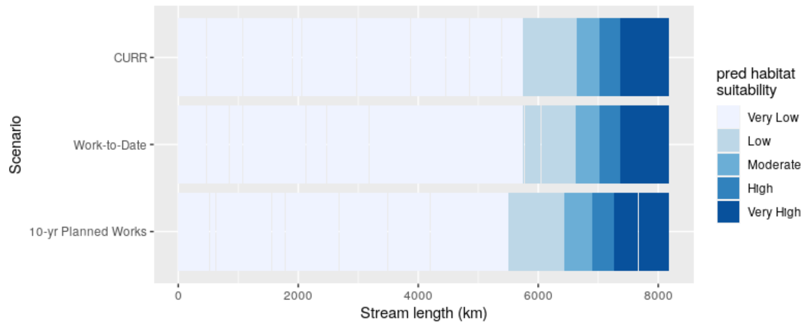

Figure 3. Stream lengths in each platypus habitat suitability category by scenario.

Habitat Suitability with Updated Climate Projections and Management Scenarios

Aquatic macroinvertebrates. When the HSM predictions of the CURR scenario are compared to the BAUF scenario (from HWS 2018), the overall proportion of streams in 'Good' and 'Very Good' condition based on aquatic macroinvertebrate families (i.e. LUMaR Index; Walsh and Webb, 2013) was expected to decrease (**Figure 4**). When these predictions were mapped across the region, declines were mostly in urban development areas and the southeastern parts of the region (not shown). Taking the new climate scenarios into account as part of the mid-term review of the Healthy Waterways Strategy, the greatest warming and drying across the region was predicted by the HadGEM-RCP8.5 scenario – resulting in a predicted further slight reduction of waterways in good and very good condition by 2070. Declines in condition using the HadGEM-RCP8.5 scenario were most notable in the west and southeastern parts of the region. However, the predicted benefits of revegetating all streams across the region (RV20) under the HadGEM-RCP8.5 climate scenario suggest that the overall percentage of streams in 'Good' and 'Very Good' condition would increase substantially (not shown). When revegetation was combined with stormwater management in new and existing urban areas (RV20_SW3) the percentage improvements further increased (**Figure 4**).

Native fish. We focused on river blackfish (*Gadopsis marmoratus*) and ornate galaxias (*Galaxias ornatus*), two species expected to be at-risk under climate change. For river blackfish and ornate galaxias, HSM predictions of habitat suitability in the CURR scenario compared to that in the BAUF scenario indicated that the overall proportion of streams in 'Good' and 'Very Good' condition would markedly decline (e.g. River blackfish **Figure 5**). The HadGEM-RCP8.5 scenario indicated that a further decrease could be expected. There were no notable predicted benefits for river blackfish and ornate galaxias of revegetating all streams across the region (RV20) or when both revegetation and was combined with stormwater management (RV20_SW3) under the HadGEM-RCP8.5 climate scenario (**Figure 5**).

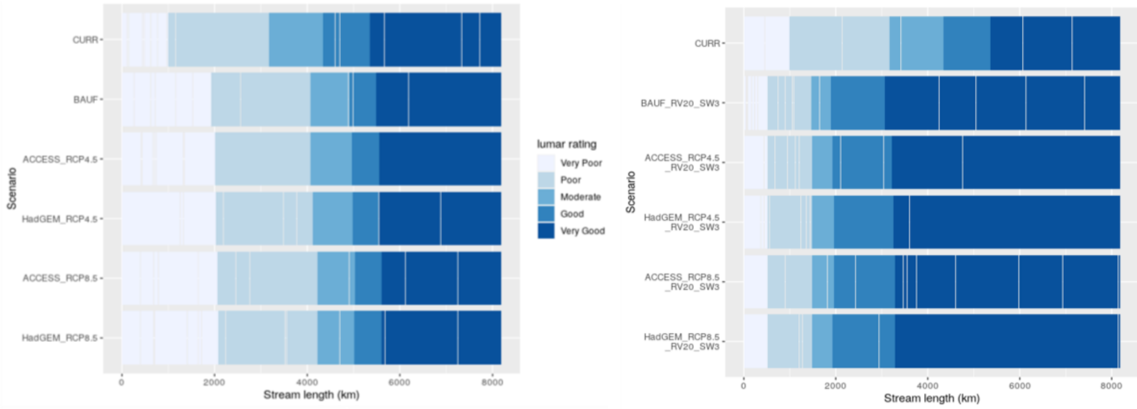

Figure 4. Summary stacked barplots of stream lengths in each aquatic macroinvertebrate rating (LUMaR) category by scenario for climate change-impacted scenarios with no mitigation action (left) and for CC-impacted scenarios with RV20_SW3 (right).

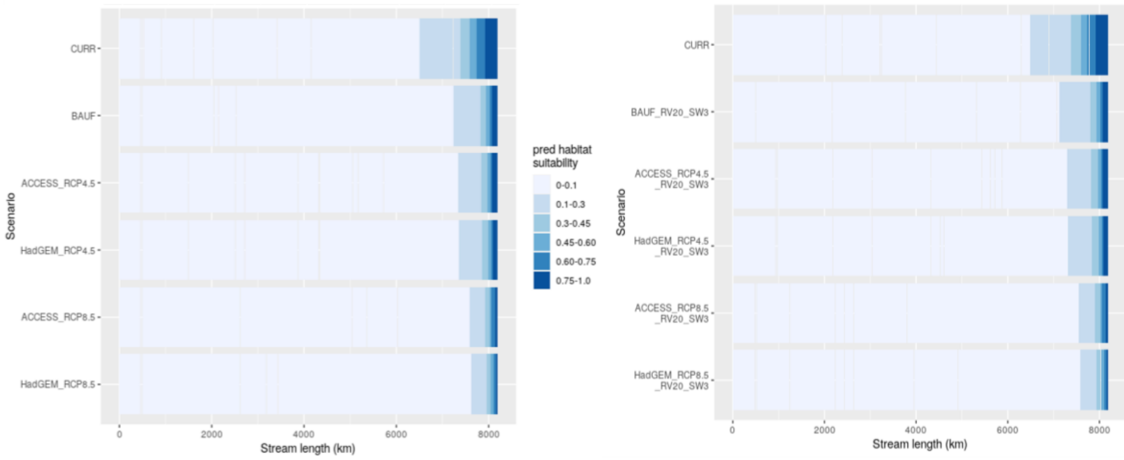

Figure 5. Summary stacked barplots for river blackfish of stream lengths in each predicted habitat suitability category by scenario for climate change-impacted scenarios with no mitigation action (left) and for CC-impacted scenarios with RV20_SW3 (right).

Platypus. For male and female platypus combined, HSM predictions of habitat suitability under the CURR scenario and the BAUF scenario indicated that the proportion of streams in good and very good condition would decline (**Figure 6**). With the HadGEM-RCP8.5 scenario, further decreases were predicted. The predicted benefits of revegetating all streams across the region (RV20) under the HadGEM-RCP8.5 climate scenario was that the overall percentage of streams in good and very good condition would increase slightly. When revegetation was combined with stormwater management (RV20_SW3) in new and existing urban areas there were no substantial predicted increases (**Figure 6**).

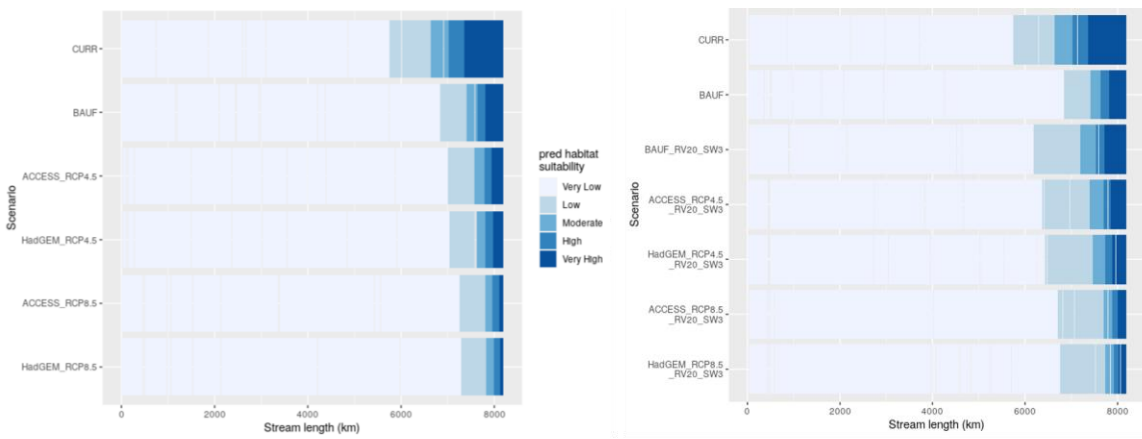

Figure 6. Summary stacked barplots for male-female platypus of stream lengths in each predicted habitat suitability category by scenario for climate change-impacted scenarios with no mitigation action (left) and for CC-impacted scenarios with RV20_SW3 (right).

Discussion and Conclusions

The predicted outcomes of works-to-date (WTD) ranged from slight deterioration to little improvement in habitat suitability for macroinvertebrates, platypus and native fish species. Slight declines from WTD overall because of increased urbanization since strategy release overriding the benefits of other activities such as revegetation and fishways. The expected outcome for 10-year planned works, on the other hand, is a substantial increase in lengths of streams with improved LUMaR ratings and habitat suitability for platypus and native fish species associated with the significant increase in volume of work required in the second half of the strategy period. It is acknowledged, however, that achievement of the 10-year planned works will be challenging – particularly given the pace of works-to-date, the scale of revegetation required, and the rapid rate of urban development and change in management approaches required to shift from BAU water quality management to stormwater flow management. The 10-year planned works scenarios also assumed average runoff conditions. The various scenario outputs show that aquatic animal habitat suitability have variable responses to individual mitigating actions of revegetation, stormwater management and fishways, and to the three actions applied in combination. This was evident in the predicted responses of the 13 native fish species (not shown). We did not investigate responses to mitigating actions individually and in combination for the 52 macroinvertebrate families but it is likely that we would have seen variable responses for families of this group as well. While LUMaR ratings are useful as an indicator of stream condition, further work is required to understand both changes in the specific families and species within those families from a biodiversity impact perspective.

For macroinvertebrates, LUMaR predictions at the region-level using the updated 2070 climate scenarios, did not differ substantially from the BAUF scenario in the 2018 Strategy. In addition, revegetation on its own (RV20) and in combination with stormwater management (RV20_SW3) appear to be effective management actions for aquatic macroinvertebrates under the updated climate change-impact scenarios. In contrast, the updated 2070 climate scenarios indicate potentially greater impacts of warming and drying on vulnerable native fish species (river blackfish and ornate galaxias) and platypus than originally estimated under the BAUF scenario. For the two native fish species, revegetation on its own (RV20) and in combination with stormwater management was predicted to have little benefit for habitat suitability under updated climate change-impact scenarios. This is because areas where they currently occur already have substantial cover of riparian vegetation and very little or no urban growth expected over the next 50 years. For platypus, revegetation on its own (RV20) had some benefit, that was strengthened in combination with stormwater management (RV20_SW3) but ultimately, the RV20 and RV20_SW3 actions did not amount to substantial mitigation under the updated climate change-impact scenarios.

One way in which this information was used for the Healthy Waterways Strategy mid-term review was to identify ‘climate change stronghold’ and ‘climate change vulnerable’ sub-catchments across all modelled taxa. This analysis was based on comparing the mapped CURR and BAUF predictions with that of mapped predictions under the ‘worst case’ HadGEM_RCP 8.5 projections. Stronghold sub-catchments were considered to be ‘resilient’ to climate change and need to be managed appropriately to ensure they remain resilient. Vulnerable sub-catchments were considered areas which are predicted to be even more impacted by climate change than predicted in HWS 2018. These areas are important because the HWS may not have considered adequate climate change adaption actions in setting long-term targets. Finally, sub-catchments were grouped into those with moderate or greater (Group A) HWS condition ratings (e.g. levels of catchment imperviousness, streamside vegetation extent and quality, water quality, physical form) and those with low or very low condition ratings (Group B). This provides information that may help prioritise effort based on findings of the HWS mid-term review.

This exercise also highlighted the vulnerability of particular environmental values under the updated climate projections, including platypus, river blackfish and ornate galaxias. Whilst proposed actions such as revegetation and stormwater management were expected to be of substantial benefit in protecting habitat suitability for these species in the face of the BAUF scenario, it appears they will not suffice in the face of the updated climate scenarios. Accordingly, we need to explore other management options for protecting and improving habitat suitability for these species into the future. For example, detailed investigation of climate risks to and opportunities for increasing climate resilience of platypus, river blackfish and ornate galaxias populations is recommended. Investigation of novel management opportunities to address stream flow stress under a changing climate across forest, rural and urban catchments is also needed, along with incorporation of diversion impacts into future habitat suitability models.

HSMs have proved to be a useful tool for quantifying potential benefits of works delivered and works planned to support progress tracking and management response. The ability to model and explore strategic considerations such as different magnitudes of climate change warming and drying, land use change, mitigating actions and their interactive effects has put us, waterway managers and our delivery partners, in a stronger position to understand, plan and respond to threats. This is vital for responding to a range of plausible futures in a more targeted and timely manner. A similar approach would also be beneficial to other waterway managers across Australia who are trying to navigate the complexities of urban growth and climate change as part of strategic planning of waterway restoration efforts.

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