Griffith UNIVERSITY
Queensland, Australia

RECONNECTING RIVER COUNTRY: WEED RISKS AND BENEFITS ASSESSMENT

SUMMARY REPORT

PREPARED FOR THE DEPARTMENT OF PLANNING AND ENVIRONMENT

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Prepared by: Samantha Capon, Rebekah Grieger, Ali Chauvenet, Jaiden Johnston-Bates, Hannah Franklin and Hannah Burgoyne

Summary

The presence and consequences of exotic plant species is a major concern for land managers and other stakeholders in the Murray and Murrumbidgee River regions. Particular concerns have been raised in relation to the potential for changes in weed distribution resulting from the relaxation of flow constraints proposed under the Reconnecting River Country program (previously the Constraints Measures Program). This program, run by the New South Wales (NSW) Department of Planning and Environment (DPE), aims to improve wetland and floodplain connectivity through investigating relaxing or removing some of the constraints or physical barriers that impact delivering water for the environment. It focuses on the following areas in the southern-connected Murray Darling Basin (the basin), including:

• Hume to Yarrawonga (River Murray)
• Yarrawonga to Wakool (River Murray)
• Murrumbidgee River As part of this program, NSW DPE contracted Griffith University to conduct an assessment of current weed distributions and consequences and assess potential risks and benefits associated with constraints relaxation.

The aims of this project were to:

- describe the current invasive weed distribution and consequences in the project areas through a compilation and synthesis of existing knowledge;
- evaluate the likelihood and consequences of various flow constraint relaxation options changing invasive weed extent and impacts in the project area; and
- develop a risk framework for invasive plant species in relation to each flow scenario.

A comprehensive review of published literature and internet resources was conducted in the first stage of this project to address the first aim. This review identified over 80 weed species of concern and described the current invasive weed distribution and consequences in the project area (see Capon et al., 2021).

To explore the current distributions of weeds in the project areas, as well as potential changes to these under the inundation scenarios, species distribution models (SDMs) were developed for each catchment (i.e., Murray and Murrumbidgee) under a base case and in relation to each inundation scenario. Seven weed species and two plant functional groups (comprising an additional 38 species) were the focus of this investigation. To build these SDMs, we used species observation data from Atlas of Living Australia and additional data held by the NSW government. Climatic data (i.e., annual rainfall, temperature range), environmental data (i.e., land use, vegetation, and wetland mapping), and inundation metrics were included as predictor variables in the models. The SDMs generated map outputs of the likelihood of the presence/absence of the weed species examined in the Murray and Murrumbidgee project areas under each scenario from which we delineated areas of suitable habitat and highly suitable habitat (i.e., top 20 % of suitable habitat). To determine the land uses, vegetation types and wetland classes with most suitable habitat for the weed species considered in each scenario and the changes predicted under these from the base case we conducted a range of spatial data analyses.

The results of the SDMs and spatial analyses are summarised below:

- Most of the species and functional groups investigated exhibited potential basecase distributions of suitable habitat between 10,000 and 60,000 hectares over the whole project area. The basecase distribution of Phyla (lippia) was much larger, covering approximately 300,000 hectares of potential suitable habitat, which mostly occurred in the Murray

catchment. Suitable habitat for Sagittaria (arrowheads) only occurred in the Murray catchment. Salix (willows) had minimal suitable habitat throughout the project area.

- Climatic variables were the most important predictors in all SDMs and annual rainfall was the most important predictor in five of seven models. Inundation metrics were moderately important for all taxa, but metrics associated with longer dry periods were particularly important for terrestrial weed taxa, e.g., Marrubium (horehounds), Lycium (African boxthorn).

- Weed hotspots (defined here as areas comprising suitable habitat for four or more modelled weed taxa) occupied less than 1 % of the project area and tended to occur in the vicinity of all the major towns in the project area (Wagga Wagga, Hay, Albury, Echuca, Deniliquin and Swan Hill) as well as along the Murrumbidgee Rivers south of Griffith.

- Distribution of suitable habitat area for amphibious or aquatic weed species (i.e. species which require flooding for their lifecycle, e.g. Phyla (lippia), Sagittaria (arrowheads) tended to decrease under relaxed constraints scenarios, particularly in the Murray but also in the Murrumbidgee, albeit to a lesser extent. Amphibious species which have thrived in some low-lying habitats under recent reduced flow conditions, appear likely to be 'drowned out' by the increased duration, frequency, and permanence of inundation events proposed under constraints relaxation scenarios.

- Terrestrial species (i.e., species which do not require flooding for their lifecycle), particularly the widespread Marrubium (horehounds) and Lycium (African boxthorn), exhibited increased potential suitable habitat area under relaxed constraints scenarios in both study catchments. The potential increase in fringing areas (i.e., where moisture is readily available more frequently but where inundation does not occur for longer periods of time) would likely favour the germination and establishment of terrestrial species under a more frequent occurrence of wetter conditions.

- Although modelled changes in weed distributions were often substantial between the basecase and flow scenarios, minimal differences in projected species distribution occurred between inundation scenarios. Where differences were notable, Salix (willows) for example, greater potential weed extents were predicted under lower constraint relaxation scenarios, suggesting that the higher flooding conditions resulting from greater constraint relaxation will be unsuitable for this species.

- Results of the expert elicitation activities largely aligned with the model findings, although experts generally noted low to moderate confidence in their responses and suggested minimal changes to weed distributions under proposed inundation changes. Model outputs showed varying directions and magnitudes of changes, however, there was little variation between constraint relaxation scenarios for each taxon.

- The weed risk assessment framework considered the potential changes in species distribution under each constraint relaxation scenario overall and in land uses, vegetation types, wetland types. Total risk scores for each species were largely consistent between constraint relaxation scenarios with an overall negative score for all scenarios in the Murray River project area corresponding to a slight overall benefit in this region. In the Murrumbidgee, the lowest constraint relaxation scenario (32GL) had an overall positive score, corresponding to a slight overall risk in this region, while the two higher constraint relaxation scenarios had an overall negative score, corresponding to a slight overall benefit in this region.

Summary of weed risk assessment framework scores for each constraint relaxation scenario in the Murray and Murrumbidgee study areas (full table in table 12).

Study area	***Murray River***				***Murrumbidgee River***		
Constraint relaxation scenario	***Y25D25***	***Y30D30***	***Y40D40***	***Y45D40***	***32GL***	***36GL***	***40GL***
Total	***-636***	***-667***	***-708***	***-627***	***261***	***-339***	***-517***
Standardised score (-100 to +100)	***-2.8***	***-3.0***	***-3.2***	***-2.8***	***1.2***	***-1.5***	***-2.3***
Overall risk	***Likely overall slight benefit***	***Likely overall slight benefit***	***Likely overall slight benefit***	***Likely overall slight benefit***	***Likely overall slight risk***	***Likely overall slight benefit***	***Likely overall slight benefit***

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We acknowledge the Traditional Custodians of the land where we work, the Yuggera, and Turrbal people, and the land which is the focus of this work, the people of the Murrumbidgee and Murray Rivers. We show our respect for Elders past, present and emerging and extent that respect to all Indigenous Australian and Torres Strait peoples.

We also thank the many other people that contributed to this project by providing data, sharing their knowledge, participating in our survey and expert workshops, and providing revisions to this report.

Glossary

Common acronyms

DPE	New South Wales Department of Planning and Environment
RRC	Reconnecting River Country Program
DPI	New South Wales Department of Primary Industry
SDM	Species Distribution Model

Common phrases

Weeds	Exotic plant species which are regarded as pests in the study region
Project area	Boundary of floodplain inundation area defined by RIMFIM
Inundation / flow scenario	Constraints relaxation scenarios (outlined in table 2) used for modelling changes in species distribution
Suitability	Areas of habitat deemed suitable by species distribution model outputs based on suitability threshold calculated with each model run. A cell must be suitable in all five model runs to be classed as suitable. Highly suitable areas are the top 20% of suitable habitat which is, in theory, a subset of suitability, however greater areas of high suitability are possible as cells do not have to fit the criteria in each of the model runs to classify.
Likelihood	In SDMs likelihood is the chance that a species can occur in a cell based on the initial occurrence data and environmental predictor variables. For risk assessment likelihood refers to the magnitude of change predicted by SDMs

Introduction

Background

The New South Wales (NSW) Department of Planning and Environment (DPE) is currently conducting a range of assessments to understand the benefits and risks associated with various flow management options in the Murray and Murrumbidgee River catchments – the Reconnecting River Country (RCC) program. The RRC program seeks to use the best available data, knowledge, and techniques to investigate ecological outcomes of a range of flooding scenarios representing different levels of relaxation in existing physical and/or human constraints to flow in these catchments.

The flows being considered under relaxed constraints aim to inundate low-lying wetlands, billabongs, flood runners (with a small portion of floodplain) at an increased frequency. These additional inundations would likely occur in winter/ spring.

As part of the RRC program, Griffith University was tasked with evaluating the risks and benefits of these inundation scenarios for weeds in the project area (Figure 1). This evaluation is needed to inform decisions regarding environmental water delivery as well as to better inform affected landholders about the likely risks and to allow the Program team to develop appropriate mitigation measures to address these.

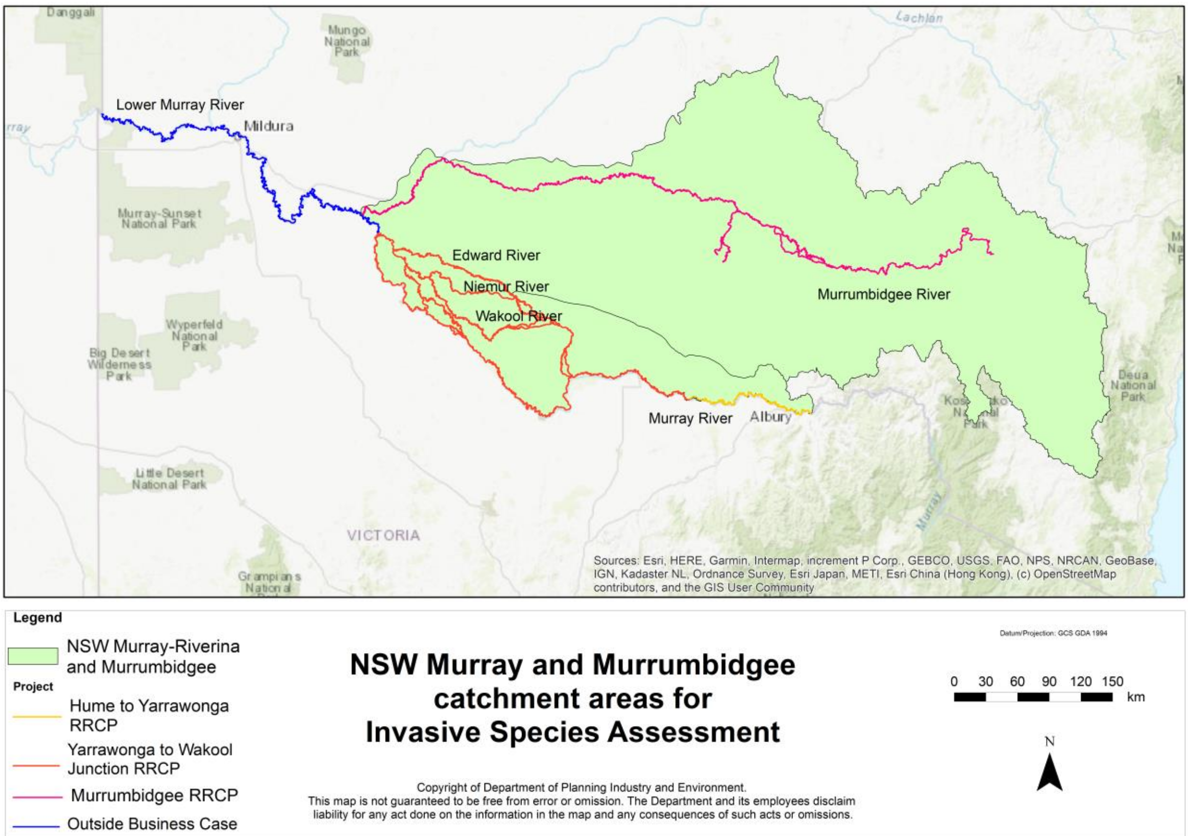

Figure 1. Map of the project areas.

The aims of this project were to:

- describe current invasive weed distributions and consequences in the project areas;
- evaluate the likelihood and consequences of various flow constraint relaxation scenarios for changing invasive weed extent and impacts in the project areas; and
- develop a risk framework for invasive plant species in relation to each inundation scenario.

Purpose and structure of this report

This report presents a summary of the project results for the second and third aims above. Additional outputs of this project include an initial report addressing the first aim above (Capon et al., 2021) and a more detailed technical report to accompany this summary (Capon et al., 2022).

This report presents a summary of the methods and results of this project of species distribution modelling and expert elicitation undertaken during this project as the development and results of the risk assessment framework.

Methods

Species distribution modelling

We developed species distribution models (SDMs) for seven priority weed species and two water functional plant groups (Brock and Casanova 1997), each comprising multiple species. Listed in Table 1, these taxa were selected as a result of consultation, an extensive knowledge review and scrutiny of available data.

Table 1. List of weed species and water plant functional groups used for species distribution modelling. N.B. * indicate taxa for which SDMs were develop.

Water Plant Functional Group	**Species (common name)**
Lycium species (Tdr)	*Lycium ferocissimum* (African boxthorn)*
Marrubium species (Tdr)	*Marrubium vulgare* (Horehound)*
Phyla species (Atl)	*Phyla canescens* (Lippia)*
Rubus species (Tdr)*	*Rubus fruticosus spp. Aggregate* (Blackberries) *(Rubus anglocandicans* *Rubus leucostachys* *Rubus ulmifolius* var. *ulmifolius* *Rubus ulmifolius* var. *anoplothyrsus* *Rubus leightonii* *Rubus phaeocarpus)*
Sagittaria species (Arp)	*Sagittaria platyphyla* (Arrowheads)*
Xanthium species (Tdr)	*Xanthium spinosum* (Bathurst burr)*
Salix species (Tda)	*Salix nigra* (Black willow)*
Tda (Terrestrial damp water plant functional group)*	*Centaurea calcitrapa* (Star thistle) *Cestrum parqui* (Green cestrum) *Salix nigra* (Black willow) *Tamarix ramosissima* (Saltcedar)
Tdr (Terrestrial dry water plant functional group)*	*Ailanthus altissima* (Tree of heaven) *Alhagi maurorum* (Camel thorn) *Alternanthera pungens* (Kahki weed) *Asparagus asparagoides* (Bridal creeper) *Cenchrus longispinus* (Spiny burr grass) *Centaurea solstitialis* (St Barnaby's thistle) *Cuscuta campestris* (Golden dodder) *Cytisus scoparius* (Scotch broom) *Eragrostis curvula* (African lovegrass) *Galenia pubescens* (Galenia / Carpet weed) *Genista monspessulana* (Cape broom) *Gleditsia triacanthos* (Honey locust) *Heliotropium amplexicaule* (Blue heliotrope) *Hypericum perforatum* (St John's wort) *Ligustrum lucidum* (Broad-leaved privet) *Ligustrum sinense* (Narrow-leaved privet) *Lycium ferocissimum* African boxthorn) *Marrubium vulgare* (Horehound) *Nassella hyalina* (Cane needlegrass) *Nassella neesiana* (Chilean needlegrass) *Nassella* (Serrated tussock grass) *Onopordum* *Onopordum acanthium* (Scotch thistle)

	Onopordum acaulon (Stemless thistle) *Onopordum Illyricum* (Illyricum thistle) *Opuntia stricta* (Prickly pear) *Physalis hederifolia* (Sticky ground cherry) *Prosopis glandulosa* (Honey mesquite) *Rhaponticum repens* (Creeping knapweed) *Rosa rubiginosa* (Sweet briar) *Sclerolaena birchii* (Galvenised burr) *Senecio madagascariensis* (Fireweed) *Solanum elaeagnifolium* (Silver-leaf nightshade) *Solanum rostratum* (Buffalo burr) *Sorghum halepense* (Johnson grass) *Tamarix aphylla* (Athel pine) *Tribulus terrestris* (Caltrop) *Ulex europaeus* (Gorse) *Xanthium spinosum* (Bathurst burr)

Our SDMs were built using a range of predictor variables for which sufficient data was available:

- Climate: i) mean annual temperature; ii) max temp in warmest month; iii) temperature range; iv) minimum temp in coldest month; v) annual precipitation; vi) precipitation seasonality.

- Land use: classified as either Dryland agriculture and plantations, Conservation and natural environments, Intensive uses, Irrigated agriculture and plantations, Water/ Wetlands or Production from relatively natural environments

- Vegetation type: broadly categorised as Blackbox woodland, Lignum shrubland, River redgum forest, River redgum woodland, Terrestrial grassland, Terrestrial shrubland, Terrestrial woodland, Wetland herbland, Perennial wetland grass, sedge, herbland, Saline wetlands

- Wetland type: broadly categorised as Temporary woodland, Clay pan, Freshwater herbaceous, Temporary shrubland, Permanent wetland, Temporary waterbody, Permanent waterbody, Permanent herbaceous, Temporary herbaceous, Floodplain woodland, Floodplain shrubland, Saline herbaceous, Waterhole, Temporary wetland or Unspecified river

- Inundation regime: inundation metrics based on modelled flow thresholds for each catchment over a 125-year period (see Table 3).

Table 2. Inundation metrics used as predictor variables in Species Distribution Models

ID	Metric	Description
N1	<30 Total Inundation	Number of years that cell is inundated less than 30 days in a year
N2	>30 Total Inundation	Number of years that cell is inundated more than 30 days in a year
N3	>60 Total Inundation	Number of years that cell is inundated more than 60 days in a year
N4	<30 Total NO Inundation	Number of years that cell is **not** inundated less than 30 days in a year
N5	>30 Total NO Inundation	Number of years that cell is **not** inundated more than 30 days in a year
N6	>60 Total NO Inundation	Number of years that cell is **not** inundated more than 60 days in a year
N7	Maximum Inter Flood <30	Maximum number of consecutive years that cell is not inundated less than 30 days in a year (number of consecutive 0s)
N8	Maximum Inter Flood >30	Maximum number of consecutive years that cell is not inundated more than 30 days in a year
N9	Maximum Inter Flood >60	Maximum number of consecutive years that cell is not inundated more than 60 days in a year

We developed species distribution models for each catchment (Murray and Murrumbidgee) under a base case (i.e., current conditions) and in relation to each RRC inundation scenario (Table 3) using flow time series spells analysis data provided by DPE to calculate the relevant inundation metrics for each scenario.

Table 3. Inundation scenario and associated flow limit options for the Murray and Murrumbidgee Rivers

Murray		
Hume to Yarrawonga ***Flow limit option at Doctors Point (ML/d)***	**Yarrawonga to Wakool Junction** ***Flow limit option at downstream Yarrawonga Weir (ML/d)***	**Scenario name**
25,000 (current operational flow limit)	15,000 (current operational flow limit)	Y15D25 (basecase)
25,000	25,000	Y25D25
30,000	30,000	Y30D30
40,000	40,000	Y40D40
40,000	45,000	Y45D40
Murrumbidgee		
Flow limit option at Wagga Wagga (ML/d)		**Scenario name**
22,000 (current operational flow limit)		W22 (hereafter 22GL, basecase)
32,000		W32 (hereafter 32GL)
36,000		W36 (hereafter 36GL)
40,000		W40 (hereafter 40GL)

Each SDM generated a map of the likelihood of the presence (or absence) of suitable habitat for the weed species examined in the Murray and Murrumbidgee project areas under each inundation scenario (see Table 3). We also calculated areas of ‘highly suitable’ habitat for each weed taxon by only including the top 20% of the modelled values above the mean’ suitable habitat threshold. A range of data analyses were then conducted to explore spatial patterns in the extent and distribution of weed habitat in relation to land use, vegetation type and wetland types under each scenario. Weed ‘hotspots’, defined here as areas in which suitable habitat was identified for at least four weed species, were also identified under each inundation scenario.

To investigate changes in weed habitat suitability under each inundation scenario from the basecase, we determined areas in which habitat was:

- unsuitable in both models;
- suitable in the base case but unsuitable in the inundation scenario (i.e. a decrease in habitat area);
- unsuitable in the base case but suitable in the inundation scenario (i.e. an increase in habitat area), and;
- suitable in both models.

We then calculated changes from the base case in the areas of suitable and highly suitable habitat predicted for each weed taxon, as well as weed hotspots, under each scenario.

Expert elicitation

We also conducted a range of expert elicitation activities during the project to support and validate the findings of the species distribution modelling including:

- consultation with the project steering committee and other relevant stakeholders (see Capon et al. 2021)
- two expert elicitation workshops
- an online survey regarding weed risks and benefits in relation to the current situation as well as possible increases in inundation in the project area.

Risk assessment framework

We developed a risk assessment framework to evaluate significant differences in the predicted outcomes for weeds of each RRC inundation scenario in relation to the base case. To build this risk assessment framework, we developed a range of criteria associated with the likelihood and consequences of any changes based on the results of the knowledge review and species distribution modelling conducted during this project (Tables 6 and 6).

Different weightings were assigned to criteria using different scores to reflect the assumed contribution of each criterion to the overall likelihood or consequence. For example, a change in 'highly suitable habitat' was deemed to be the most important risk criterion and was thus allocated higher scores than 'suitable habitat' criteria. Changes in land use, vegetation types and wetland classes were also included as risk criteria because these reflect the diversity of spatial units that may be affected by a change in weed extents. We assumed, for instance, that the risk of a weed that expands into multiple land uses or vegetation types is greater than that posed by a weed expanding with the same proportion in terms of area but in only one land use or vegetation type.

Scoring was then completed for each weed taxon as well as for weed hotspots, with consequence scores only calculated for the specific weed species examined. Likelihood scores were then summed for each taxon for each flow scenario to indicate the likelihood of risks for each taxon under each scenario.

Consequence scores were also summed for each weed species for each catchment. For each weed species, an index of overall risk under each flow scenario was then calculated by multiplying the relevant likelihood and consequence values. Finally, an overall risk score was calculated by summing these overall risk scores for species and the summed likelihood values for water plant functional groups and weed hotspots. Resulting values were standardised to give a final score from +/- 0 – 100, whereby a large positive result indicates a high proportionate risk and a negative value indicates a potential benefit.

Table 4. Criteria and scores to rank the likelihood of an increased distribution of a weed taxon.

Criteria	Large proportional decrease (> 10% from base case)	Slight proportional decrease (<10% from base case)	No change	Slight proportional increase (< 10% from base case)	Large proportional increase (> 10% from base case)
Change in total habitat					
Change in suitable habitat	-8	-2	0	+2	+8
Change in highly suitable habitat	-16	-4	0	+4	+16
Change in dominant land uses occupied					
Conservation and natural environments	-4	-1	0	+1	+4
Dryland agriculture and plantations	-4	-1	0	+1	+4
Intensive uses	-4	-1	0	+1	+4
Irrigated agriculture and plantations	-4	-1	0	+1	+4
Production from natural environments	-4	-1	0	+1	+4
Water and wetlands	-4	-1	0	+1	+4
Change in dominant vegetation types occupied					
BB woodland	-4	-1	0	+1	+4
Lignum shrubland	-4	-1	0	+1	+4
Perennial wetland GRS	-4	-1	0	+1	+4
RRG forest	-4	-1	0	+1	+4
RRG woodland	-4	-1	0	+1	+4
Terrestrial grasslands	-4	-1	0	+1	+4
Terrestrial shrublands	-4	-1	0	+1	+4
Terrestrial woodlands	-4	-1	0	+1	+4
Wetland herblands	-4	-1	0	+1	+4
Changes in dominant wetland classes occupied					
Claypan	-4	-1	0	+1	+4
Floodplain woodland	-4	-1	0	+1	+4
Freshwater herbaceous	-4	-1	0	+1	+4
Permanent herbaceous	-4	-1	0	+1	+4
Permanent waterbody	-4	-1	0	+1	+4
Temporary herbaceous	-4	-1	0	+1	+4
Temporary shrublands	-4	-1	0	+1	+4
Temporary waterbody	-4	-1	0	+1	+4
Temporary wetlands	-4	-1	0	+1	+4
Temporary woodland	-4	-1	0	+1	+4
Unspecified river	-4	-1	0	+1	+4
Waterhole	-4	-1	0	+1	+4

Table 5. Criteria and scores to rank the potential consequence of an increased distribution of a weed taxon. (N.B. only relevant to weed species, not water plant functional groups).

Criteria	**Scores**			
Weed of national significance	Yes = 10	No = 0		
Regional Weed Priority	Prevention = 4	Eradication = 2	Containment = 2	Of concern = 1
Impacts to fauna	Yes = 2	No = 0		
Impacts to vegetation	Yes = 2	No = 0		
Impacts to humans	Yes = 2	No = 0		
Impacts to agriculture	Yes = 2	No = 0		
Other impacts	Yes = 2	No = 0		

Results

Weed distributions under the base case

Lippia was predicted to have the most suitable habitat under the base case, occupting approximately 30 % of the total project area (Figure 2). This was considerably higher than the next most widely distributed taxon, the Terrestrial dry (Tdr) group which had suitable habitat in around 6% of the total project area. Horehound, African boxthorn and Bathurst burr also had moderately high areas of suitable habitat. Willows had the least predicted suitable habitat.

Of the species with relatively high predicted areas of suitable habitat, several species (lippia, African boxthorn and arrowheads) had relatively low areas of highly suitable habitat and almost no highly suitable habitat was detected for horehound and Terrestrial dry (Tdr) species (Figure 2). In contrast, blackberries and Terrestrial damp (Tda) species had similar areas of suitable and highly suitable habitat. Bathurst burr had the most highly suitable habitat in the project area under the base case, representing 1.9 % of the total project area (Figure 2).

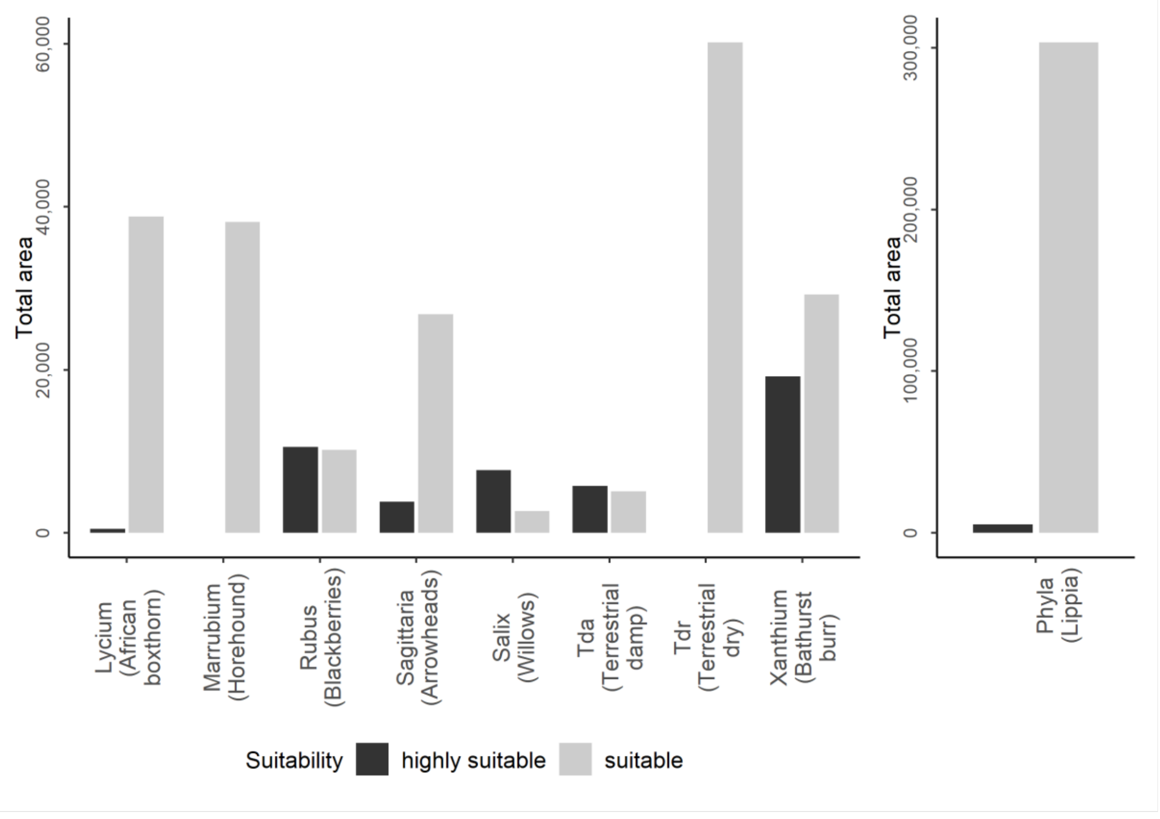

Figure 2. Total suitable habitat area (ha) and total highly suitable habitat area (ha) in the overall project area for each of the nine modelled taxa under the base case.

Major drivers of weed distribution

The most important predictors of weed distribution tended to be climatic with annual rainfall a key driver for five of the nine taxa. Inundation metrics were moderately important predictors of distribution for all weed taxa including both the amphibious and terrestrial taxa (Table 7). For Terrestrial dry (Tdr) species, including horehound and African boxthorn, inundation metrics associated with longer dry periods were particularly important.

Weed hotspots

Under the base case, 684 hectares in the Murray project area and 1286 hectares in the Murrumbidgee project area were identified as weed hotspots, defined here as areas with suitable habitat for at least four of the modelled weed taxa, representing less than 0.1 % and ~ 0.4 % of the project areas in each of these catchments respectively. (Figure 3).

Weed hotspots tended to occur in the vicinity of all the major towns in the project area (Wagga Wagga, Hay, Albury, Echuca, Deniliquin and Swan Hill) as well as along the Murrumbidgee Rivers south of Griffith (Figure 3). Most weed hotspots under the base case were within the `production from relatively natural environments` and 'water/wetlands' land uses. River red gum forests and woodlands were the vegetation types with most weed hotspots.

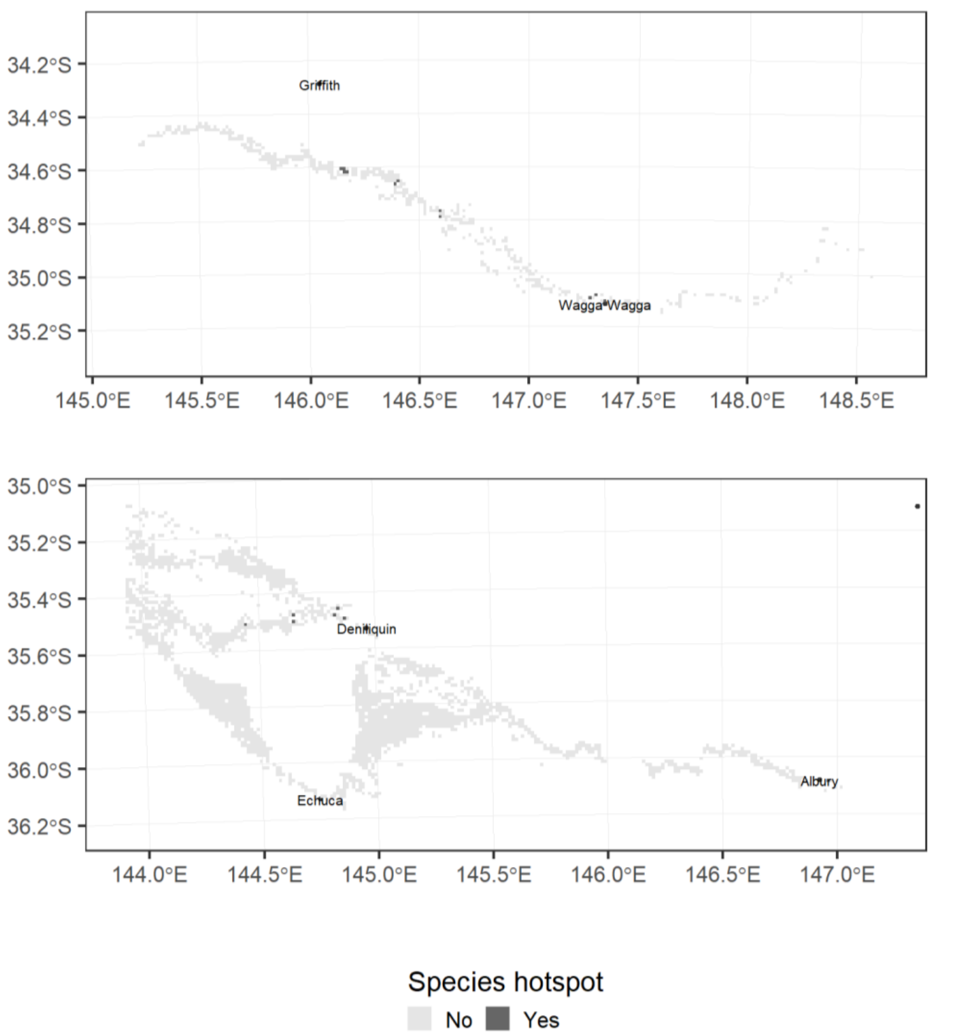

Figure 3. Distribution of modelled weed hotspots in the Murrumbidgee project area (top) and the upper Murray project area (bottom).

Weed distributions under constraint relaxation scenarios

Predicted areas of suitable and highly suitable habitat both increased and decreased for modelled weed taxa under the RRC inundation scenarios considered (Figures 4-7). For each taxon, the direction and magnitude of predicted change from the base case was mostly similar across all inundation scenarios within each catchment. In general, suitable habitat for Terrestrial dry (Tdr) species increased in both catchments, with similar changes mostly predicted across the different inundation scenarios. In contrast, suitable habitat for Terrestrial damp (Tda) and amphibious species decreased.

In the Murray, greater suitable habitat was predicted under the RRC inundation scenarios compared to the base case for Terrestrial dry (Tdr) species as a group and for the Tdr species considered individually (i.e., African boxthorn, horehound, blackberries and Bathurst burr. In contrast, significant declines in suitable habitat were predicted for amphibious species (e.g., lippia and arrowheads) and, to a lesser degree, Terrestrial damp (Tda) species, including willows (Figure 4). Patterns for highly suitable habitat were mostly similar although no highly suitable habitat for Tdr species as a group was predicted (Figure 5). Willows were the exception with a slight increase in highly suitable habitat under RRC inundation scenarios from the base case.

In the Murrumbidgee, suitable habitat also increased under inundation scenarios for three of the Tdr species (African boxthorn, horehound and blackberries) but fell slightly for Bathurst burr and completely disappeared for Tdr species as a group (Figure 6). Slight declines in suitable habitat were also predicted for the amphibious and Tda species (Figure 6). Increases in highly suitable habitat in the Murrumbidgee were predicted for lippia and arrowheads (Figure 7).

Distribution by land use

In the Murray, the greatest changes in the proportion of suitable habitat areas were predicted for the Conservation and natural environments land use across all RRC inundation scenarios and all taxa except for lippia. Increases in suitable habitat under RRC inundation scenarios were also predicted for horehound and Tdr species in the Dryland agriculture and plantations and Water/wetlands land uses, for African boxthorn and Bathurst burr in the Production from relatively natural environments land use and for blackberries in the Irrigated agriculture land use. In contrast, the greatest changes in the proportion of suitable habitat areas for the amphibious and Terrestrial damp (Tda) species were all declines, mostly in the Intensive uses, Irrigated agriculture and plantations, Dryland agriculture and plantations and Water/wetlands land uses.

For the Murrumbidgee, the greatest changes in the proportion of suitable habitat were all declines for all RRC inundation scenarios and weed taxa. The only exception was for African boxthorn, for which increases were predicted in Dryland agriculture and plantations and Water/wetlands land uses in all scenarios and in Conservation and natural environments in the 32GL and 40GLscenarios and Production from natural environments for the 36GL scenario. For the other taxa, predicted declines were similar for the 36GL and 40GL scenarios which were greater than those predicted under the 32GL scenario. Increases in the proportion of highly suitable habitat were predicted however including significant increases for lippia in Conservation and natural environments, Dryland agriculture and plantations and Water/wetlands (+235 ha 40GL) land uses, mainly in the 36GL and 40GL scenarios. Highly suitable habitat was also predicted to increase for Terrestrial damp (Tda) species, especially t in the Production from natural environments land use under the 36GL scenario.

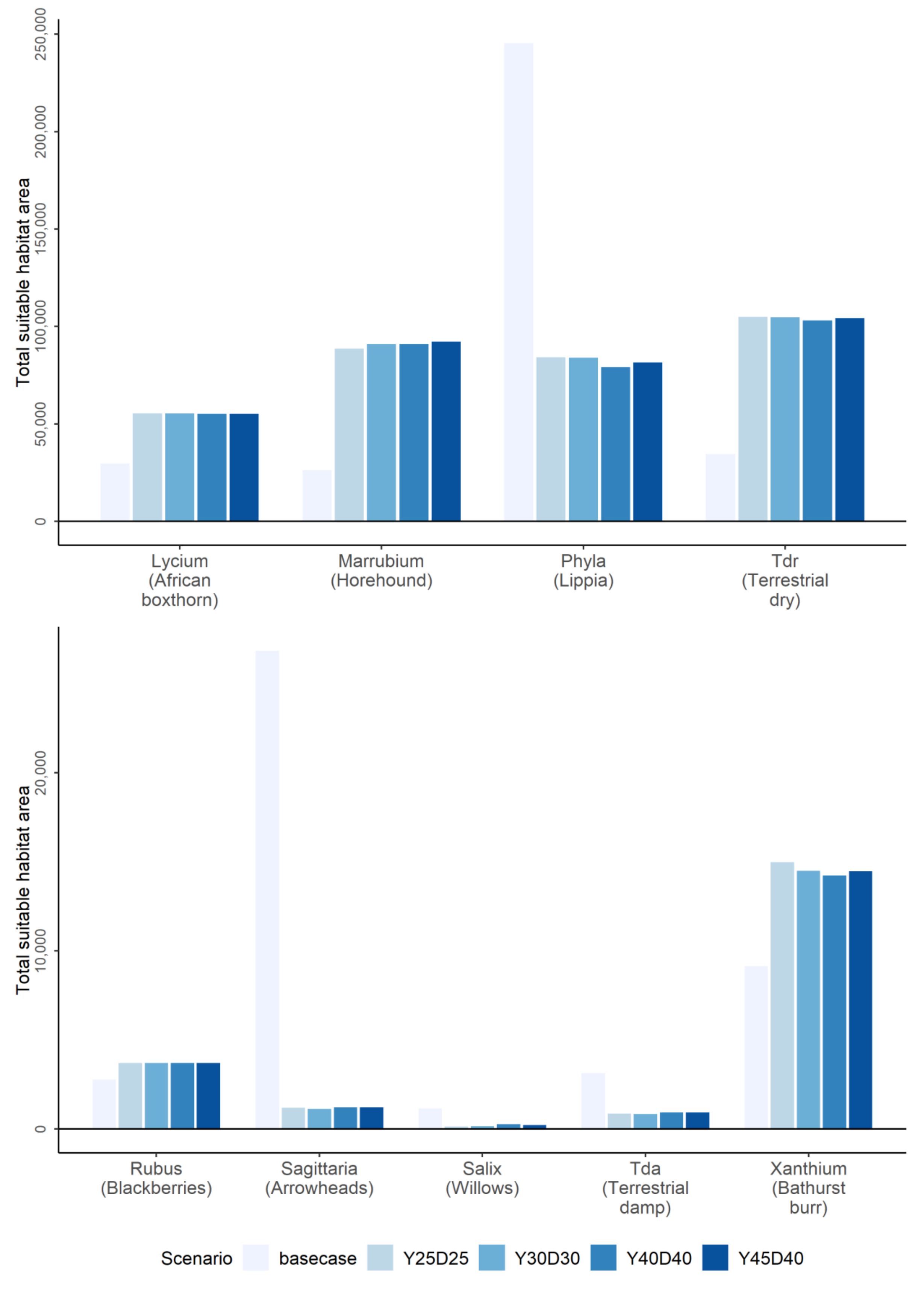

Figure 4. Total area (ha) of suitable habitat predicted by SDMs for all modelled taxa in the Murray under the base case and each RRC inundation scenario.

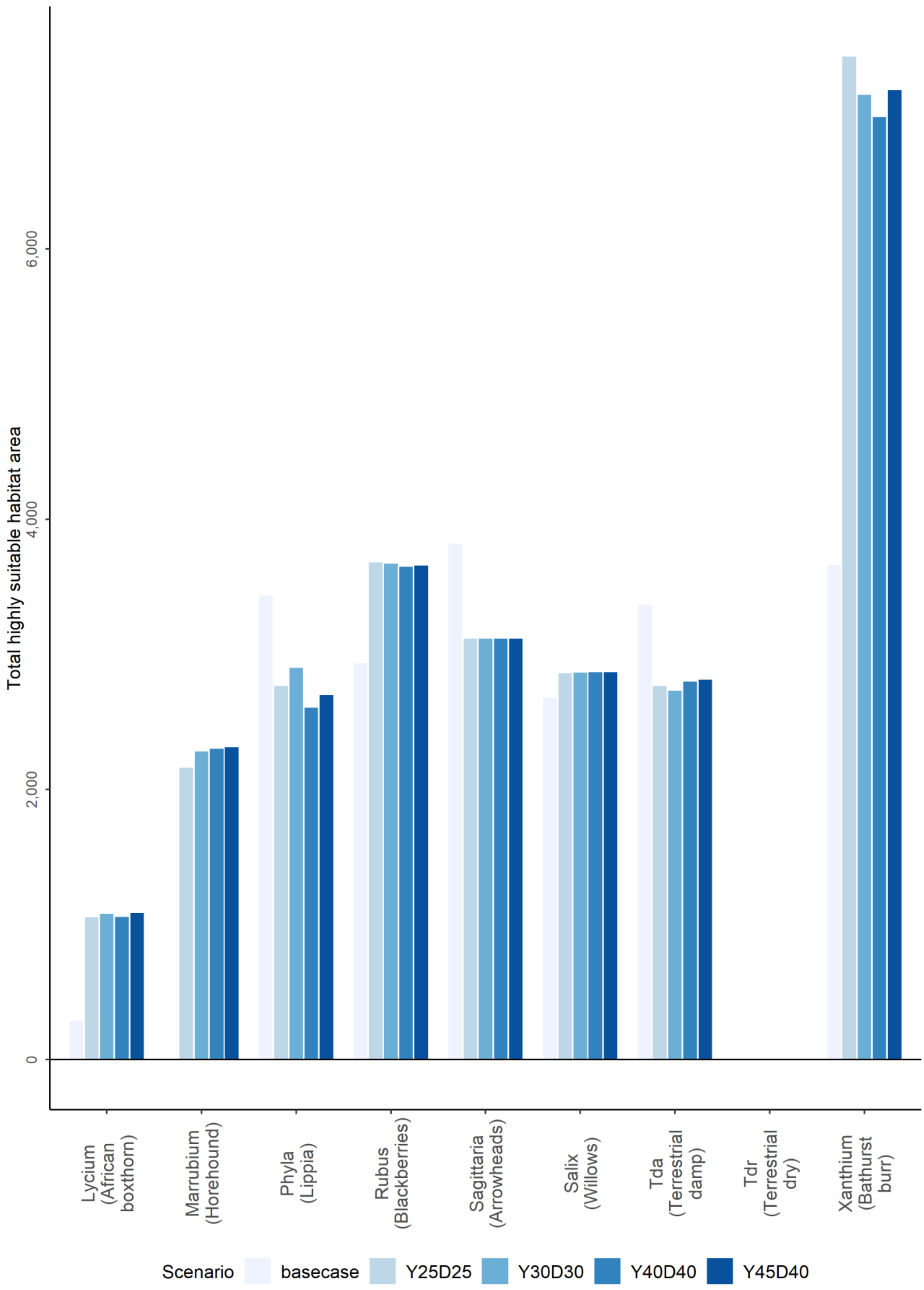

Figure 5. Total area (ha) of highly suitable habitat predicted by SDMs for all modelled taxa in the Murray under the base case and each RRC inundation scenario.

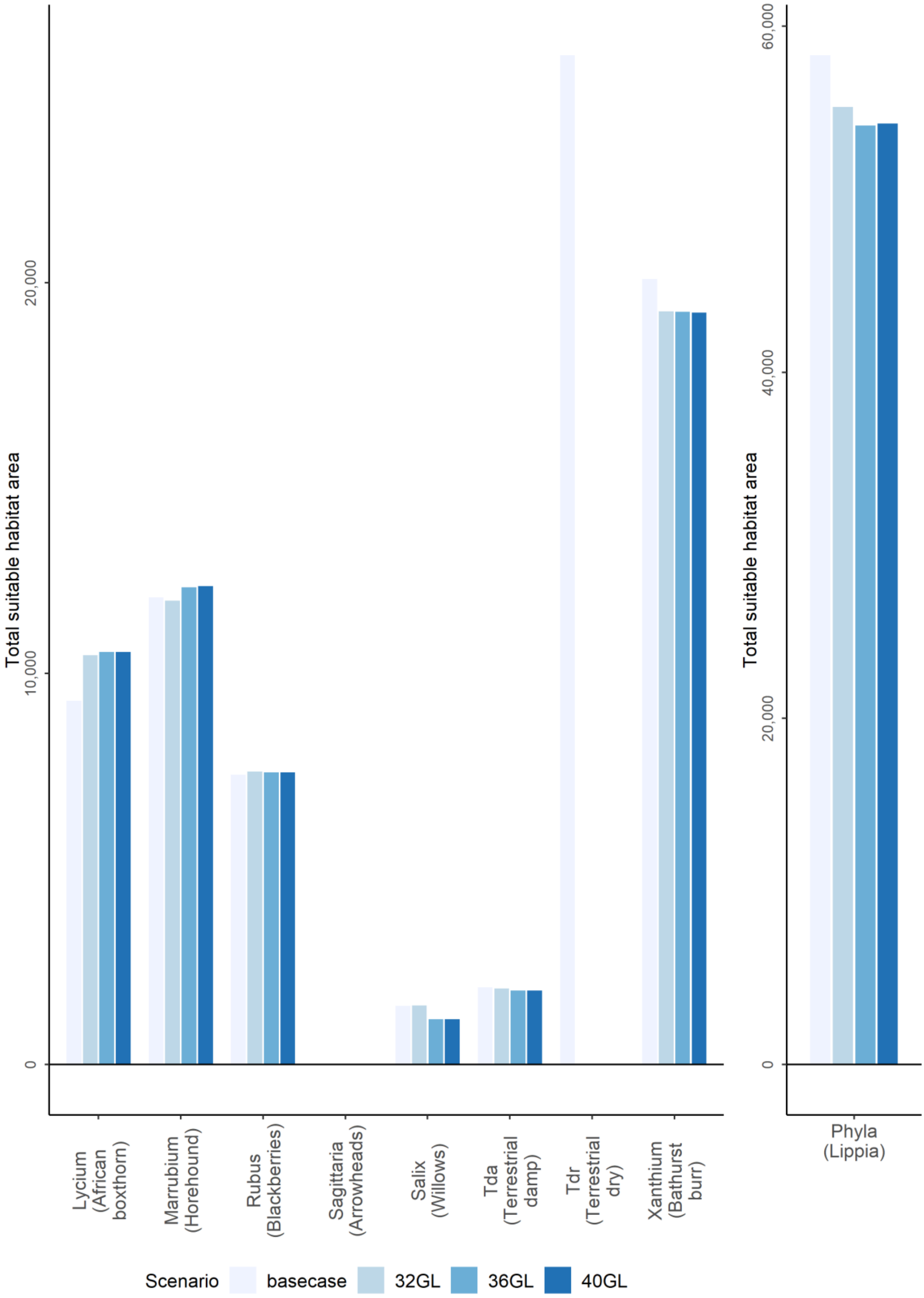

Figure 6. Total area (ha) of suitable habitat predicted by SDMs for all modelled taxa in the Murrumbidgee under the base case and each RRC inundation scenario.

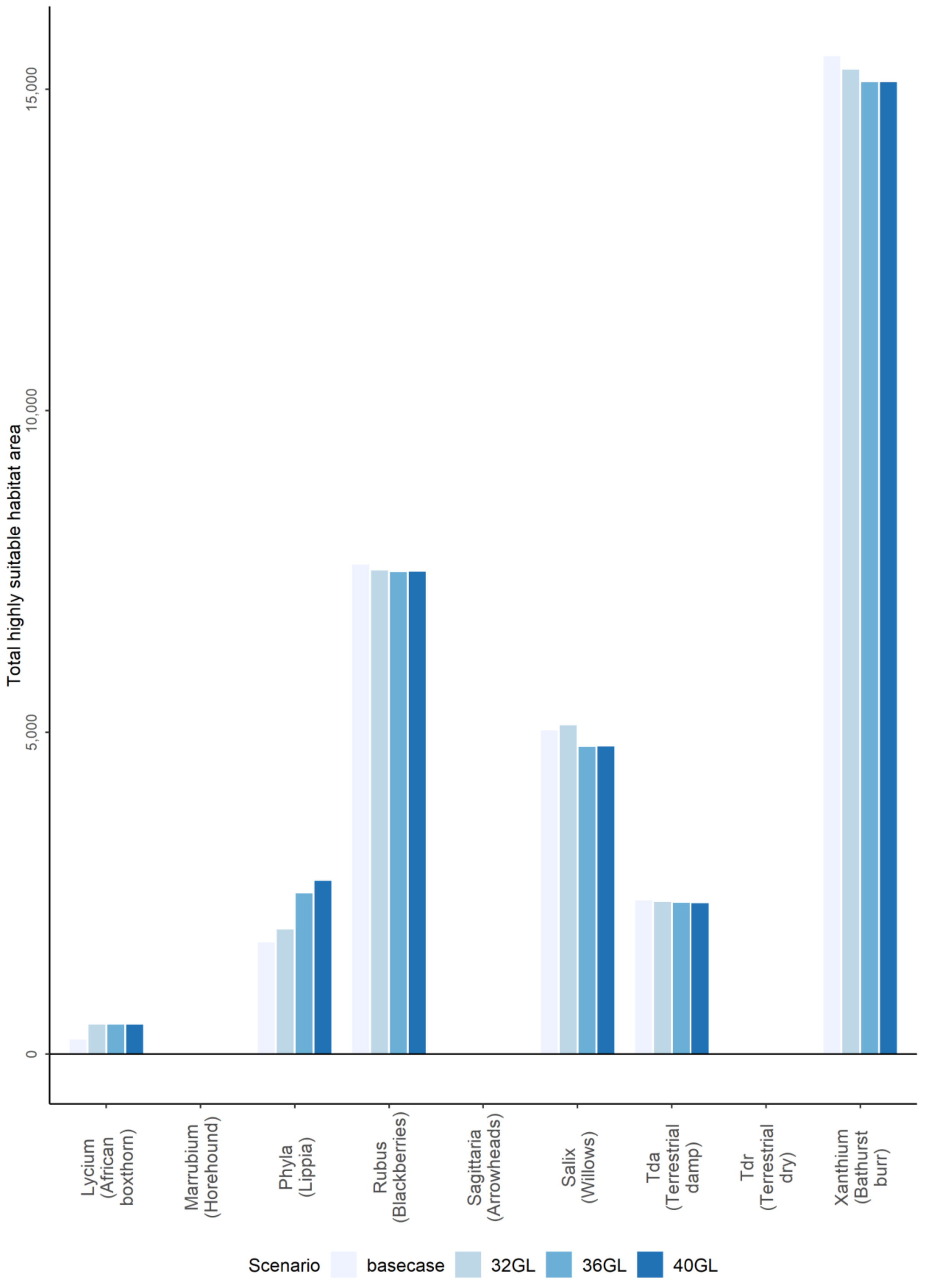

Figure 7. Total area (ha) of highly suitable habitat predicted by SDMs for all modelled Taxa in the Murrumbidgee under the base case and each RRC inundation scenario.

Distribution by vegetation type

For the Murray, the biggest increases in the proportion of suitable habitat for modelled weed taxa, across all scenarios, were for horehound in Perennial wetland grass, sedge and rush lands, River red gum forests, and Wetland herblands while the greatest increase in highly suitable habitat for this taxon occurred in River red gum woodlands and Terrestrial woodlands. Wetland herblands in the Murray also had significant increases in the proportion of suitable habitat predicted under all RRC inundation scenarios for Terrestrial damp (Tdr) species and Bathurst burr, both of which also increased in Lignum shrublands. Significant declines in lippia suitable habitat were predicted under all scenarios in the Murray for all vegetation types but increases in highly suitable habitat were predicted for Terrestrial woodlands, Perennial wetland grass, sedge and rush lands and Terrestrial grasslands.

In the Murrumbidgee, significant increases in the proportion of suitable habitat were predicted across all inundation scenarios for African boxthorn in Black box woodland, Terrestrial shrubland and Wetland herbland with more change predicted under the 36GL and 40GL scenarios. Large increases in highly significant habitat for this species were also predicted in Terrestrial grasslands and Terrestrial woodlands under the 36GL and 40GL scenarios but not the 32GL scenario. Proportions of suitable habitat for horehound were predicted to increase in all inundation scenarios in the Wetland herblands but highly suitable habitat for this taxon declined, especially in River red gum forest. Suitable habitat for lippia increased in Lignum shrublands but only under the 40GL scenario while highly suitable habitat increased in all scenarios, mainly in Black box woodland, Terrestrial shrubland and Wetland herbland vegetation types. Other taxa exhibited declines in the proportion of suitable habitat across a range of vegetation types in the Murrumbidgee with declines particularly apprarent in Terrestrial woodlands.

Distribution by wetland class

In the Murray, the greatest changes in proportion of suitable habitat under all scenarios were increases for Tdr species in Temporary wetlands and horehound in Permanent herbaceous wetlands. Large increases in the proportion of highly suitable habitat for horehound were also predicted in Temporary waterbodies. Highly suitable habitat for Bathrust burr also increasd under all scenarios in Temporary shrublands and for lippia in Temporary wetlands under all scenarios except Y30D30. A significant increase in the proportion of highly suitable habitat for blackberries was only predicted under the Y25D25 scenario.

In the Murrumbidgee, the wetland classes predicted to have the greatest changes in the proportion of suitable habitat included Floodplain woodlands and Temporary wetlands across all scenarios and Temporary shrublands in the 32GL and 36GL scenarios, particularly for African boxthorn, horehound and Terrestrial dry (Tdr) species. Highly suitable habitat for most taxa was predicted to decline in specific wetland classes.

Weed hotspots

Significant declines in the total area of weed hotpots from the base case were predicted for the Murray across all RRC inundation scenarios with the biggest decline predicted under the inundation scenario with the lowest level of constraint relaxation and decreased with increasing constraint relaxation (Table 6). In the Murrumbidgee, declines in the overall area of weed hotspots were also apparent under all inundation scenarios but were relatively small. Overall, greater declines in the area of weed hotspots in the Murrumbidgee was modelled for the higher degree of constraint relaxation scenarios.

Table 6. Net change in area (ha) of modelled weed hotposts under each inundation scenario for the Murray and Murrumbidgee project areas.

	Murray				Murrumbidgee		
	Y25D25	Y30D30	Y40D40	Y45D40	32GL	36GL	40GL
Total change	- 227 ha	- 278 ha	-283 ha	- 344 ha	- 1276 ha	- 1241 ha	- 1187 ha

Expert elicitation

Survey results and expert elicitatation during workshops were in broad agreement with the results of the species distribution models.

Most respondents considered weeds to be currently somewhat to moderately prevalent in the project area. Only two respondents considered them to be very prevalent. Half of the respondents considered the overall prevalence and extent of weeds in the project area to be stable while the other half perceive weed prevalence and extent to be growing.

Weeds were considered most prevalent in the Intensive land use category followed by Production from dryland agriculture and plantations, and Production from irrigated agriculture and plantations. This is in contrast to the species distribution modelling results which suggest that Production from natural environments and Production from irrigated agriculture had the greatest areas of suitable habitat for the weed taxa modelled.

Vegetation types expected to be most affected by weeds included terrestrial grasslands and wetland herblands with the least expected in lignum shrubland and saline wetlands. This was also in contrast with results of species distribution modelling which indicated black box woodland and lignum shrublands had the most suitable habitat for the weed taxa examined.

Permanent wetlands were identified by experts as the wetland class most likely to have a medium to high prevalence of weeds currently. In contrast, the species distribution models suggest that temporary waterbodies, floodplain woodlands, and permanent waterbodies contain the largest areas of suitable weed habitat.

In general, very small changes to weed distributions were expected by experts under RRC inundation scenarios with most expecting no change in overall weed prevalence, impacts or management in the project area.

Risk assessment

Overall risk scores for changes to the distribution and consequence of weeds in the project areas were very low (Table 7). In the Murray catchment, there was very little variation between overall risk scores between the RRC inundation scenarios while greater variation between scenarios was apparent for the Murrumbidgee.

In the Murray, the species distribution modelling conducted in this project suggests potential conservation benefits of constraint relaxation in terms of overall declines in the extent of arrowheads, lippia, willows, Terrestrial damp (Tda) species and weed hotspots. Potential risks of constraint relaxation in the Murray include increased extents of horehound, Bathurst burr, blackberries, Terrestrial dry (Tdr) species and especially African boxthorn. For blackberries and horehound, this risk is likely to be highest with the greatest relaxation of constraints but for African boxthorn and Bathurst burr, the risk is higher with lower levels of constraint relaxation.

In the Murrumbidgee, an overall risk of increased weed extent and consequences was identified under the 32 GL inundation scenario while overall benefits are predicted for the 36 GL and 40 GL scenarios. This difference is largely due to the greater risk of increased willow extent under the 32 GL scenario.

For a detailed description of risk scoring, please see the technical report accompanying this summary document.

Table 7. Total risk scores for each weed taxa and weed hotspots under each inundation scenario and overall total and standardised scores (i.e., total divided by maximum possible score *100). A negative risk score indicates reduced weed risk (red) and a positive risk score indicates increased weed risk (green).

	Murray				**Murrumbidgee**		
Taxa	**Y25D25**	**Y30D30**	**Y40D40**	**Y45D40**	**32GL**	**36GL**	**40GL**
Sagittaria (Arp)	-2048	-2048	-2048	-2048	0	0	0
Phyla (Atl)	-1088	-1088	-1088	-1088	-414	-405	-414
Salix (Tda)	-1512	-1512	-1512	-1512	324	-576	-576
Rubus (Tdr)	1071	1071	1071	1122	-323	-374	-374
Marrubium (Tdr)	460	490	500	530	45	145	130
Lycium (Tdr)	1717	1717	1666	1666	1020	1190	1071
Xanthium (Tdr)	801	747	747	747	-324	-270	-270
Species sub-total	***-599***	***-623***	***-664***	***-583***	***328***	***-290***	***-433***
Tda species	-104	-104	-104	-104	-21	-2	-11
Tdr species	128	128	128	128	-44	-45	-71
Weed hotspots	-61	-68	-68	-68	-2	-2	-2
Total	***-636***	***-667***	***-708***	***-627***	***261***	***-339***	***-517***
Standardised score (-100 to +100)	***-2.8***	***-3.0***	***-3.2***	***-2.8***	***1.2***	***-1.5***	***-2.3***
Overall risk	***Likely overall slight benefit***	***Likely overall slight benefit***	***Likely overall slight benefit***	***Likely overall slight benefit***	***Likely overall slight risk***	***Likely overall slight benefit***	***Likely overall slight benefit***

Discussion

Proposed flow constraints relaxation in the Murray and Murrumbidgee Rivers can be expected to influence the extent of the weed species investigated here within this region. Relaxation of constraints will generate conditions where water delivered to the river and floodplain environments occurs more frequently and for longer durations, particularly in low-lying wetlands, billabongs, and flood runners. These inundation conditions are likely to reduce the suitable habitat available for some weed species and increase it for others.

Responses of amphibious weed species

Species distribution modelling indicates that it is very likely that there will be reduction in the area of suitable habitat available for the significant amphibious weed species lippia and arrowheads under proposed RRC inundation scenarios.

These amphibious species are likely to be favoured by flood regimes of intermediate inundation frequency and duration. Presently, these amphibious weeds occur in areas such as permanent and temporary waterbodies and floodplain woodlands, where reduced flood duration and magnitude under current flow conditions may have facilitated their invasion and dominance. Lippia, for instance, typically becomes dominant in areas where water regulation and agricultural practices have altered the natural flooding regime (Macdonald et al. 2012) and restoring more natural inundation regimes, particularly longer summer floods in the northern MDB, is known to reduce the extent and dominance of Lippia(Price et al. 2010).

The more frequent and longer periods of inundation associated with proposed constraints relaxation scenarios investigated here may exceed the flood tolerances of these amphibious weed species. Our results suggest that for the Murray and Murrumbidgee regions, the increased frequency and duration of inundation events proposed with relaxation of constraints, will reduce the extent of lippia. The predicted reductions in suitable habitat are expected to be reasonably similar across the different scenarios, all of which are predicted to generate inundation regimes in current areas of suitable habitat for these species which reduce its suitability (e.g. temporary wetlands, black box woodlands).

Responses of terrestrial weed species

Our models predict increases in suitable habitat available for the terrestrial weed species considered under proposed inundation scenarios. Our modelling suggested that the distribution of terrestrial weed species is associated with environmental drivers of extended dry periods (e.g., maximum inter flood metrics, and days of no inundation metrics). The increases in suitable habitat predicted are therefore likely due to the larger fringing areas generated by flooding under the RRC scenarios in which moisture is readily available more frequently but where inundation does not occur for longer periods of time. Terrestrial species do not require flooding for completion of their lifecycle, but still require moisture for germination and establishment. These fringing areas of flood extents may provide suitable conditions for the germination for these weeds which can quickly establish and dominate a region, potentially minimising habitat for native species and reducing the productivity of agricultural land (Downey et al. 2010; Noble et al. 2013).

Responses of weed hotspots

Detected weed hotspots in the project areas mostly comprised multiple terrestrial weed species, especially horehound, African boxthorn and Bathurst burr, and were mostly located on the main river channels in urban areas,

Substantial declines in the total extent of weed hotspots (i.e., areas with suitable habitat for four or more modelled taxa) are predicted under all constraint relaxation scenarios compared with the base case in the Murray and, to a lesser degree, the Murrumbidgee. In the Murray, net decline in the predicted area of weed hotspots was greatest in the inundation scenario with the lowest level of constraint relaxation and decreased with increasing constraint relaxation. The opposite trend was predicted for the Murrumbidgee.

Differences between RRC inundation scenarios and catchments

Very little difference in changes to suitable habitat area of the weeds considered was predicted between the different constraint relaxation scenarios. Where differences did occur, these were mostly between scenarios with lower levels of constraint relaxation.

The distribution of Salix (willows) in the Murrumbidgee is one example where an increase in suitable habitat was projected under the lowest constraint relaxation scenario (32GL) but a decline in suitable habitat was predicted under the higher scenarios. it is likely that the conditions provided under the lowest constraint relaxation scenario are suitable for dispersal and establishment of Salix propagules while the higher relaxation scenarios, associated with more frequent and longer flooding, may result in dieback of new recruits under prolonged flooding (Stokes 2008). Consecutive flood events or prolonged inundation can favour native species over exotics resulting in reduced weed species richness in riparian areas (Greet et al. 2015).

The changes in weed species distribution modelled in this project are also largely consistent between the two focus catchments, the Murray and Murrumbidgee Rivers, although the magnitude of change often differed. For species which showed contrasting changes between catchments (i.e. blackberries and Bathurst burr), the changes were generally larger in the Murray compared to the Murrumbidgee catchment where changes were relatively minimal, potentially due to more fringing habitat in the Murray floodplain.

Recommendations

We suggest the following management actions be implemented to address the potential impacts of constraint relaxation on weed distributions and consequences in the study area:

- develop management plans for weed species and areas that do not currently have these
- develop targeted management plans for weed hotspot areas
- increase weed monitoring and evaluation in the study area guided by habitat distributions and hotspots modelled here
- invest in research to better understand weed responses to hydrological regimes and other drivers

This project has also highlighted the need for further research, including the need to:

- Conduct on-ground surveys of vegetation communities to better assess the prevalence and distribution of weeds within the region. Surveys and management actions could be incorporated in a citizen science program, particularly for urban regions identified as weed hotspots. Including soil seed bank assessments would be preferable to gain an understanding of invasion potential.
- develop species distribution models for other classifications of plant functional groups (e.g., in relation to life history and plant form) and for joint species groups to investigate weed hotspots, over a larger area (e.g. Basin-wide) to increase the availability of suitable data
- extend inundation modelling past the floodplain extent to capture variation in habitat types and better predict areas of change

- further analysis of current modelling results to investigate responses associated with highly suitable habitat to provide more in-depth assessment of weed risk
- explore how water will flow through the landscape under relaxed constraints scenarios to further understand patterns in weed distribution and dispersal and differences between catchments

Conclusions

- Our results indicate that the extent and distribution of priority weeds in the project areas, across a range of functional groups, are moderately associated with patterns of flooding and drying. Longer dry periods appear to be particularly important drivers for the Terrestrial dry (Tdr) species group and key species within this group, e.g. African boxthorn, horehound.
- Under current conditions (i.e., the base case), weed hotspots (i.e., areas with suitable habitat for four or more modelled taxa) occupy < 0.1 % and ~ 0.4 % of the Murray and Murrumbidgee project areas respectively. Hotspots mostly occur on main river channels near major towns and in Production from relatively natural environments and water/wetlands land uses and in river red gum forest and woodland vegetation communities.
- Both increases and decreases in suitable habitat of weeds can be expected under potential constraint relaxation flow options depending on the taxa. Little variation, however, is predicted between different RRC inundation scenarios within each catchment for predicted suitable habitat of each weed taxa. Greater variation between inundation scenarios was predicted in changes of highly suitable habitat for some taxa, e.g. lippia, Bathurst burr in the Murray.
- In the Murray, suitable habitat for Terrestrial dry (Tdr) species, both as a group and for individual species, is likely to increase under RRC inundation scenarios compared to the base case. It should be noted, however, that no highly suitable habitat for Tdr species as a group was predicted in the Murray). In contrast, significant declines in suitable habitat can be expected under the RRC inundation scenarios for the amphibious species (i.e., lippia and arrowheads) and, to a lesser degree, Terrestrial damp (Tda) species, both as a group and for the member species (i.e., Salix). Slight increases in highly suitable habitat for Salix, however, can be expected under the inundation scenarios in the Murray.
- In the Murrumbidgee, suitable habitat can be expected to increase under all inundation scenarios for three of the terrestrial species considered – African boxthorn, horehound and blackberries - and decline slightly for Bathurst burr. Our results also indicate that highly suitable habitat for Terrestrial dry (Tdr) species as a group may completely disappear under constraint relaxation. Slight declines in suitable habitat can be expected for amphibious and Terrestrial damp (Tda) species. Increases in highly suitable habitat in the Murrumbidgee were predicted, however, for lippia and arrowheads.
- Predicted changes in weed distribution can be attributed overall to increasing duration and sizeof inundation events which may drown amphibious species but provide more fringing habitat for terrestrial species to establish.
- Substantial declines in the total extent of weed hotspots (i.e., areas with suitable habitat for four or more modelled taxa) can be expected under all inundation scenarios compared with the base case in the Murray project area and, to a lesser degree, in the Murrumbidgee. Net decline in the predicted area of weed hotspots was greatest in the inundation scenario with the lowest level of constraint relaxation and decreased with increasing constraint relaxation while the opposite trend is predicted for the Murrumbidgee.
- Most experts consulted during this project expect slight to no increases in the prevalence and consequences of weeds in the project area in response to increased inundation under proposed constraints relaxation scenarios. However, there is a considerable degree of uncertainty regarding outcomes of changes to inundation and their importance relative to other drivers of weed distribution, impacts and management.
- Risk assessment scores were largely consistent with findings of expert elicitation and suggest that only slight increases or decreases in weed risk are likely under constraint relaxation.

- In the Murray, benefits are likely to accrue under all RRC inundation scenarios in relation to reductions in the distribution and extent of arrowheads, lippia and willows as well Terrestrial damp (Tda) species and weed hotspots. However, there is a potential for increases in the extents of horehound, Bathurst burr, blackberries and African boxthorn especially, as well as Terrestrial dry (Tdr) species as a group. This risk is likely to be greatest for blackberries and horehound under the greatest relaxation of constraints while the reverse is predicted for Bathurst burr and African boxthorn. The risk of increasing the extent of Terrestrial dry (Tdr) species in the Murray, however, is unlikely to vary across scenarios according to our risk assessment.
- In the Murrumbidgee, a significant difference between inundation scenarios is associated with a greater risk of increase in the extent and distribution of willows under the 32 GL scenario compared to the 36 GL and 40 GL scenarios under which there is a likely benefit of constraint relaxation in relation to this weed's extent and distribution.
- Overall, our risk assessment suggests a likely overall benefit of constraint relaxation on the distribution and consequence of weeds in the Murray across all inundation scenarios, to a slightly greater degree in intermediate scenarios, and in the Murrumbidgee under the 36 GL and 40 GL scenarios. An overall risk for weeds, however, is indicated for the Murrumbidgee under the 32 GL scenario.

References

Brock, MA and Casanova, MT. 1997. Plant life at the edges of wetlands; ecological responses to wetting and drying patterns. In *In: Frontiers in Ecology; Building the links (Eds N. Klomp and I. Lunt* (pp. 181–192). Elsevier Science.

Capon, SJ, Grieger, R, Chauvenet, Al, Franklin, H and Burgoyne, H. 2021. Weed distribution and consequences: Hume to Yarrawonga (Murray), Murrumbidgee and Lower Murray. Report 1. Report prepared by Griffith University for NSW Department of Planning and Environment, December 2021.

Downey, PO, Scanlon, TJ, Hosking, JR (2010) Prioritizing weed species based on their threat and ability to impact on biodiversity: A case study from New South Wales. *Plant Protection Quarterly,* 25(3): 111-126

Greet, J, Webb, JA, Cousens, RD (2015) Floods reduce the prevalence of exotic plant species within the riparian zone: evidence from natural floods. *Applied Vegetation Science,* 18(3): 503-512

Macdonald, MJ, Whalley, WRDB, Julien, MH, Sindel, BM, Duggin, JA (2012) Flood-induced recruitment of the invasive perennial herb <i>Phyla canescens</i> (lippia). *The Rangeland Journal,* 34(3): 269-276

Noble, MR, Rose, MC, Balnaves, J (2013) *African Boxthorn National Best Practice Manual: Managing African Boxthorn (Lycium ferocissimum) in Australia*: Tasmanian Department of Primary Industries, Parks, Water and Environment

Price, J, Gross, CL, Whalley, W (2010) Prolonged summer flooding switched dominance from the invasive weed Lippia (Phyla canescens) to native species in one small, ephemeral wetland. *Ecological Management & Restoration,* 11(1): 61-63

Stokes, KE (2008) Exotic Invasive Black Willow (Salix nigra) in Australia: Influence of Hydrological Regimes on Population Dynamics. *Plant Ecology,* 197(1): 91-105