MID-TERM REVIEW

Modeling the risk of Key Revegetation Species to a Changing Climate

Strategic alignment

Regional Performance Objectives (RPOs):

- RPO 30: Climate change resilient revegetation management practices are understood and implemented by selecting plant species, provenances and vegetation communities suited to projected future climatic conditions.

Key Research Areas:

- Streamside vegetation and instream habitat: Understanding the potential impacts of climate change on riparian vegetation communities and opportunities to effectively build resilience or transition vegetation communities.

Summary

The conservation of much biodiversity relies on healthy vegetation, but Victoria’s native vegetation communities are increasingly suffering from the effects of multiple pressures including habitat loss and fragmentation and climate change (DELWP 2017). The loss of vegetation and continued pressure on what remains is compromising not only ecosystem health but also the associated socio-economic services and cultural values that are reliant on these ecosystems (Pecl et al. 2017). In response to long-term climate projections or the greater Melbourne area, and that the climates our revegetation efforts experiences today could be quite different to climates the same trees will experience in decades to come, the Healthy Waterways Strategy advocates that we need to increase our ‘understanding of the potential impacts of climate change on riparian vegetation communities and seek opportunities to effectively build resilience or transition vegetation communities’ (Melbourne Water 2018).

Faced with a changing climate, many species will need to disperse to new locations with a more suitable climate or adapt locally to avoid extinction (Thomas et al, 2004). Yet this is challenged by the rapid rate of climate change and barriers to species dispersal (from habitat loss and fragmentation). The result is that fragmented populations may be unable to adapt locally without intervention. This has implications for revegetation and restoration practices that select plant species for the cooler and wetter conditions of the past. Species currently chosen for revegetation (especially long-lived species) may not be able to tolerate future climate conditions leading to wide ranging failures in planted sites, resulting in increased revegetation costs and reduced ecosystem services (e.g. water quality) provided by this vegetation. Guidelines on how best to make re- stored and remnant vegetation communities more resilient to a changing climate have been developed (Jellinek & Bailey 2020), but they did not identify which revegetation species are most likely affected by climate change.

One management strategy is to select species that are likely to tolerate future climates (McLachlan et al. 2007; Lunt et al. 2013). Another strategy is to move pre-adapted variants of a plant species (genotypes) around the landscape to maximise species resilience to climate change (Hoegh-Guldberg et al. 2008).

To do this, however, we need to better understand what the impacts of climate change may be on the current distribution of key plant species used in revegetation, where potentially pre-adapted plants are located and what other species traits ought to be considered to take account of potential plant survival risks.

The aims of this project were to:

1. Investigate how key riparian revegetation species used by Melbourne Water are likely to be influenced by a changing climate.
2. Identify which key revegetation species are at greatest risk as a result of climate change.
3. Investigate important mechanisms at critical life-history stages such as germination and seedling establishment that influence species responses to climate change.
4. Investigate if provenance selection may ameliorate the risk of climate change on a key revegetation species River Red Gum *Eucalyptus camaldulensis ssp. Camaldulensis.*
5. Explore how climate-matching methods could support climate-adapted seed-sourcing to build resilience in our revegetation programs to projected future climatic conditions

Recommendations

- Across the Melbourne Water region, wetter and cooler areas are predicted to increase in aridity at a faster rate than areas that were initially more arid. These more rapidly drying areas may need to be prioritized for climate adaptation management. Climate-adjusted seed/seedling sourcing for plantings may be helpful in these areas.
- Species that are currently broadly distribut- ed across climate gradients have more potential climate analogues available to be used compared to species with a distribution across a narrower climate gradient. Species selection for revegetation should consider multiple provenances from broad- ly distributed species in areas that have been identified as higher risk areas.
- Research on both narrowly and broadly distributed species should be undertaken to determine the adaptive capacity to

warm- ing and drying that exists within those spe- cies. To determine adaptive capacity, the performance of individuals from similar climate future analogues in different bioregions should be tested in revegetation tri- als.

- In the absence of specific environmental and genetic data, we recommend collecting climate adjusted seed from IBRA bioregions that minimize the difference in other environmental variables (e.g., soils).
- We recommend use of the Prober et al. (2015) protocol that includes 60% local stock, 30-35% from hotter and drier climates and 5-10% from wetter and cooler climates. In addition, to increase planting climate resilience, we suggest that (where possible) climate adjusted seed be collected from future climate analogue locations that represent the predicted conditions over the next 10-30 (2030-2050) as well as 50-70 years (2070 – 2090).
- When sourcing both local and climate adapted seed we strongly advocate that this material is collected from large, genetically diverse populations. This follows the general recommendations of the Florabank guidelines (Commander et al. 2021) and other conservation genetics research (e.g., Frankham et al 2019; Pickup et al. 2012).
- Melbourne Water consider updating their revegetation policies and procedures to incorporate learnings from the research, and explore establishment of trial sites to test and learn from applying a new climate resilient approach.

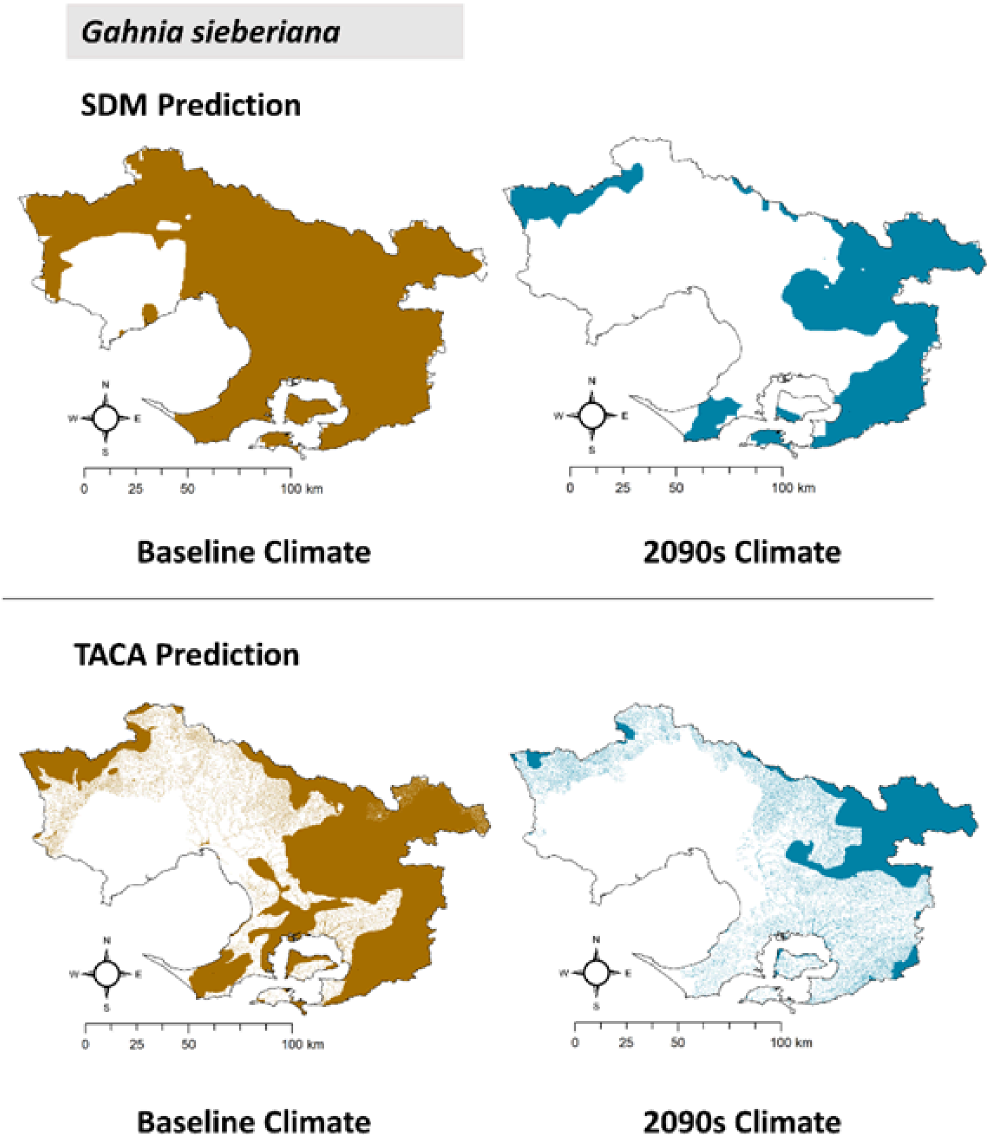

Figure 1. *Predicted changes in climate niche based on SDM (top) and mechanistic modelling (bottom). Baseline climate predictions (left and brown) and future predictions (right and blue) show divergent predictions. SDM modelling predicts wider climatic niche and less contraction thanTACA modelling. TACA modelling highlights importance of riparian areas in both base and 2090s climate scenarios. The probability threshold of 0.48, identified in the SDM analysis for discriminating presence from absence sites, was used to classify the maps.*

What did we do?

The aims of this project were addressed by employing multiple methods including statistical species distribution modelling (aims 1, 2), glasshouse seed germination and in-ground seed- ling establishment trials (aim 3), mechanistic species distribution modelling (aims 1-4), and climate-matching and genetic analysis of seedlings (aims 4, 5).

Future predictions of species' suitable habitat were compared to current suitable habitat to understand changes in extent and severity in decline, and thus characterise species' risk to a changed climate in their current climatic niche (i.e., areas of current modelled climatic suitability). Measurements of species' sensitivities to climate stresses at germination and seed- ling establishment stages were incorporated into mechanistic species models to explore how species responses to climate change vary by modelling approach. For example, while the habitat could be predicted to be suitable for a mature tree, it may not be suitable for critical life stages (e.g. seed germination) to ensure ongoing recruitment. Climate-matching anal- yses identified areas within the present-day distribution of species of interest, that match with projected future climate scenarios for the Melbourne Water region. These climate analogues are potential source locations for seeds or seedlings of provenances that may be able to tolerate future climatic change (i.e., climate-adjusted).

Species distribution modelling

Species distribution models (SDMs) are used to predict the distribution of a plants and animals in response to changing or different environmental conditions. We developed SDMs to characterise the preferred environmental conditions for 31 Melbourne Water key revegetation species (and 4 subspecies) identified by Melbourne Water staff. These SDMs have been used to estimate potential climate change impacts on the climate suitability and future distribution

Mechanistic modelling

A short coming of SDMs is that they may not capture other important mechanisms that determine a species response to climate (Yee-Law et al., 2021), such as the sensitivity of critical life-stages like germination and establishment (Mok et al., 2012).

To account for this, we developed mechanistic models to integrate species responses to climatic stresses (e.g. moisture levels and temperature) at germination and seedling establishment phases, for a subset of 10 species (representing a range of life-forms). These species were: *Acacia implexa* (Lightwood), *Ac. dealbata* (Silver Wattle), *Ac. mearnsii* (Black Wattle), *Ac. melanoxylon* (Blackwood), *Allocasuarina verticillate* (Drooping Sheoak), *Bursaria spinosa* (Sweet Bursaria), *Eucalyptus camal- dulensis* (River Red Gum), *E. viminalis* (Manna Gum), *Gahnia sieberiana* (Red-fruit Saw-sedge) and *Olearia lirata* (Snow Daisy-bush). This mechanistic model was used to explore how the 10 species sensitivity to climate factors (at critical life-stages) would influence the suitability of habitats under future climate conditions.

Exploring provenance in mechanistic modelling

We investigated the importance of provenance selection on determining species risk to climate change, using *Eucalyptus camaldulensis* as a case study. Fourteen provenances of *E. camaldulensis* were selected (sourced from southern NSW, South Australia and across Victoria), with glasshouse experiments used to quantify provenance-specific germination responses for stratification, temperature and moisture (drought). Models were used to test the potential adaptive capacity at the regeneration phase, and asses potential to offset the species risk to climate change. Further genetic analysis of the 14 provenances of E. camaldulensis will quantify genetic variability in the provenances (to be reported by end of 2023).

Climate Matching to identify potentially climate-adjusted provenances.

Climate-matching is an approach that identifies areas within the present-day distribution of species of interest, that match with projected future climate scenarios for the Melbourne Water region. For 10 of the 31 key MW revegetation species (including tree, shrub and herbaceous species), Greening Australia conducted a climate-matching analysis using projection data from the ACCESS 1.0, moderate emission RCP 4.5 scenario for 2030, 2050, 2070 and 2090 (Greening Australia 2021). This climate analogue approach was used to identify seed source locations for selecting potentially climate-adjusted provenances that may be able to tolerate future climatic changes

What did we find?

Species Distribution and Risk Modelling

- Under projected climate conditions (ACCESS 1.0 RCP 8.5 scenario), statistical and mechanistic species distribution models predicted shifts in climatic suitability that could involve both contractions of a species' present-day range as well as expanded suitability in areas they do not presently occur in. This is illustrated in Figure 1 for *Gahnia sieberiana* and Figure 2 for *Allocasaurina verticillata*.
- A common pattern of species model predictions was a shift of suitable habitat to higher elevations and contraction towards riparian areas (see Figure 3).

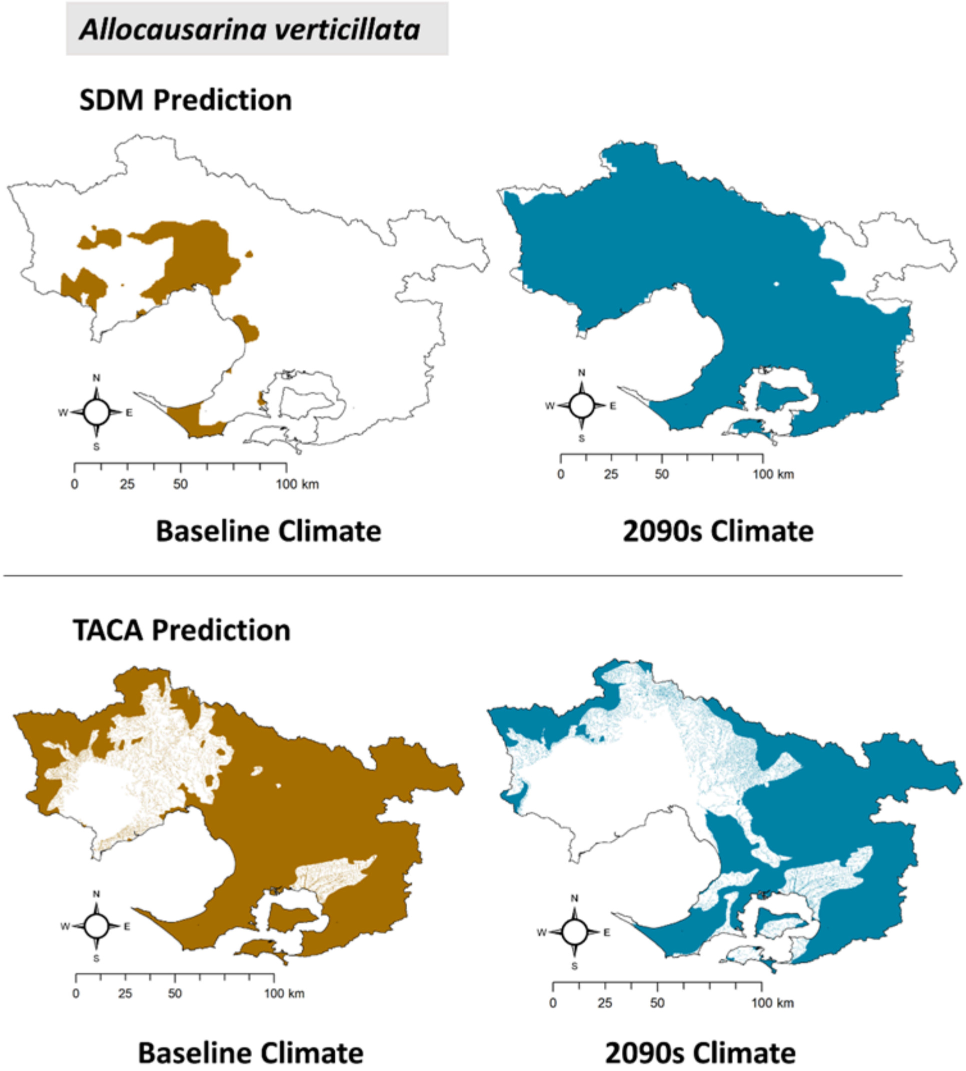

Figure 2. Predicted changes in climate niche based on SDM (top) and mechanistic modelling (bottom). Baseline climate predictions (left and brown) and future predictions (right and blue) show divergent predictions. SDM modelling predicts maintenance of current niche and expansion which equals no risk while mechanistic modelling predicts wider baseline niche but contraction under climate change. Contraction in mechanistic model categorises species at high risk. The importance of riparian areas (linear features) for the species in parts of the landscape is illustrated in TACA model outputs. The probability threshold of 0.22, identified in the SDM analysis for discriminating presence from absence sites, was used to classify the maps.

- Current species used widely in revegetation are at moderate to extreme risk to a changing climate. Risk was moderate to extreme for both mechanistic and SDM models, though divergence occurred within species between approaches . *Allocasaurina verticillata* had the largest divergence between model type outcomes. Differences between SDM and mechanistic models highlight the need to consider key physiological processes in modelling species response to climate (see Figure 1 and 2).
- Statistical SDMs tended to over or under predict compared to corresponding mechanistic models. For 9 of the 10 species, this resulted in differences in risk vulnerability classification within the Melbourne Water region.
- Though statistical and mechanistic models pre- dicted differing extents of spatial contractions, suitable habitat predictions were consistent. For instance, in many areas, where a species' statistical model predicted occurrence, the mechanistic mod- el predicted occurrence in the riparian areas sug- gesting that soil water availability in these areas is important for species recruitment and persistence (see Figure 1,3).
- For *A. implexa* and *A. verticillata*, the statistical and mechanistic models made conflicting predic- tions. The statistical models predicted wide habitat suitability across the Melbourne Water region under projected future climate while the mechanistic models suggested declines in habitat suitability (see Figure 2). These discrepant predictions could be a result of mechanisms that affect regeneration processes incorporated in the mechanistic model.

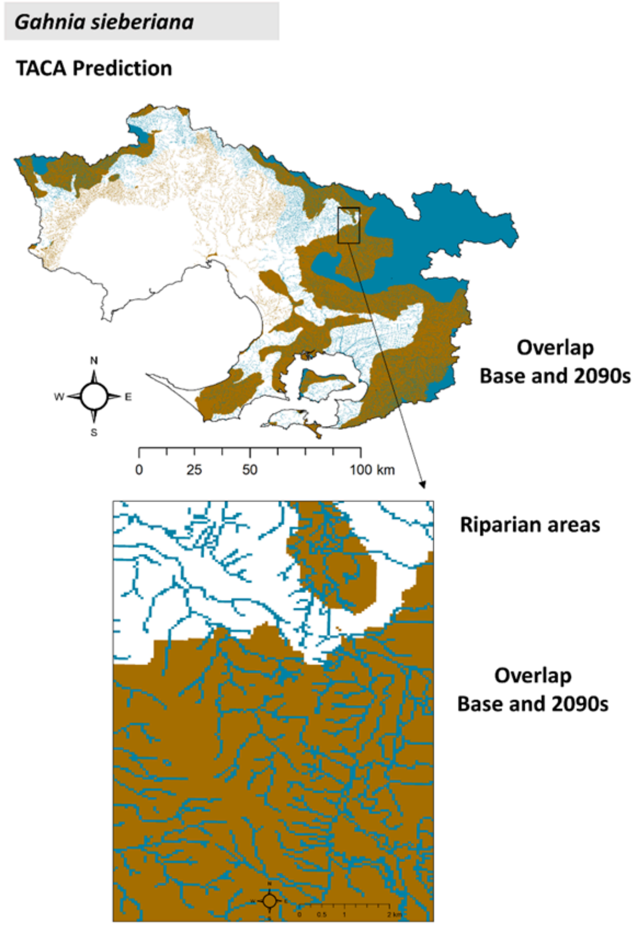

***Figure 3**. Difference in predicted range of Gahnia sieberiana based on TACA mechanistic modelling and importance of riparian areas. The maps show the areas where the species was not predicted to occur (white), areas it contracted from by the 2090s (brown) and the areas where it persisted or expanded to in the 2090s (blue). The probability threshold of 0.48, identified in the SDM analysis for discriminating presence from absence sites, was used to classify the maps.*

Climate Matching

- Under the projected climate conditions (ACCESS 1.0, RCP 4.5 8.5 scenarios), wetter and cooler areas were predicted to increase in aridity at a faster rate than areas that were initially more arid. These more rapidly drying areas may need to be prioritized for climate adaptation management.
- Species that are currently broadly distributed across climate gradients (e.g., *Eucalyptus camaldulensis*) had more potential climate analogues (areas where the current climate is similar to the projected future climate) available under future climate conditions compared to species with a narrower current climate gradient distribution (e.g., *Pomaderris aspera*).
- For a given species, drier and hotter locations (e.g. Dandenong) generally had less climate analogue locations compared to wetter and cooler locations (e.g. Watts River).

Provenance Trials and Modelling

- Provenance specific modelling based on regeneration and drought traits for *E. camaldulensis* found that differences in germination ecology and ecophysiology did not lead to divergence in modelled response to climate variability and change. All provenances were identified to be at high risk to climate change. This indicates that observed variation between provenances for the traits measured are unlikely to foster adaptive capacity. These traits appear to be tightly adapted to a range of climatic variation.

Future directions and knowledge gaps

- Melbourne Water Look for opportunities to update policies and procedures with emerging knowledge from this and other research.
- Expand mechanistic modelling to all species of interest for revegetation including provenances and species from warmer and drier climates. This requires conducting studies on germination ecology and ecophysiological responses to drought (prioritised based on current knowledge regarding species distributions or traits).
- Undertake field trials to validate predictions from the statistical and mechanistic models. This involves planting species in predicted refugia and monitoring establishment success and survivorship over time, as well as testing new approaches for seed sourcing (practical opportunities and constraints).
- Test the underlying assumption of the climate-matching approach. The assumption is that provenances from the appropriate climate analogue region are locally adapted to current climate conditions, and therefore "pre-adapted" to the expected future climate conditions (Hoegh-Guldberg et al. 2008). But this an assumption that needs testing since species may not be locally adapted (Leimu & Fischer 2008). What is required are robust approaches to identifying seed sources that are pre-adapted to future climates without assuming local adaptation (Browne et al. 2019). The *E.*

camaldulensis provenance seed germination and seedling establishment trials and mechanistic modelling highlights the im- portance of testing these assumptions and provides a means of addressing the issue.

- Experimentally test different proportions of seed stock to better understand the short- and long- term implications of implementing climate- adjusted seed-sourcing. This could be undertaken by combining information on climate analogues with experiments that examine the traits and performance of individuals from different climate sources.

How are we sharing findings?

- Project report: Assessing the vulnerability of key revegetation species to changing climate: species distribution and regeneration modelling. Report submitted to: Melbourne Water in requirement of deliverables for Melbourne Waterway Research-Practice Partnership project: D5: Modelling the Species to a Changing risk of Key Revegetation Climate. 30 November 2021.
- Project Report: Modelling Species Distributions in a Changing Climate: Climate Adjusted Seed Sourcing for Melbourne Water. June 2022
- Conference Poster: Assessing the risk to key revegetation species from a changing climate. Biodiversity Across Borders Conference, Federation University, 10 June 2022.
- Final Technical Report and datasets. Provided August 2022 with spatial maps of modelled distributions provided via share folder.

For more details on the research outcomes of this project,
or other projects of the MWRPP, please contact:

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