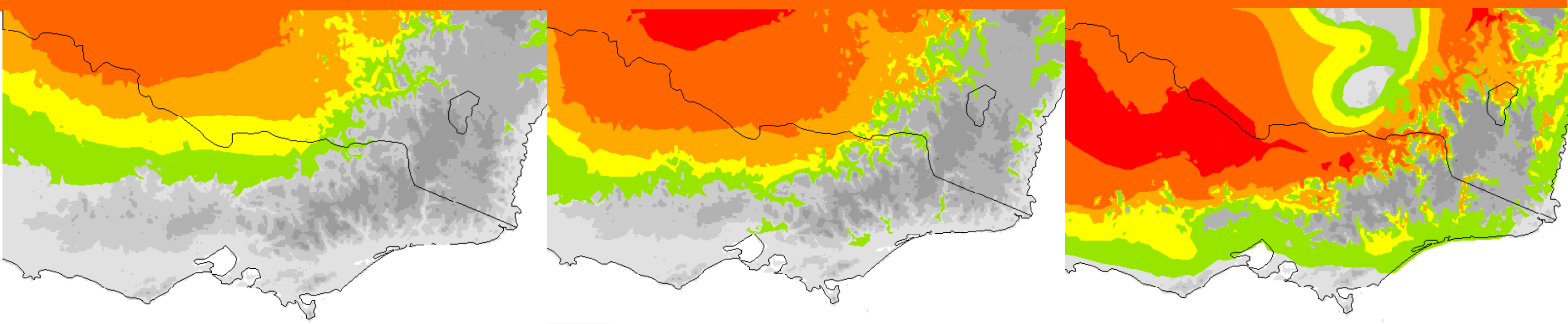
Climate change and potential distribution of weeds

Whither the weeds under climate change?



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Whither the weeds under climate change

Jackie Steel[1], Michele Kohout[2], Graeme Newell[2]
1. Department of Primary Industries, Frankston
2. Department of Sustainability and Environment, Heidelberg

Summary

The effect of climate change on weed species in Victoria will be an important determinant in the success of weed management programmes in this state. Modelling of weed distributions under climate change has given us the opportunity to observe which species are likely to be better able to establish in Victoria in the future, whilst some will become less invasive and others will not show such a noticeable response to climate change.

Climate change will increase the chance that some species that are largely distributed in more northern climes will have negative impacts in Victoria. These include *Acetosa vesicaria* (bladder dock), not yet naturalised in Victoria, and species that are established, but only in small numbers, including *Asparagus aethiopicus* (basket asparagus), *Bidens pilosa* (cobbler's pegs), *Heliotropium amplexicaule* (blue heliotrope), *Medicago laciniata* (cut-leaf medick) and *Sida rhombifolia* (Paddy's lucerne). This risk is not reflected in the potential distribution of these species under baseline conditions and as such has not informed management decisions for these species. However, climate change modelling warns of the increased risk of these species in the future, giving us an opportunity to eradicate them or prevent their spread before they can impact on Victoria's agricultural and natural resources.

Two northern species, *Prosopis pallida* (mesquite) and *Passiflora suberosa* (corky passionvine), did not show a potential distribution in Victoria under any climate scenario. Not all problem plants from the north will pose a risk to Victoria under climate change.

Species with more southern distributions are likely to become less of a problem under climate change. Whilst conditions across a large part of the state will remain suitable for their survival in the short term, over the next 50 years there is likely to be a large decline in area of suitable climatic conditions for widespread weeds such as *Cotoneaster glaucophyllus* and *Senecio jacobaea* (ragwort). Whilst their current high impacts warrant management to protect biodiversity assets and agricultural returns, a decline in climatic suitability is likely to reduce their ability to spread in the future. In this case, eradication programmes might more fruitfully be targeted at populations that are likely to remain in climatically suitable areas of the state, rather than those that might decline in response to climate change without human intervention. Similarly, less widely distributed weeds, such as *Leycesteria formo*sa (Himalayan honeysuckle), *Billardiera heterophylla* (bluebell creeper), and *N. trichotoma* (serrated tussock) may become easier to control as their range and vigour is reduced under climate change. Although climate change is likely to significantly reduce the potential distributions of the widespread *Rubus fruticosus* agg. (blackberry) and spreading *Nassella neesiana* (Chilean needle grass), large areas of the state will remain climatically suitable for their establishment.

Only two of the species included in this study are likely to maintain a similar potential distribution under climate change. *Echium plantagineum* (Paterson's curse) is likely to remain a problem across most of the state although climatic suitability will decline, which may reduce growth rate or fecundity of this species and enable it to be managed more successfully. *Hordeum glaucum* (blue barley-grass) is currently naturalised in few locations, but has a large potential distribution that is likely to remain just as large, and very climatically suitable under climate change.

The ability of this modelling technique to predict range changes for weeds in Victoria may make it a useful part of weed risk assessment that is currently part of the noxious weed review. It may be one of the triggers in a decision tool for the ongoing review of the noxious weed list. Similarly, this information will be useful in

formulating regional weed plans. It could also contribute to national priority setting for weed management, including a review of the Weeds of National Significance (WoNS).

Further use could be made of this modelling for assessing the risk of the Victorian Alert species, however, the technique would need to be improved such that distribution data from overseas locations could be used in the model. Currently the model is restricted to using data from Australian weed locations. Similarly, a technique that models aquatic and riparian species more accurately would expand the range of species that could be assessed using this method.

Data gleaned from assessing noxious weed nominations and Victorian Alert species would contribute to a larger dataset that could be used to develop some principles of the response of weeds to climate change. By formulating and testing some assumptions we will avoid having to model all species to make some judgement about their likely response to climate change.

The modelling can be made more useful by providing some interpretation of the different degrees of climate match, in terms of changes to weed vigour and infestation densities. This research will enable us to determine, in part, how quickly weed distributions will respond to climate change.

A more complex model of weed distribution under climate change would also aid in predicting weed responses to climate change. This model might include further factors that constrain species distributions, such as soil type, management techniques, and other factors that might also show climate change responses: vegetation/landuse change, the frequency of disturbances such as fire, and the distribution of major competing native species and biocontrols.

Of the 25 species included in this study, we were able to successfully model the distribution of 20 under a range of climate change scenarios. We chose to model both agricultural and environmental weed species from a range of climatic conditions, and with differing life forms: grasses, shrubs, trees and vines; annuals and perennials. The potential distributions of these species at 2030 and 2070 are presented in this report.

Introduction

Victoria's changing climate

CSIRO has summarised the likely effects on Victoria's climate as a result of global warming as outlined below. Links to more detailed reports, including climate projections for each of Victoria's regions can be found at www.greenhouse.vic.gov.au/greenhouse/wcmn302.nsf.

By 2070, in Victoria:

- temperatures are likely to be 0.8 to 5.0°C warmer than 1990, with summer temperatures increasing more than winter temperatures.
- days above 35°C will become more frequent.
- frost frequency is likely to decrease.
- rainfall is likely to decrease, changing by +10% to -25% in most southern and eastern regions, and +10 % to -40% in most northern regions, with most rainfall decreases likely to occur in spring.
- extreme weather-related events are likely to increase, including ecological disturbance factors such as intense rainfall, bushfire and drought.

from www.greenhouse.vic.gov.au/greenhouse/wcmn302.nsf.

Changes in temperature and rainfall are likely to change the distribution of plants, including weeds. Government investment in many aspects of weed management needs to take account of possible changes in vigour or extent of weeds already present and of possible increases in risk of invasion of new weeds.

There is currently substantial investment in managing some weeds of cooler parts of Victoria eg. *Senecio jacobaea* (ragwort). If these species are likely to decline substantially in the next 20 years due to climate change, then the priority of investment in these species compared to other serious weed should be reviewed.

The Victorian WRA process is used to inform regional priorities for weed management and as a major input to the process of reviewing the list of weeds declared noxious in different categories under the CaLP Act. An important element of WRA is scope for further spread, based on potential distribution under baseline climate. It may be that in future the WRA should also consider one or more climate change scenarios and be adjusted to allow for likely range changes.

Biological control can be an effective technique to reduce the impact of established weeds; however the cost of biocontrol means that only a small number of species can be addressed by this approach. When identifying possible future targets for biocontrol, species that are predicted to remain important or to increase under climate change should be given priority over those predicted to decline.

This report displays the projected changes in suitable climate for a range of weed species. More ecological disturbance is also likely to increase the ability for weeds to invade, and conversely, land use and vegetation types are likely to constrain species' distributions, but these were not modelled for this report.

Method

We created bioclimatic models of a range of weed species to illustrate how their distributions might change under future climate scenarios.

Choice of species

Species were chosen for assessment to represent a range of life forms, from annuals to perennials; grasses, herbs, shrubs, trees and vines; and from different climatic zones. Our species selection was limited to those that had sufficient distribution data within Australia, as data from locations outside this country could not be used in this model. At least 100 location points were required and the presence-only model assumed that the species had reached their potential range under prevailing climatic conditions, so new and emerging weeds could not be included.

The potential distribution models were created in the climate analysis program Anuclim 5.1 (Houlder *et al*. 2000). This program constructs climate profiles, or envelopes, for a species by referring species distribution points to thirty five climatic parameters (listed in Appendix 1). These 35 parameters were derived within Anuclim from five primary climate variables (maximum temperature, minimum temperature, rainfall, radiation with rainfall and evaporation), which are modelled surfaces from site-based long-term meteorological data. Climate records were used to form a climate surface that mapped species presence data (longitude, latitude, altitude) to estimated climatic values for each of the 35 parameters.

Species presence data was obtained from the Australian Virtual Herbarium (AVH) website and supplemented by data requested from state herbaria, Weeds of National Significance (WoNS) coordinators and from Victoria's Integrated Pest Management System (IPMS). These datasets were examined by plant researchers from around Australia that have expertise in each species. Datapoints that they deemed to be erroneous, associated with mis-identification, or with microclimatic (rather than broadscale climatic) conditions were removed from the dataset.

If all 35 climatic parameters are used to create a species' model, Anuclim may over constrain a species' potential distribution. When used to compare current potential distribution with that under future climates, Anuclim has been found to consistently predict a decreased potential distribution because it fails to predict a climate match if the value of a parameter is different under climate change compared with current climate (Hijmans & Grahame, 2006). However, this study also concluded that the climate matches that Anuclim *does* identify are likely to be fairly accurate, and that false negative errors can be minimised by using fewer parameters to create the climate profile.

Furthermore, because Anuclim creates 35 climatic parameters from 5 climatic variables, there is considerable redundancy in the parameters because there is a high degree of correlation between them. Reducing the number of parameters that are used to model each species aims to not only reduce the false negative errors, but also minimise the undue influence of any one climatic variable.

In this study we used several techniques to reduce the number of parameters used for modelling each species. Firstly, we examined the histograms/cumulative frequency curves of each parameter in the climatic profile to determine which were likely to be influential in the complete climate profile. Parameters that did not appear to influence the climate profile were removed from further analyses. When this was not a clear cut decision, we used information about the biology and ecology of the plant to identify climatic parameters that are important factors limiting the plant's distribution and these were kept in the model. For each species, we produced a series of at least ten potential distribution maps (see Appendix 2) that resulted from each set of parameters. Expert opinion was used to choose which of these ten potential distributions most accurately reflected each plant's likely range. This baseline climate profile for each species was a combination of biologically and ecologically important parameters, which also had normal histograms/cumulative frequency curves. In some cases potentially (biologically) important parameters were removed in this process because their distributions were not normal.

Baseline climate match – the iterative process

Tamarix aphylla as an example

Appendix 2 shows the iterative process that was used to determine the potential distribution of *T. aphylla* under baseline climatic conditions.

Using all 35 bioclimatic parameters (a) gave a potential distribution that covered few current distribution points. After examining the histograms/cumulative frequency curves of each parameter in the climatic profile, any that did not appear to influence the climate profile were removed. The resulting potential distribution maps (b-d) show that the climate envelope changed very little, expanding NE further into Qld at iteration c, but then blowing out to cover a vastly larger area (d) when only parameter 1 was used (annual mean temperature). This climate envelope encompassed all the distribution points, but was not considered to be an accurate depiction of the species' potential distribution.

As Athel pine is confined to waterways, rainfall was not considered to be an important determinant of its distribution. When only the rainfall parameters were removed (e), a climate envelope similar to b emerged. The iterative process of removing parameters that did not appear to influence the climate was continued from this point (f-j). A similar pattern emerged, of very little change (f &g), some expansion NE further into Qld (h) and then the hugely expanded area (i & j) that was rejected as d was also rejected.

Only 58 records of this species' potential distribution were originally found. A further 3 records, from WA were sourced and added to the dataset. The same parameters from j were used to create a potential distribution that included these new data points (k). The climate envelope contracted slightly at the northern boundary, but it was still deemed too large. Further iterations showed no change (l & m).

The most accurate potential distribution until this point appeared to be h, so the same parameters were used with these new datapoints. A very similar climate envelope emerged that was considered the best climate match; however there was concern that it had been generated by using 15 climatic parameters. An examination of the two iterations that had produced the best climate matches (c & h) revealed that the only parameter that was used in both was 10 (mean temperature of the warmest quarter). When this parameter alone was used, with the full set of current distribution data points, the same potential distribution was generated. This iteration was chosen as the baseline climate for Athel pine.

The iteration process just described was repeated for each species to generate a baseline climate match for each one.

The baseline climate envelope for Athel pine did not enclose a large number of current distribution points, including the worst infestations in the Northern Territory. This may be due to the association that this species has with waterways. Its distribution is probably confined more by the availability of water than by prevailing climate. A climate analysis, such as this one, assumes that a species is located where it is because of climatic conditions, rather than geographic conditions, such as waterways. This reduces the effectiveness of the statistical analysis of the climate match for aquatic or riparian species. Due to this problem, no further species were assessed that have an association with waterways.

The climatic envelopes that were developed using current climatic conditions were then projected onto future climate scenarios (in 2030 and 2070) to show how each plant's potential distribution might change. A brief description of the scenarios is in table 1. More detailed descriptions of the scenarios can be found in the IPCC Summary Report for Policy Makers at http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Pub_SPM-v2.pdf .

Description of the climate change scenarios used

The scenarios that were used to model the climate envelopes of the 25 species in this report are in Table 1. Recent observed climate trends show that atmospheric carbon concentrations are increasing as projected, whilst the observed increase in global mean surface temperature is in the upper range of IPCC projections, and sea level rise has occurred at a faster rate than projected by any of the models (Rahmstorf *et al.* 2007). This suggests that the A1F scenario may reflect the most accurate climatic response to increasing atmospheric carbon.

Scenario	World focus	Global average surface warming compared to 1990 (°C)*	
		2030	2100
A1F	Economic development, fossil fuel-intensive	1	5.3
A2	Economic development, no reliance on any one energy source	0.9	4.4
B1	Sustainable development, clean and resource-efficient technologies	0.9	2.4

Table 1. Description of climate change scenarios

*Average surface warming as an estimate of the relative degree of global warming that may occur under each scenario compared to 1990. These figures do not indicate the degree of warming that will necessarily occur anywhere in Victoria. Figures from IPCC (2001).

At 2030 the global average surface warming is projected to be very similar under all emissions scenarios. At 2100 there is projected to be a large difference in global average surface warming. The increased difference between the scenarios over time should be kept in mind when interpreting the results of the modelling in this study. It explains why the 2030 results for a species are so similar, but at 2070 the differences between the scenarios were more obvious.

Key

Climatic suitability*

- Very high
- High
- Moderately high
- Moderate
- Likely

Height above sea level

- -33 to 0 m
- 0 to 200m
- 200 to 500m
- 500 to 1000m
- 1000 to 2000m
- 2000 to 4000m

Distribution

- Current distribution location (presence in a 17km grid square)

*See appendix 3 for an explanation of climatic suitability

A greater climatic suitability can be interpreted as better conditions for establishment and growth of the weed species. A high climatic suitability indicates that the impacts of the weed are likely to be greater than a lower climatic suitability. However, even at likely suitability, the weed may be capable of establishing and causing impacts.

Areas of the map where the greyscale "height above sea level" is visible are considered climatically unsuitable for the species to establish and grow.

Results

Acacia farnesiana (L.) Willd.

mimosa bush

syn. *Vachellia farnesiana*

Widespread and native through the tropics and subtropics of North, Central and South America, often naturalized in Africa and Asia (Kodela 2006; Parrotta 2003), this species "probably arrived in Australia prior to European settlement, which affects its classification as 'native' or 'introduced'" (Kodela 2006).

It grows in open woodland, shrubland and grassland, in alluvial clay soils and sandy loams, on open plains and near watercourses in NSW Qld W.A. S.A. & N.T. The foliage and young, green pods are palatable to cattle and sheep. However, it is a potential weed of grasslands (Kodela 2006), can colonise pastures and "often forms dense thickets on disturbed sites" (Parrotta 2003). It has been identified as an invasive scrub species that may be responding to changed fire and grazing conditions since European settlement (Science and Information Board 2004).

Acacia farnesiana "does not tolerate frost and grows well in areas receiving between 500 and 750 mm of rainfall with a dry season of 4 to 6 months. Its best growth occurs on well-drained soils" (Parrotta 2003) and it withstands drought well (Land Protection 2006).

The parameters chosen to model this species were 1 & 9.

The baseline climate match for this species (Fig. 1) encompassed more than 90% of the current distribution points that were used to generate the climate model for this species. Due to concerns that this species might have undergone a recent range expansion towards the south, perhaps as a response to climate change since 1970, the records used were restricted to those that were made prior to this date. However, the climate match still poorly reflected the concentration of data points in northern NT and WA.

Acacia farnesiana

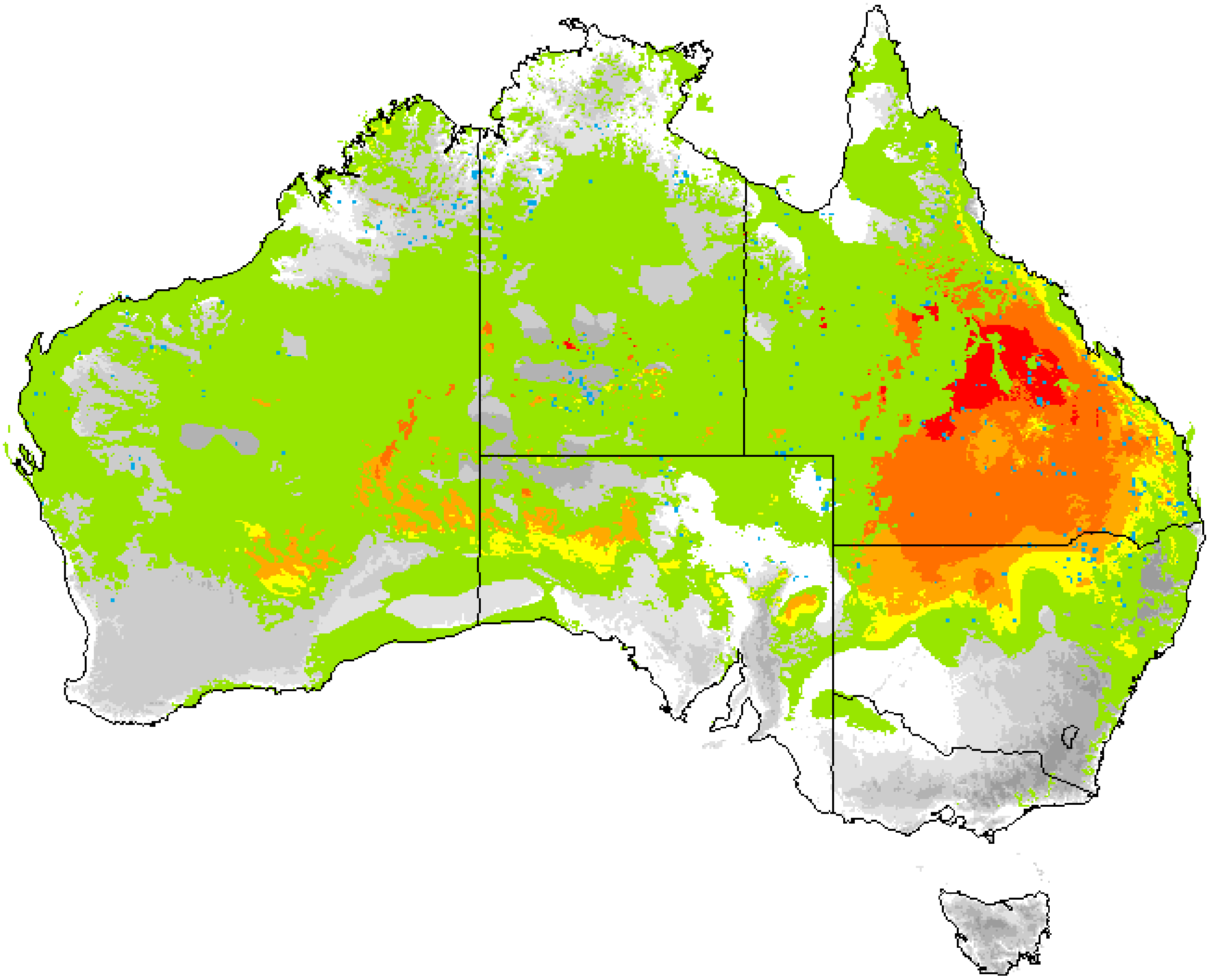
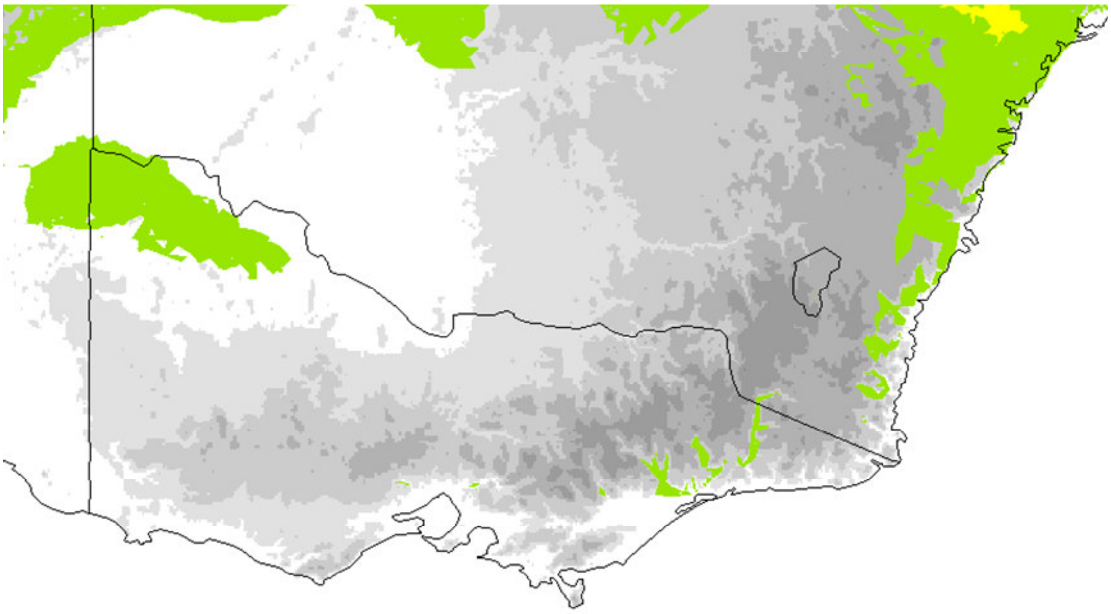
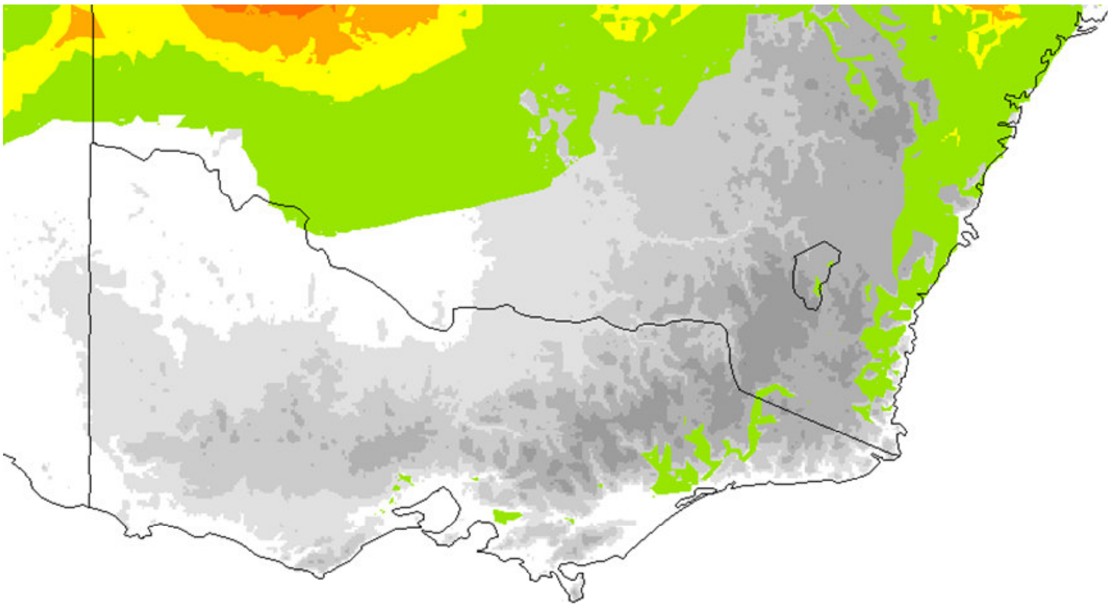


Figure 1. Comparison of current distribution with baseline climate match

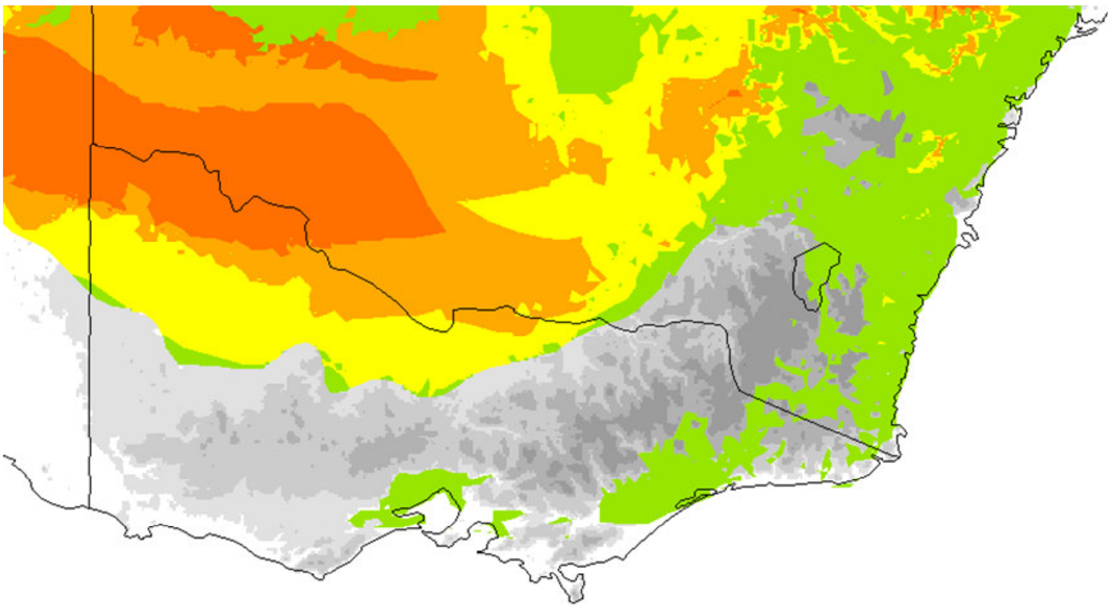
Figure 2a. *Acacia farnesiana* B1 scenario (low)



Baseline climate

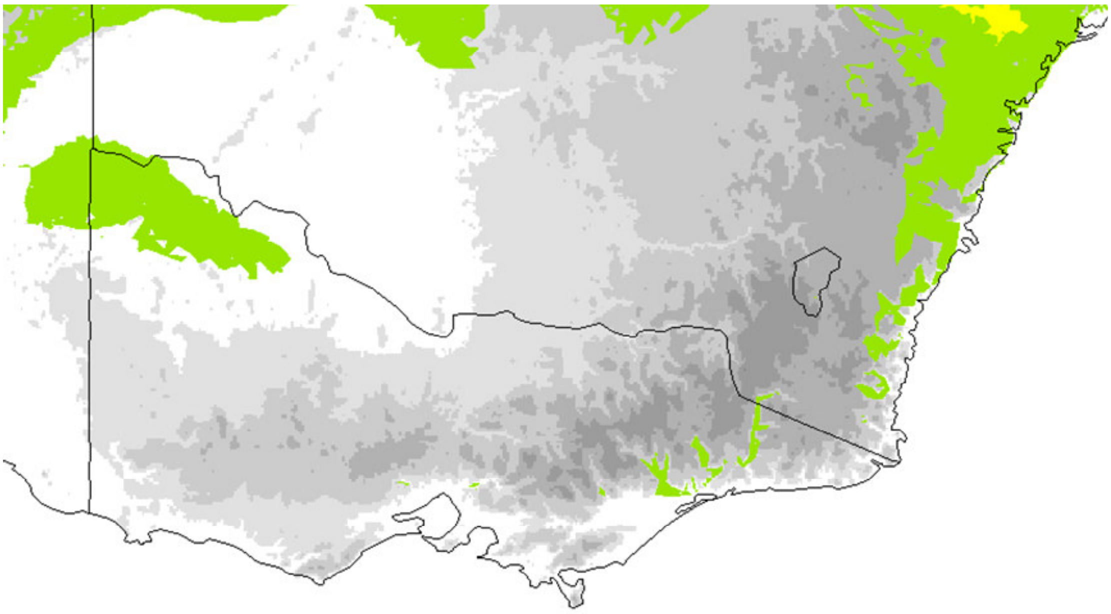


2030

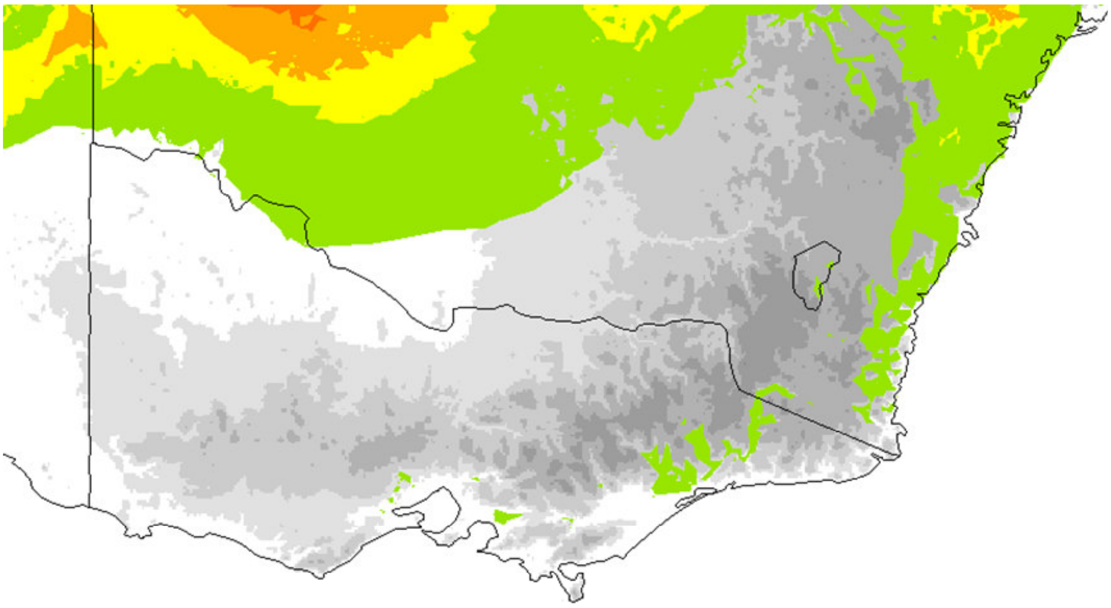


2070

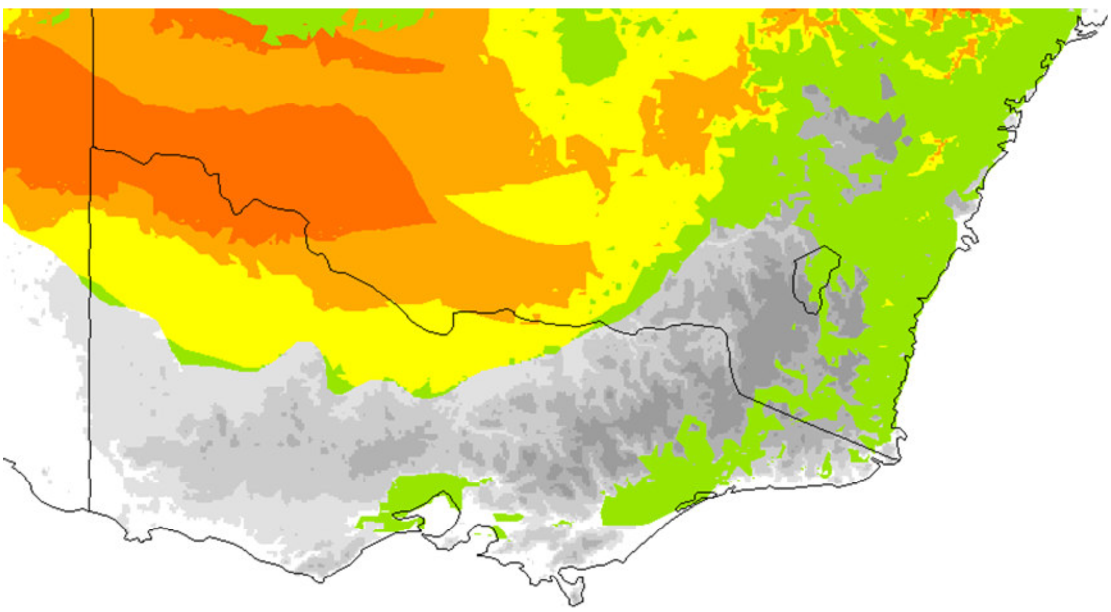
Figure 2b. ***Acacia farnesiana*** A1 scenario (mid)



Baseline climate

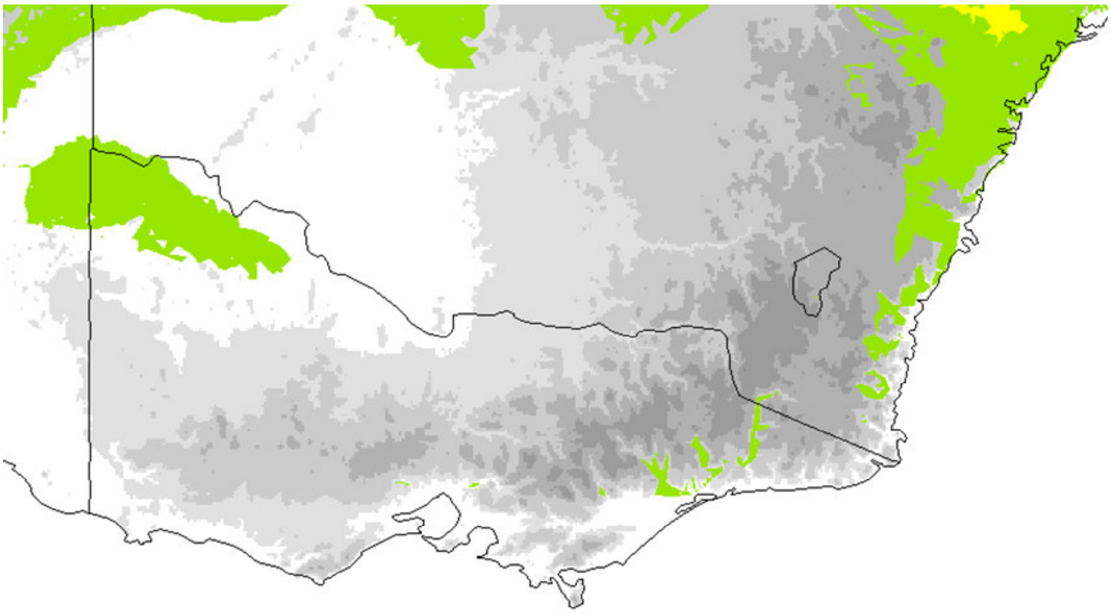


2030

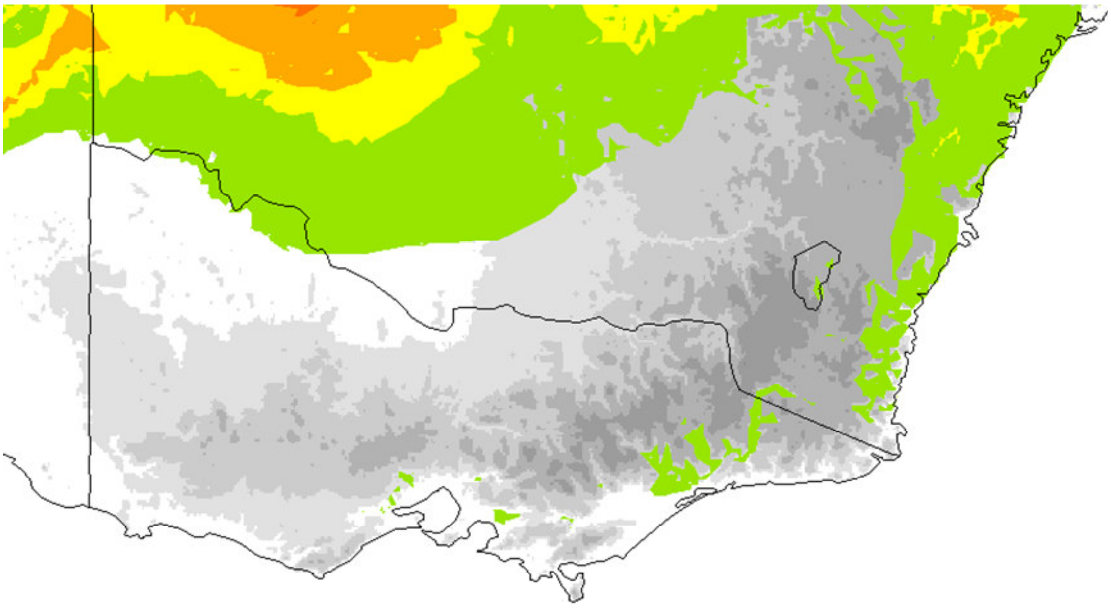


2070

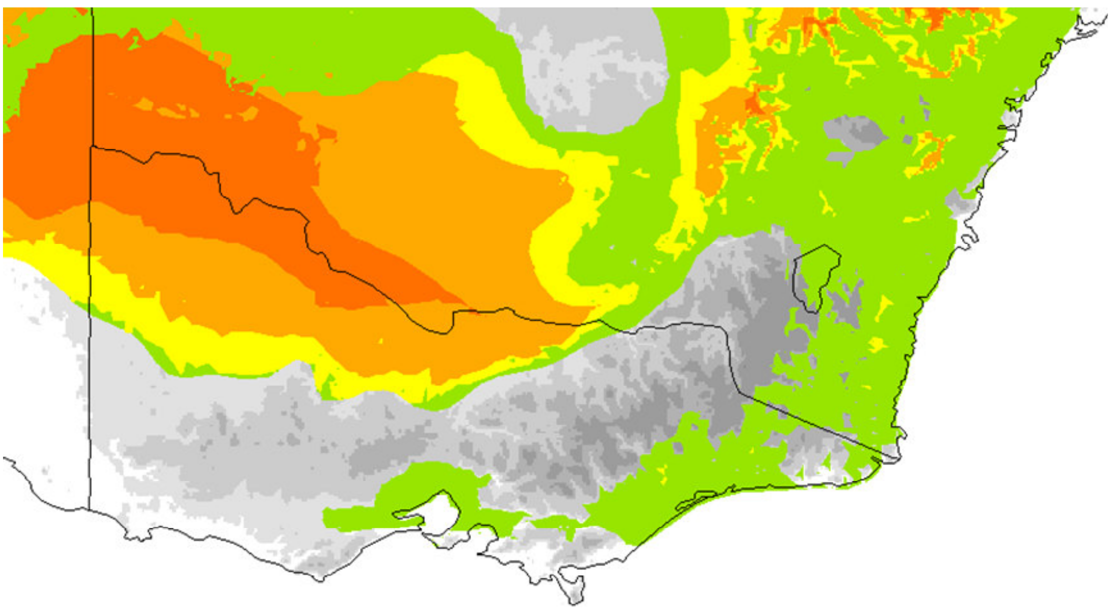
Figure 2c. *Acacia farnesiana* A1F scenario (high)



Baseline climate



2030



2070

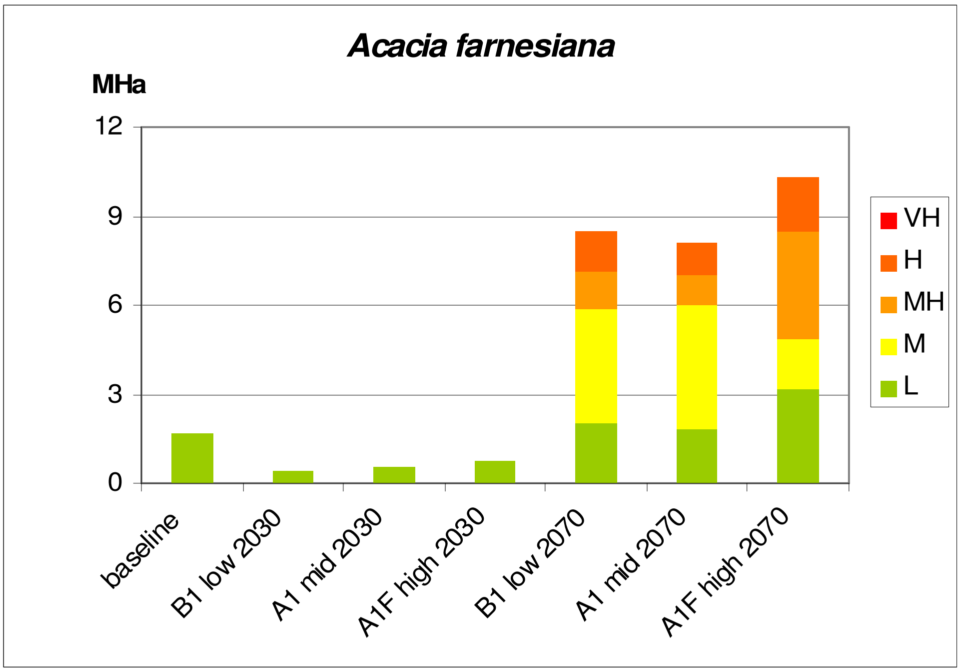


Figure 3. Area occupied by the climate envelope for *Acacia farnesiana* under a range of climate scenarios over time

Results summary for *Acacia farnesiana*

The pattern observed in changes to the climatic suitability in Victoria for this species was not consistent with that of other species. At 2030 the climate envelope reduced dramatically in size under all scenarios. At 2070 however, the climate envelopes expanded dramatically in both size and degree of climate suitability. The maps show that under baseline conditions, a patch of likely climate suitability is present within Victoria, but separate from and below the main climate envelope for this species. At 2030 the main climate envelope expanded to the south, whilst the disconnected patch disappeared. By 2070 the main climate envelope had expanded well into Victoria.

B1 (low) (Fig. 2a)

2030

As described above, the climate envelope within Victoria was dramatically reduced at 2030 due to the disappearance of the isolated patch of likely climate match that was present under baseline conditions.

2070

By 2070 the main climate envelope had expanded south into Victoria and almost all of the north west of the state became moderately to highly suitable for the establishment and growth of this species.

A1 (mid) (Fig. 2b)

2030

There was little difference between this scenario and B1 low at 2030.

2070

There was little difference between this scenario and B1 low at 2070.

A1F (high) (Fig. 2c)

2030

There was little difference between this scenario and B1 low at 2030.

2070

The climate envelope was at its largest under the A1F scenario at 2070. The climate envelope expanded a little further south from the border and the degree of climatic suitability in the north of the state was increased by comparison with the other scenarios at this time point. In the south of the state the likely climate matches around greater Melbourne and in Gippsland also expanded.

Acetosa vesicaria (L.) A. Love

Bladder dock

Bladder dock is "indigenous to desert and semi-desert areas of North Africa (including the Canary Islands), the Middle East and South-east Asia (Bangladesh, India, Indonesia and Pakistan)" (Schatral & Osbourne 2006). In Australia, it occurs in Western Australia, Northern Territory, South Australia, Queensland, New South Wales, and sporadically in Victoria (Spooner *et al*. 2007a). It "is an environmental weed, with the potential to have a significant impact on the natural flora and fauna in areas" (Schatral & Osbourne 2006). It grows "amongst low (sclerophyll) shrubland; occurring in desert areas but not confined to low rainfall habitats; in rocky or stony soil, gravelly soil, sand, loam, clay; occupying road sides; growing in disturbed natural vegetation, on bare areas" (Spooner *et al*. 2007a).

The parameters chosen to model this species were 1, 2, 3, 5, 7 & 11.

The baseline climate match for this species (Fig. 4) was excellent. It encompassed all of the current distribution data points, and the very high and high climate suitability concurred with the greatest concentrations of infestations.

Acetosa vesicaria

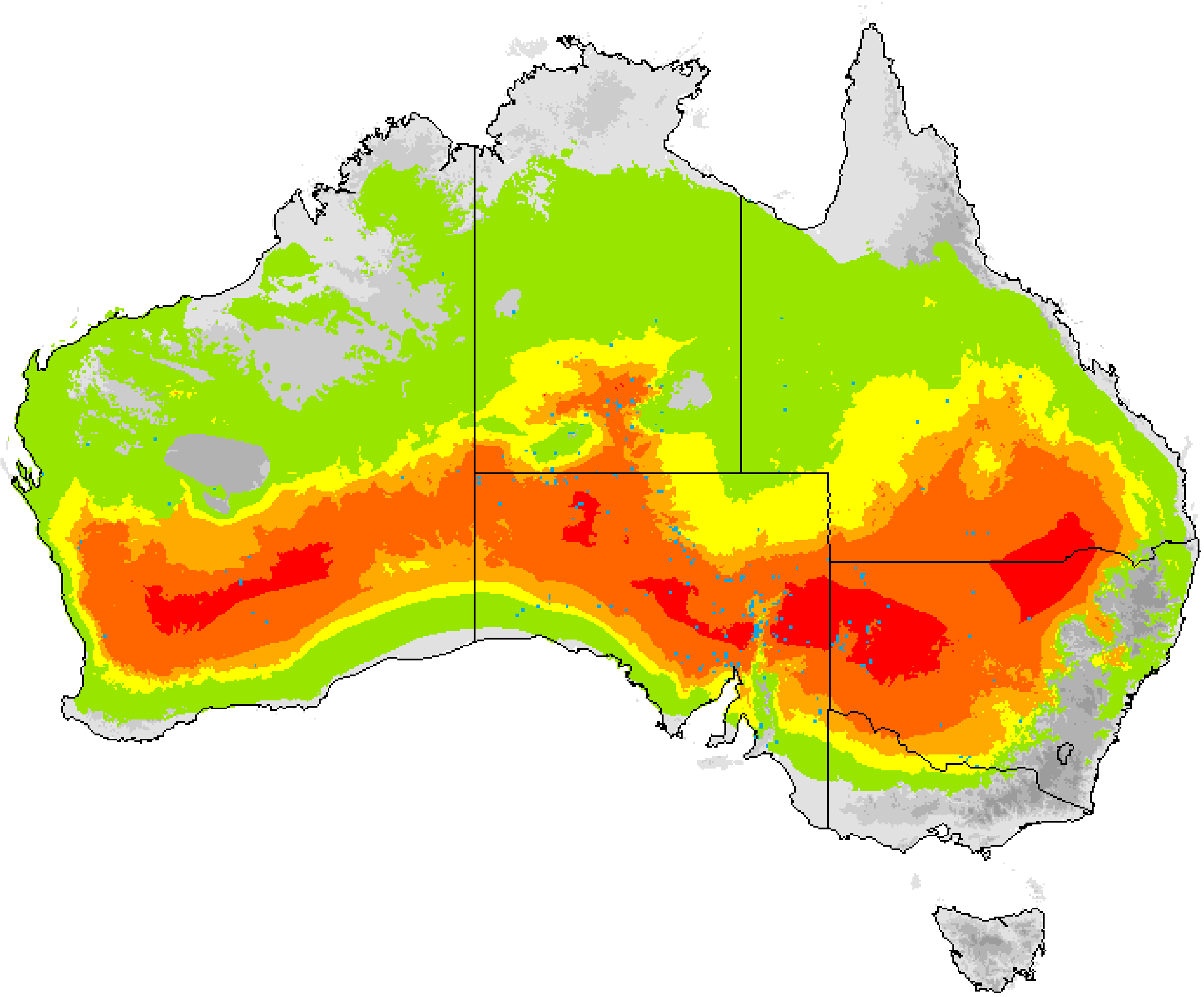
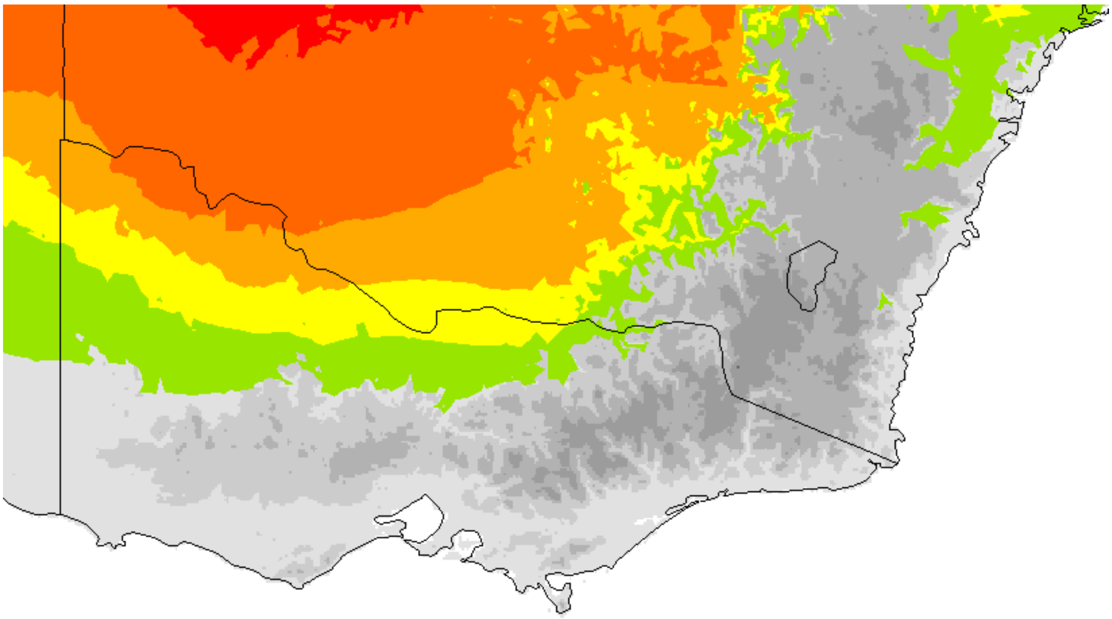
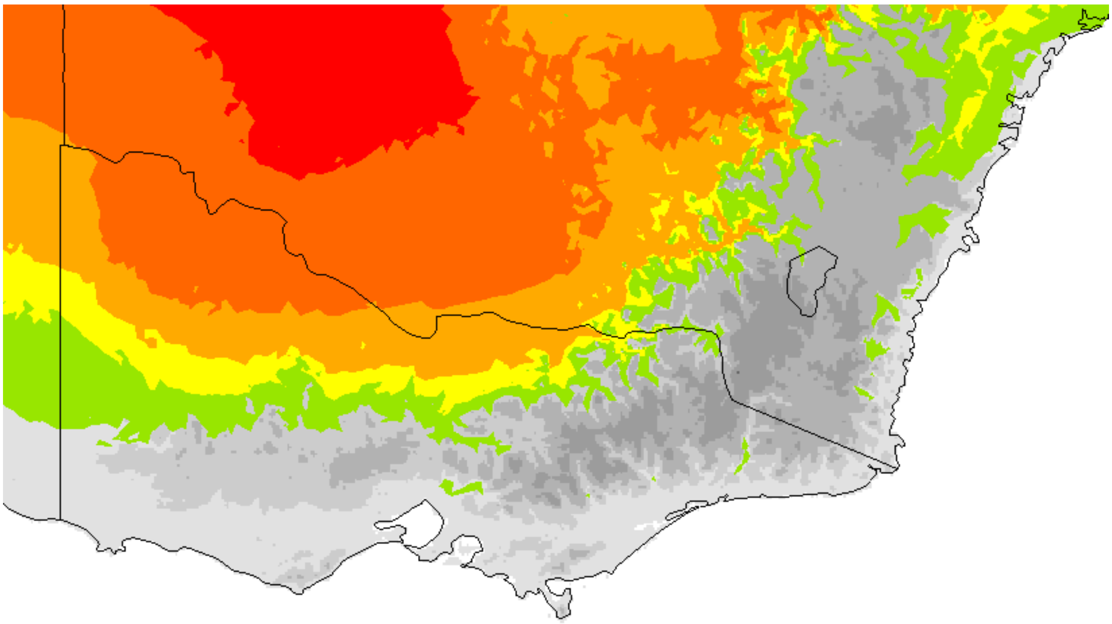


Figure 4. Comparison of current distribution with baseline climate match

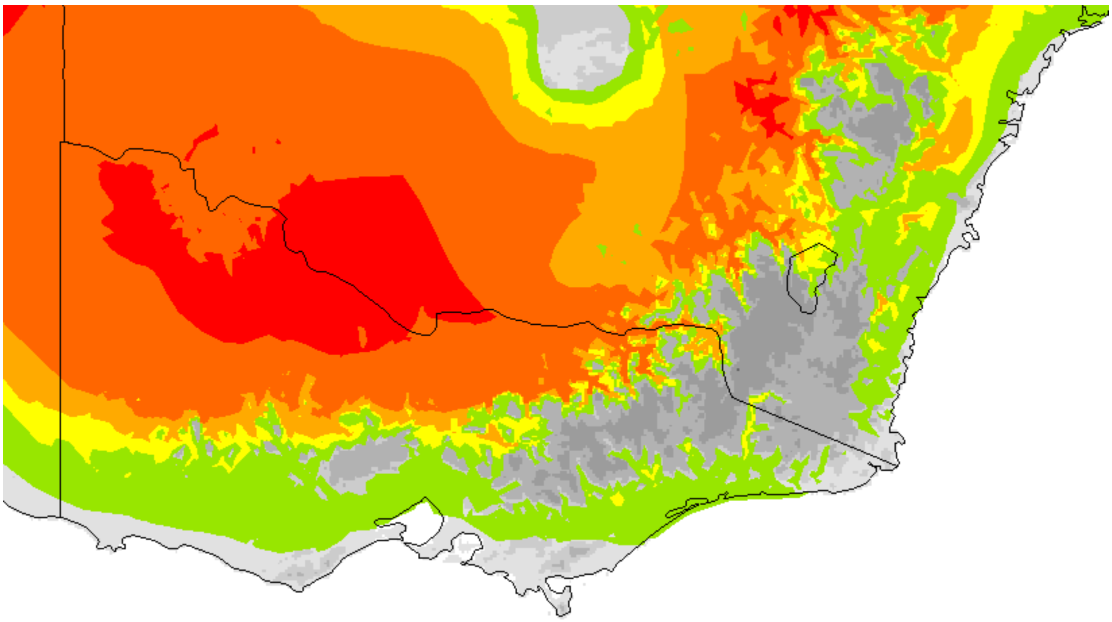
Figure 5a. ***Acetosa vesicaria*** B1 scenario (low)



Baseline climate

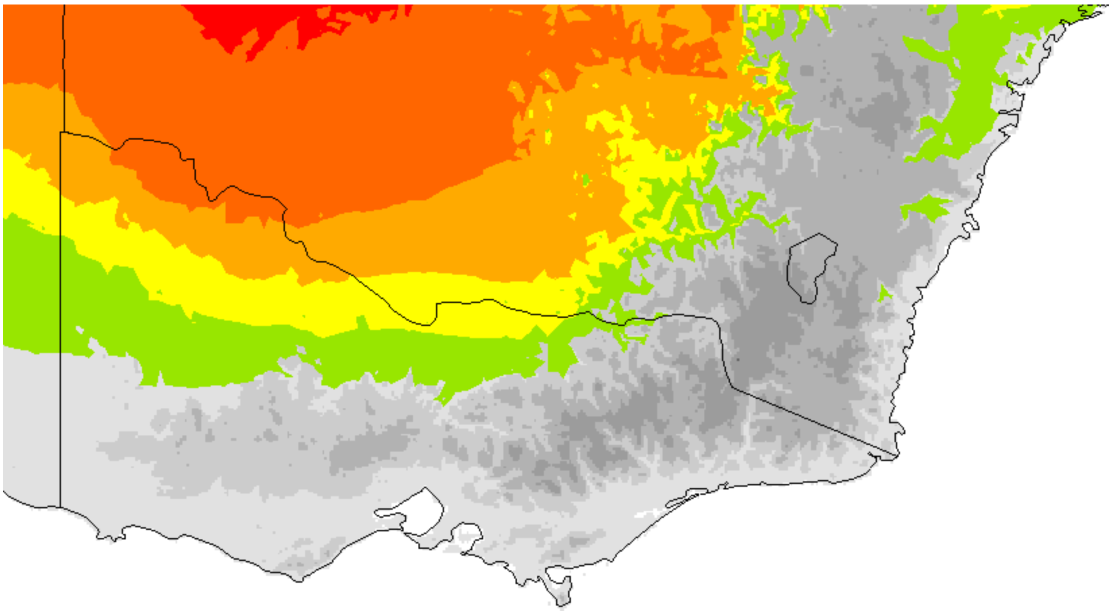


2030

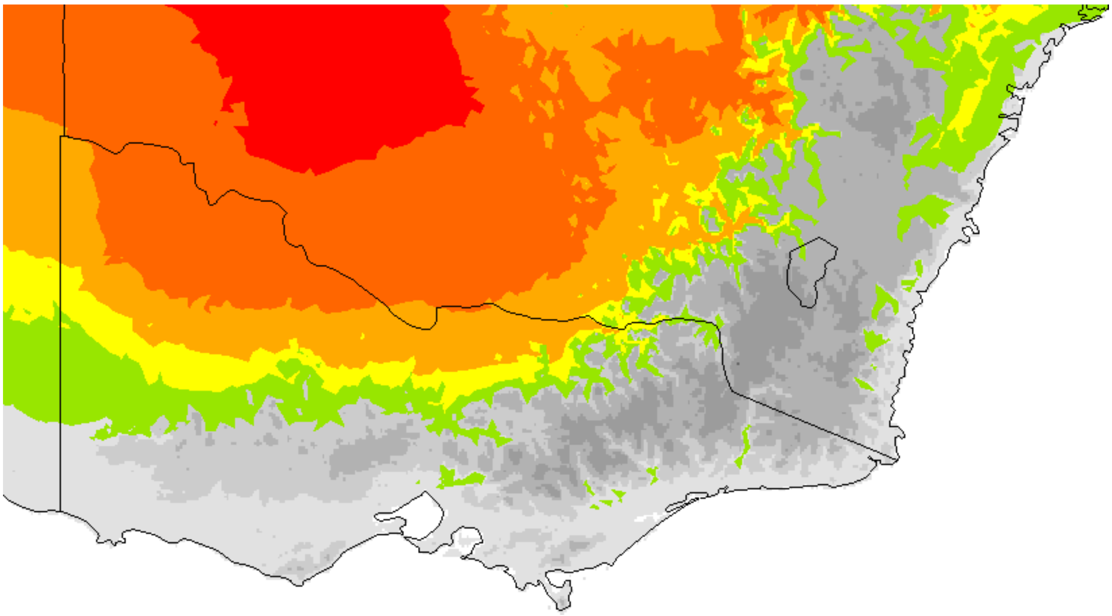


2070

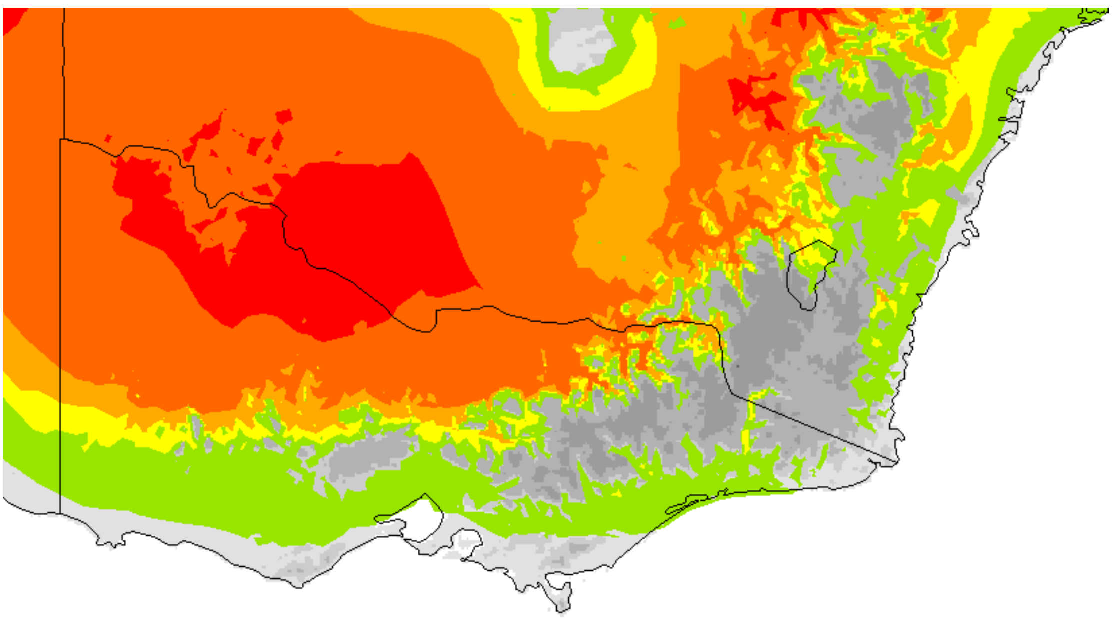
Figure 5b. *Acetosa vesicaria* A1 scenario (mid)



Baseline climate

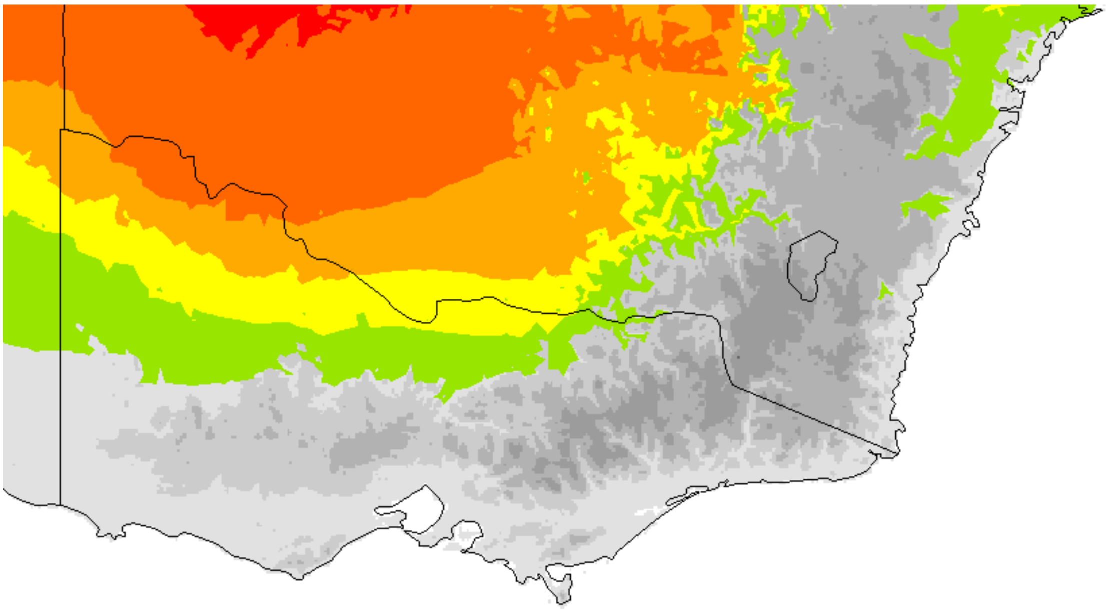


2030

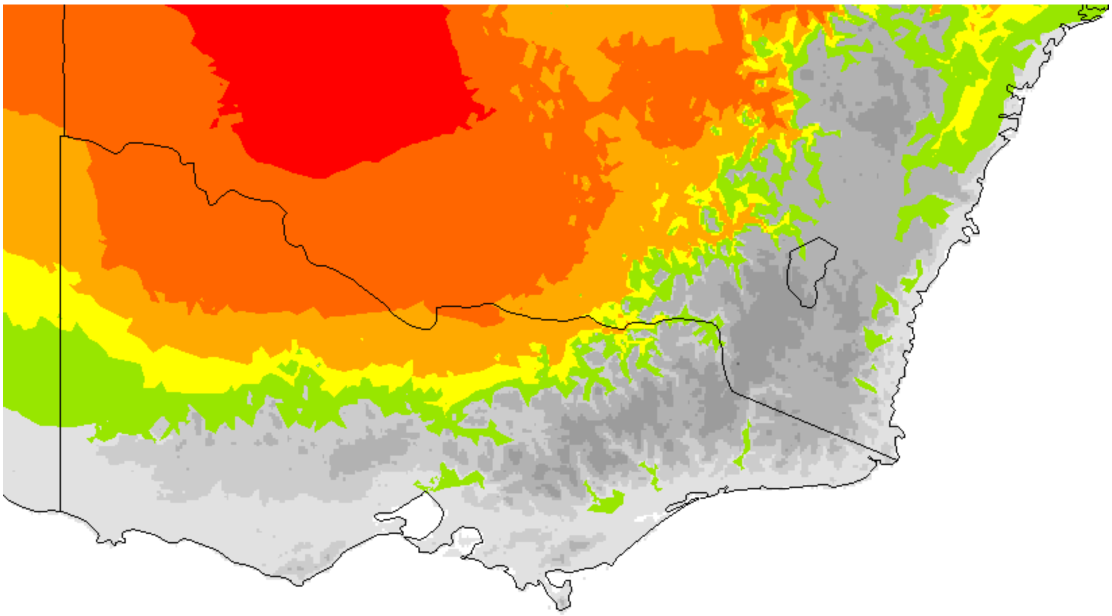


2070

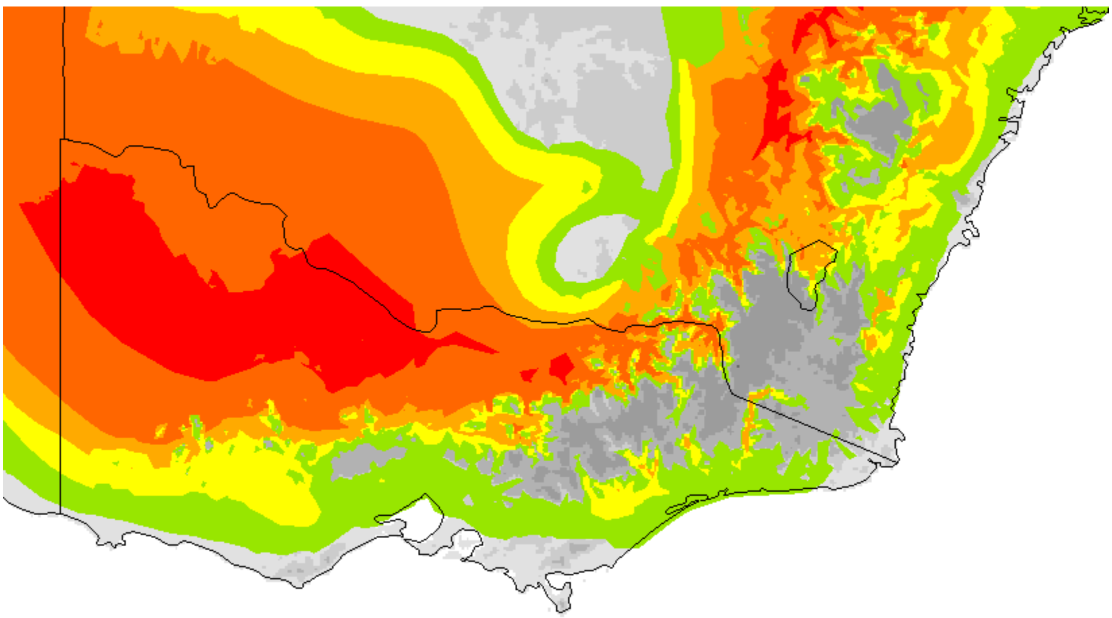
Figure 5c. *Acetosa vesicaria* A1F scenario (high)



Baseline climate



2030



2070

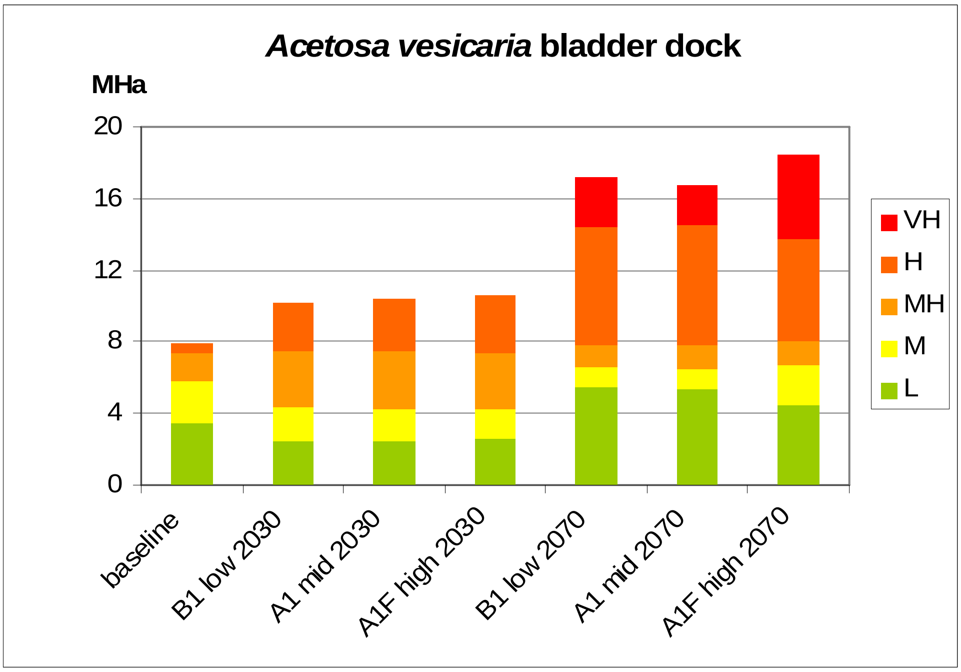


Figure 6. Area occupied by the climate envelope for *Acetosa vesicaria* under a range of climate scenarios over time

Results summary for *Acetosa vesicaria*

The climate envelope increased noticeably and continually under all scenarios and at 2070 it had expanded to more than twice the size of the baseline area. The degree of climatic suitability also increased and large parts of the state became very highly suitable for the establishment and growth of this species. It is not currently recorded as present in Victoria.

B1 (low)

2030

The climatic envelope expanded to the south and larger areas of moderately high and highly suitable climate developed.

2070

The climate envelope expanded much further to the south and a large are of very high climate match developed in the north-west and north-central parts of the state.

A1 (mid)

2030

The model responded to this scenario in a very similar way to B1 low, however the climate distribution had a slightly more southerly limit.

2070

The model responded to this scenario in a very similar way to B1 low, however there was a slightly reduced area and climatic suitability by comparison.

A1F (high)

2030

The climate envelope expanded further south than under the other scenarios at this time point.

2070

The climate envelope reached its largest size at this time point under this scenario. It also had the biggest area of very high climate match, extending in a band across north-central and north-west Victoria.

Asparagus aethiopicus L.

A. aethiopicus is an herbaceous perennial that originated in southern Africa and is now a weed of south-east Queensland and coastal New South Wales in woodlands and forests. It has also naturalised in a few locations in the south-east of South Australia and Victoria (Scott & Batchelor 2006).

A CLIMEX model based on distribution data from South Africa found that optimal and limiting low temperatures, and cold stress, dry stress and hot-wet stress were important parameters for modelling the species' distribution in Australia. Upper optimal and limiting temperatures were also used, along with optimal and limiting low and high moisture (Scott & Batchelor 2006).

The parameters chosen to model this species were 2, 10 & 17.

The baseline climate match for *Asparagus aethiopicus* (Fig. 7) reflected the current distribution of this species. Almost all of the data points were captured in the climate envelope, with the highest climate matches concurring with the high numbers of infestations recorded in coastal Qld and NSW.

Asparagus aethiopicus

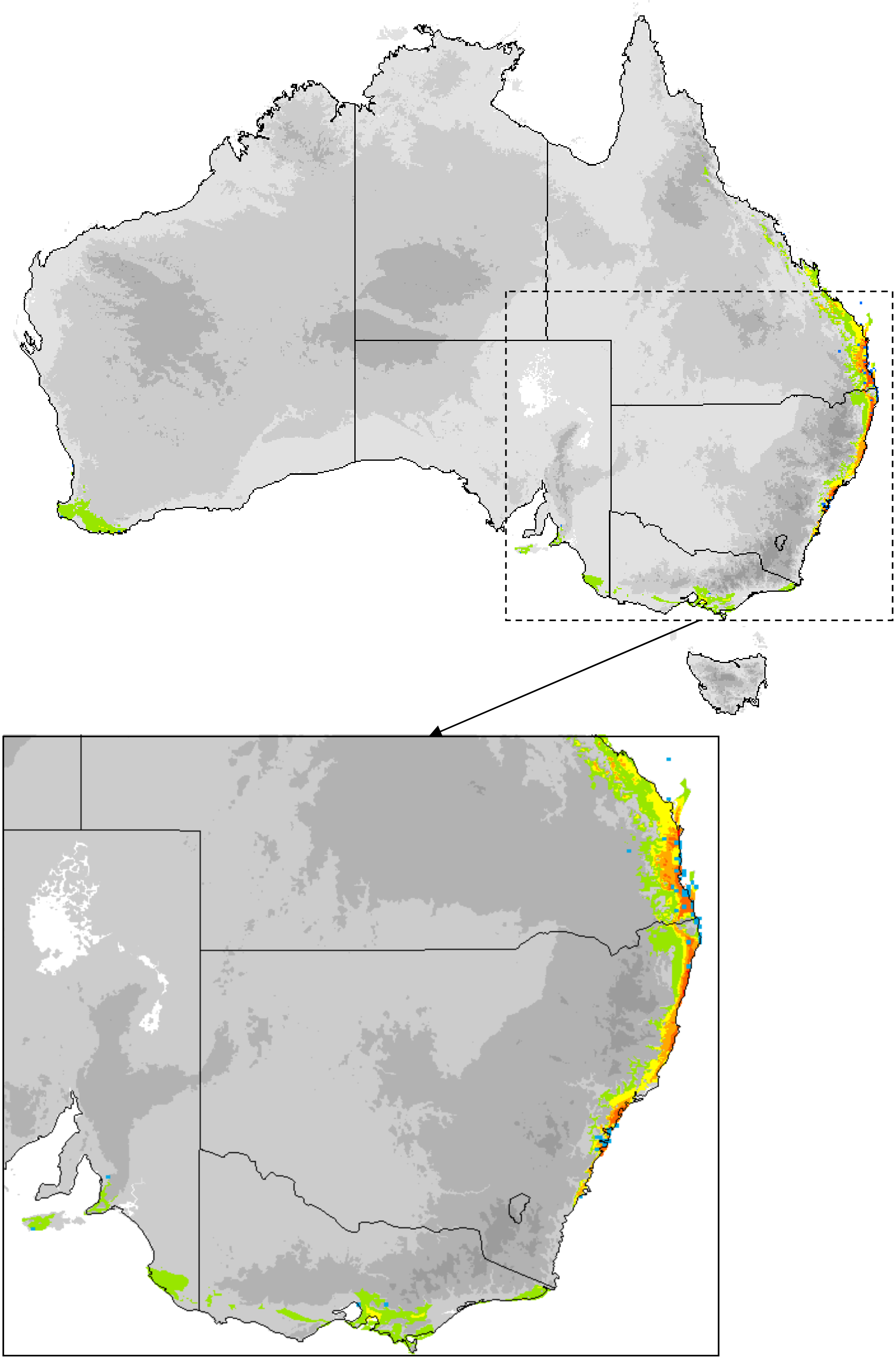
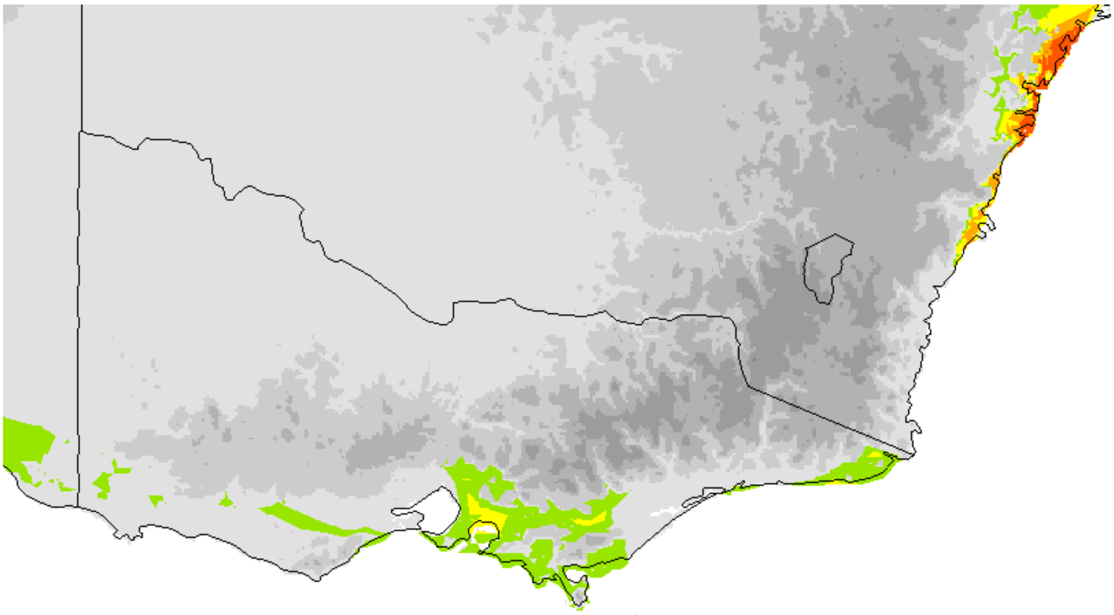
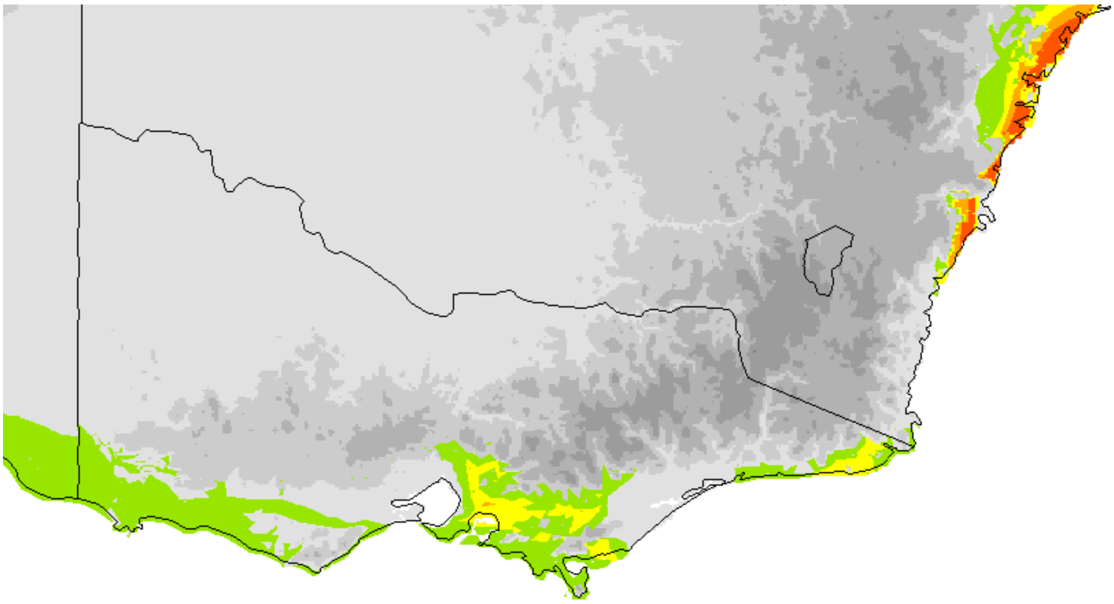


Figure 7. Comparison of current distribution with the baseline climate match

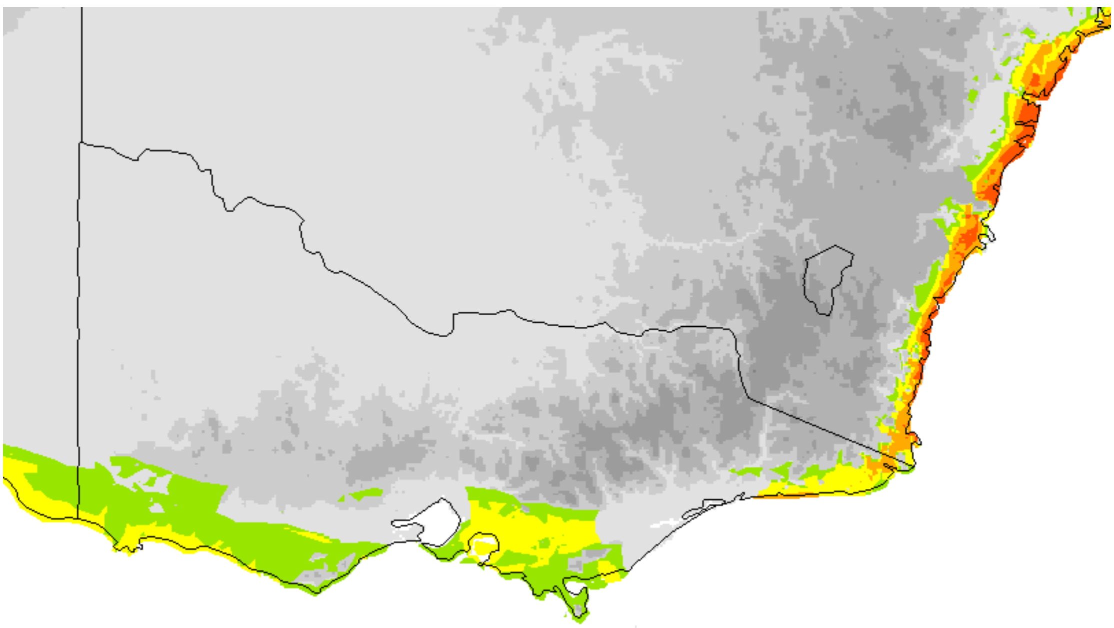
Figure 8a. *Asparagus aethiopicus* B1 scenario (low)



Baseline climate

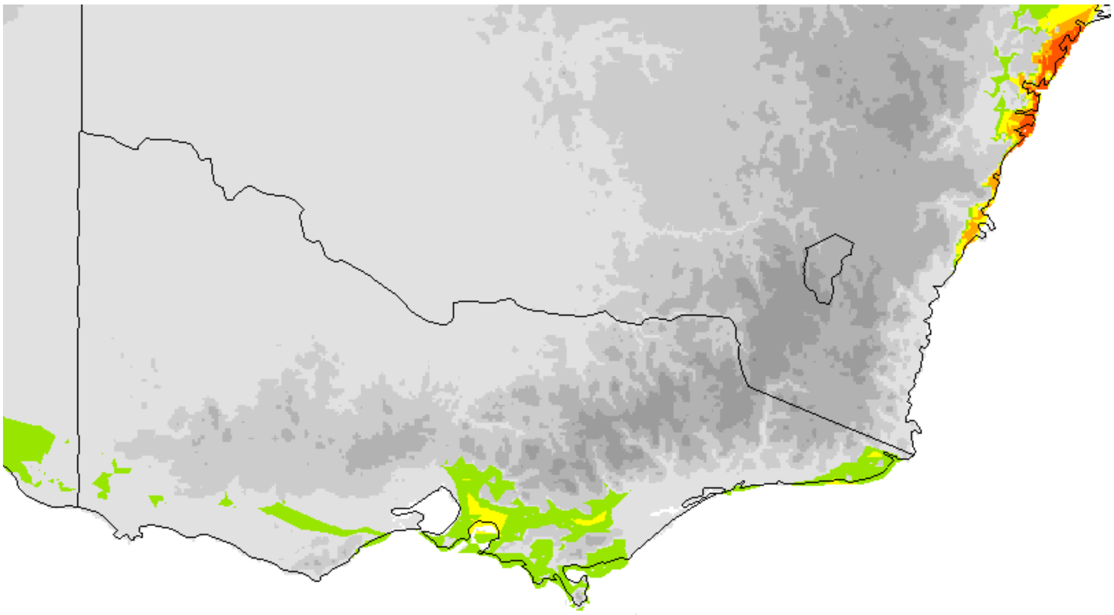


2030

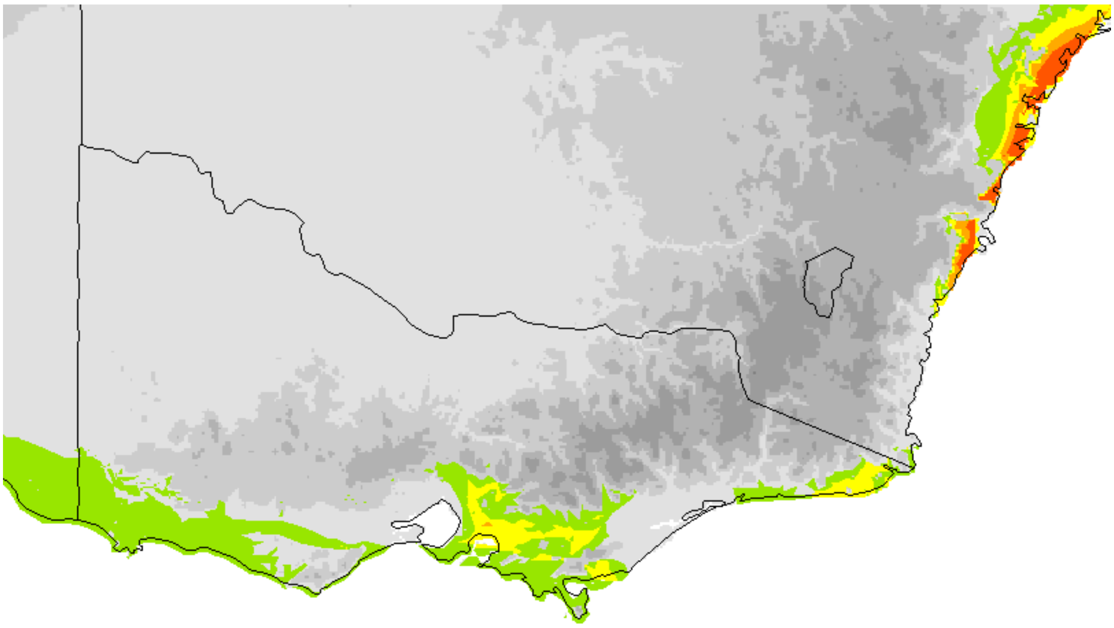


2070

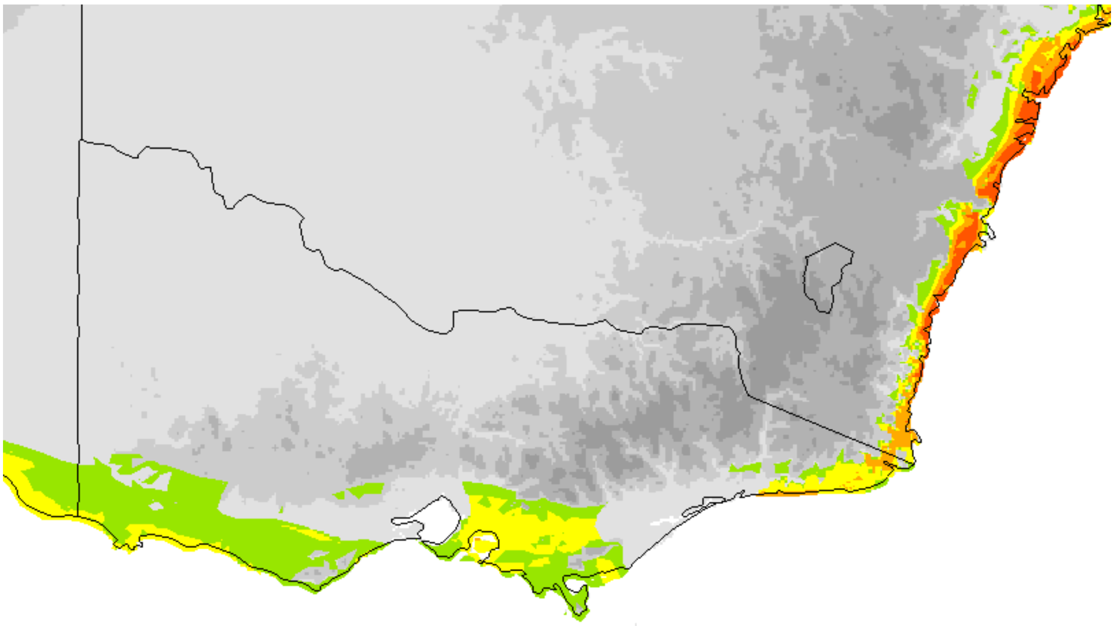
Figure 8b. ***Asparagus aethiopicus*** A1 scenario (mid)



Baseline climate

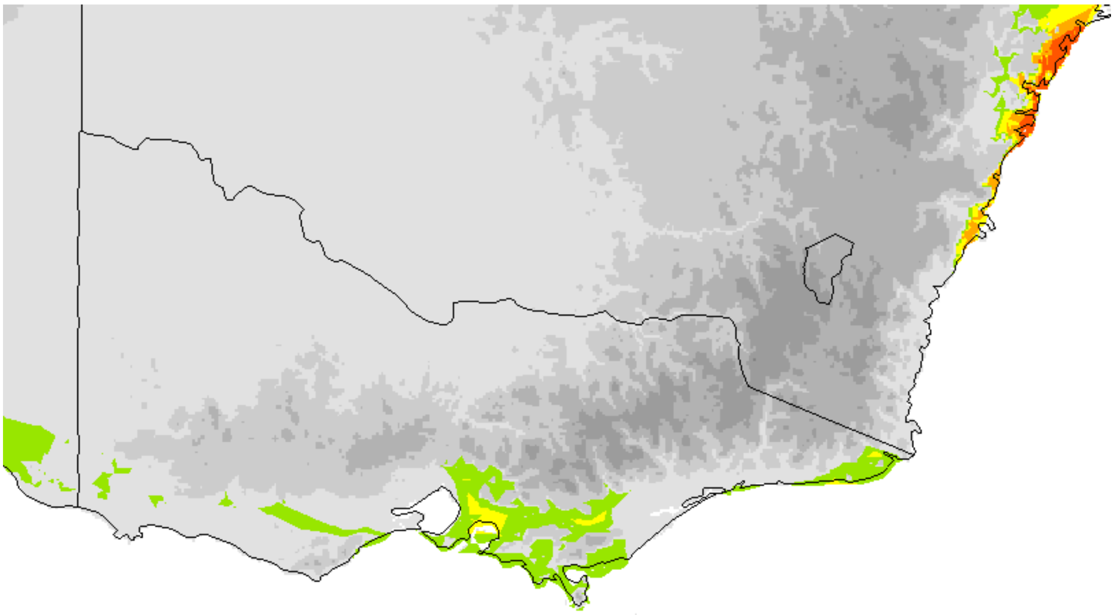


2030

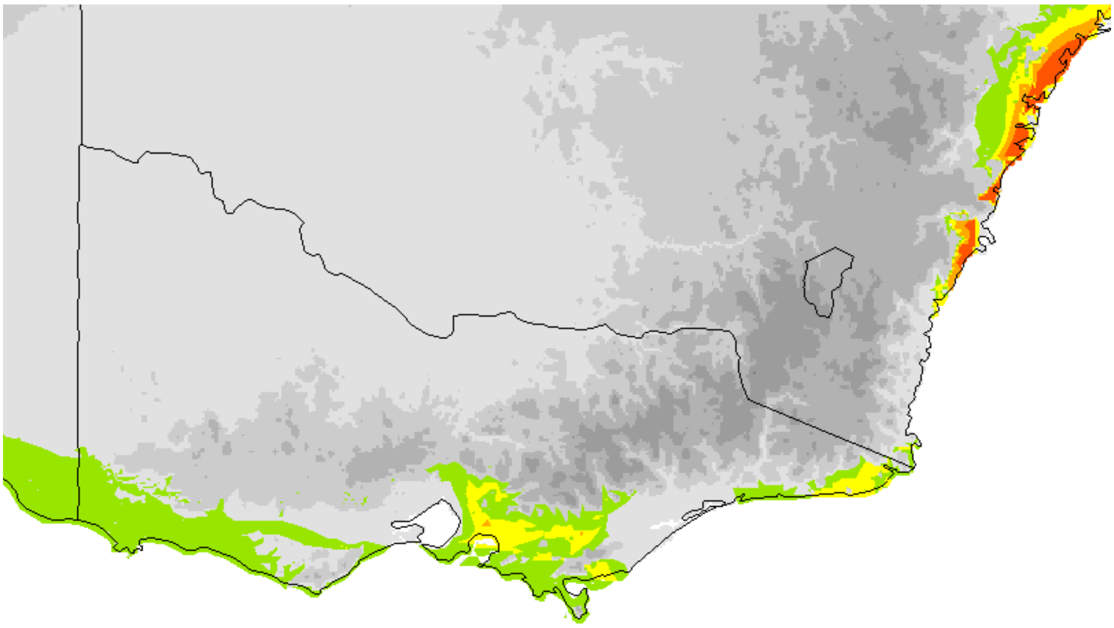


2070

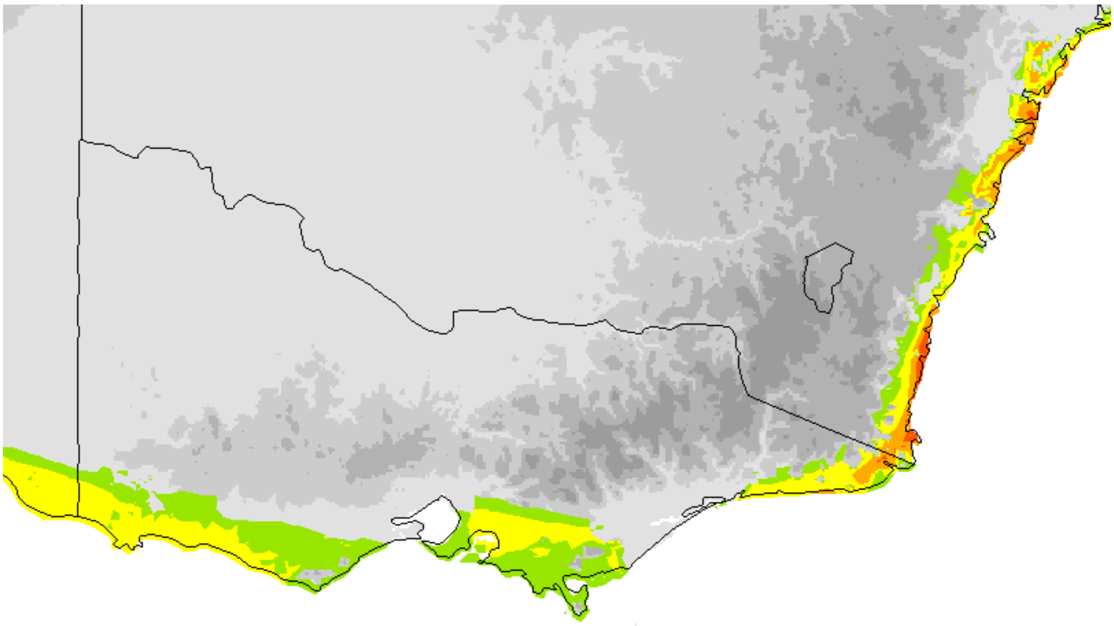
Figure 8c. *Asparagus aethiopicus* A1F scenario (high)



Baseline climate



2030



2070

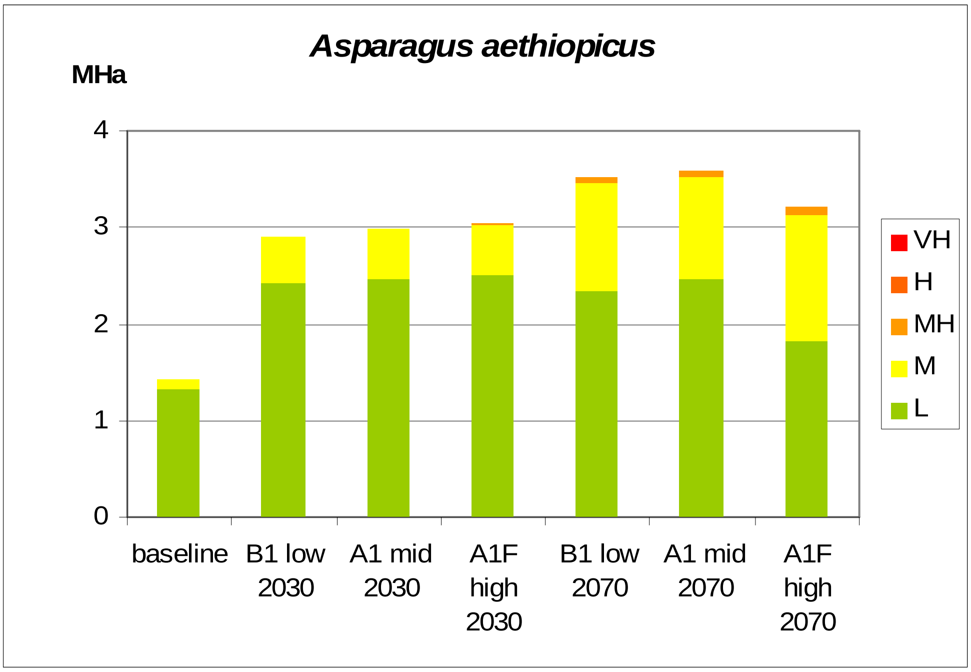


Figure 9. Area occupied by the climate envelope for *Asparagus aethiopicus* under a range of climate scenarios over time

Results summary for *Asparagus aethiopicus*

The general trend for the climate envelope of this species is an increase in the size of the climate envelope over time as the climate changes. There was also a shift in climate suitability, with parts of the state showing moderately high suitability at 2030 under all climate change scenarios, with a high climate match appearing under the A1F high (+5.8^{o}C) scenario at 2070. This species has the potential to spread further under climate change than under prevailing (baseline) climatic conditions.

B1 (low)

2030

The main increase in the climate envelope occurred as a result of an expansion towards the coast in the south west of the state. The moderately high suitable climate match appeared to the east of Melbourne, around the Pakenham area.

2070

There was a general expansion of the climate envelope to the south, but also noticeable to the north, associated with areas of higher altitude. The climate match near the coast also became stronger.

A1 scenario (mid)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

There was little difference between this scenario at 2070 and the changes observed under the B1 low scenario.

A1F scenario (high)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

The climate envelope expanded in a similar way as occurred under the other scenarios at 2070; however the area did not increase as much. In the south-western part of the state, the climate match was stronger under this scenario at 2070 than any other scenario; however the climate match between Port Phillip Bay and Sale appeared weaker. An area of high climate match appeared at the eastern tip of the state.

Bidens pilosa L.

cobbler's pegs

B. pilosa is a summer annual (Gurvich *et al.* 2004) or short-lived herb (Smith 1985; Holm *et al.* 1977). It originated in tropical America and has spread to the warm regions of the world, where it grows most actively in the warmer and wetter parts of the season (Holm *et al.* 1977). It is abundant where temps range 15-25^{o}C (Santra *et al.* 1981), with optimal temperatures for germination between 20-35^{o}C (Reddy & Singh 1992). It can withstand temperatures to -15^{o}C (Holm *et al.* 1977), and its distribution is limited by temperatures above 45^{o}C.

B. pilosa tolerates arid conditions (GCW 2001) and survives all but the most extreme drought (Labrada 2001), but osmotic stress decreases germination (Reddy & Singh 1992).

It is a weed of field and plantation crops (Holm *et al.* 1977). It has become established in all mainland states in Australia (Richardson & Richardson 2006).

The parameters chosen to model this species were 10, 18 & 33.

The baseline climate match for this species (Fig. 10) matched the current distribution particularly well in the eastern states with the highest climate match reflecting large numbers of infestations there. There was a lesser fit in NT and WA, where many data points weren't captured. Generally the climate match was good, with more than 90% of the current distribution locations captured by the climate envelope.

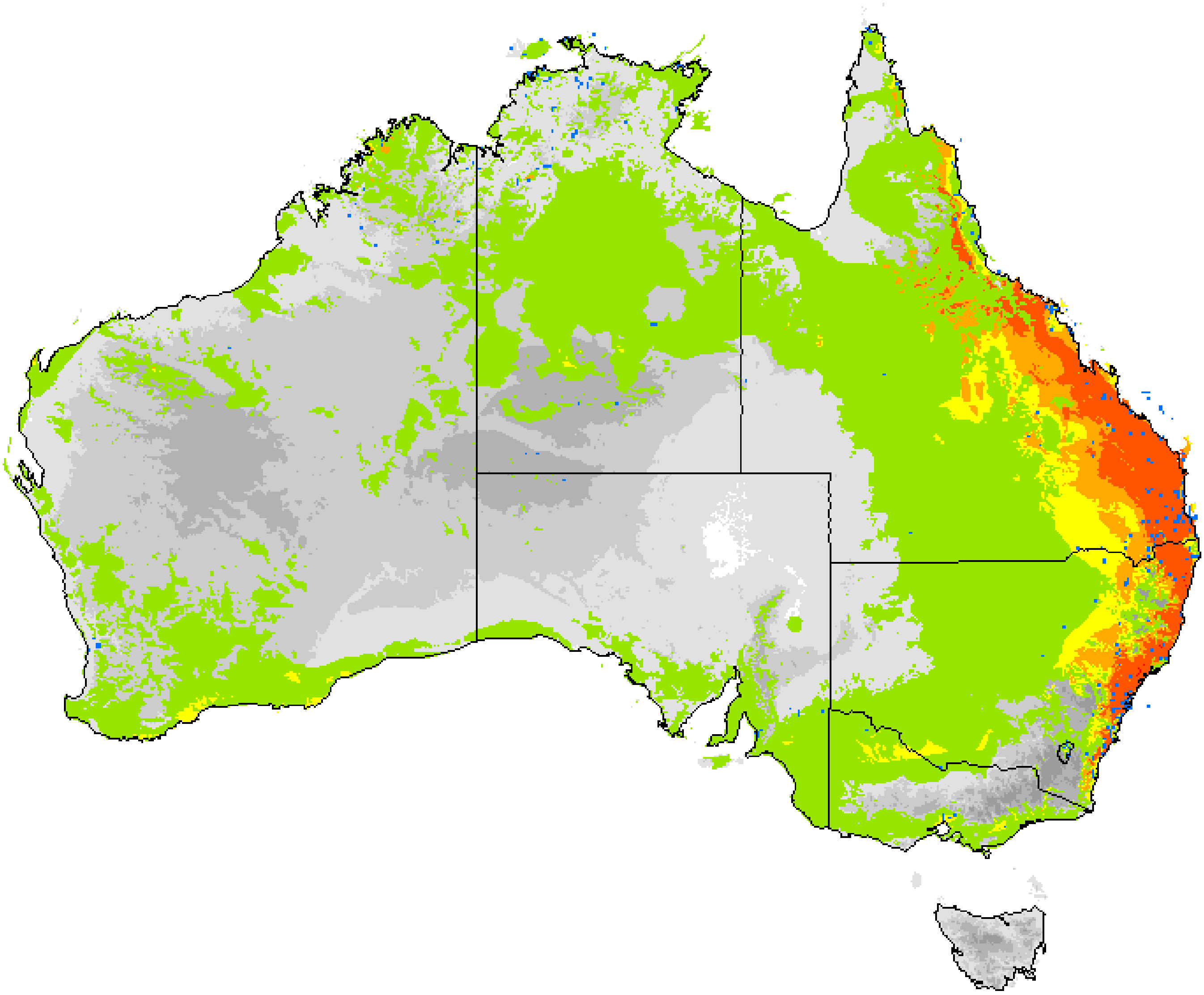
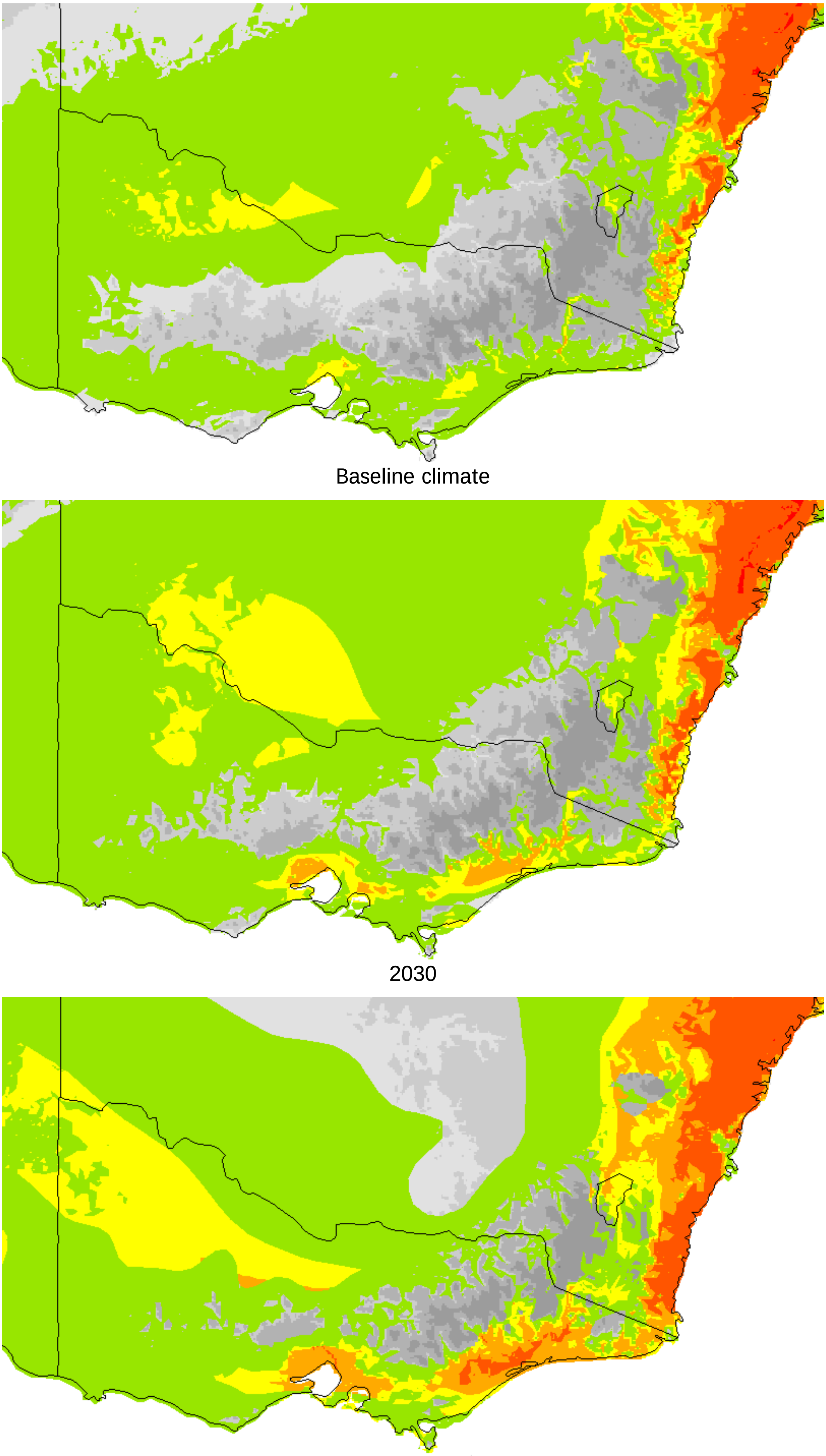


Figure 10. Comparison of current distribution with the baseline climate match

Figure 11a. *Bidens pilosa* B1 scenario (low)

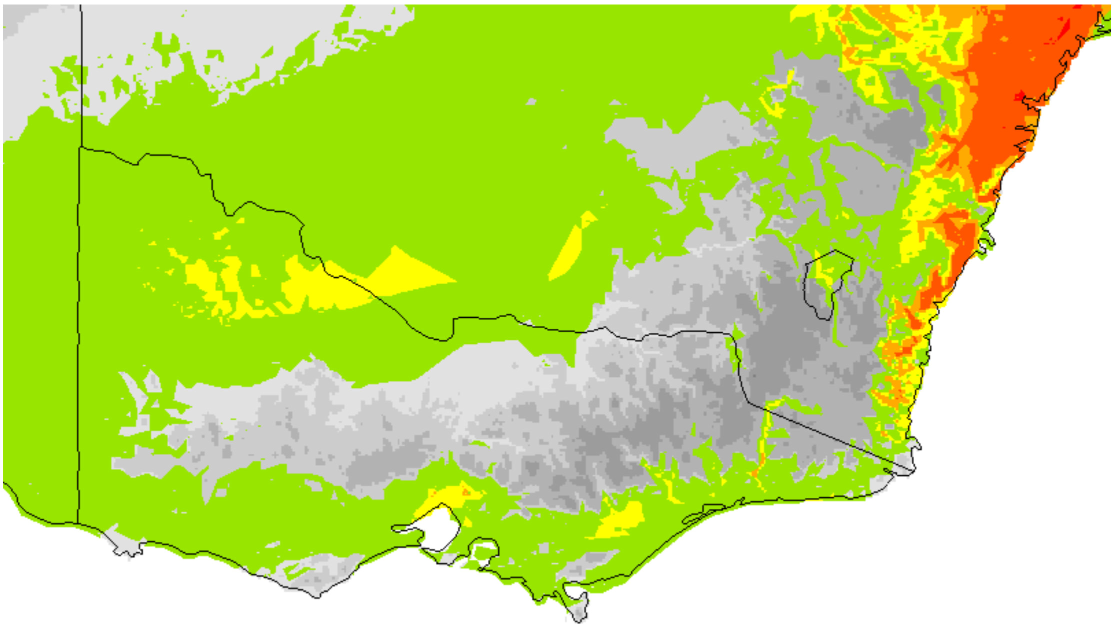


Baseline climate

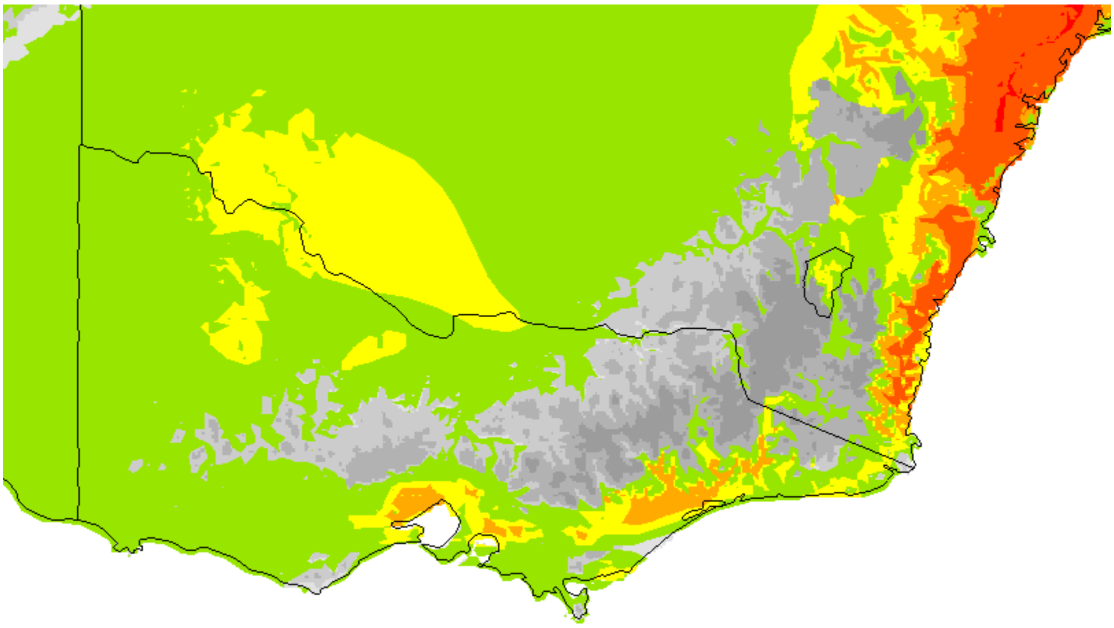
2030

2070

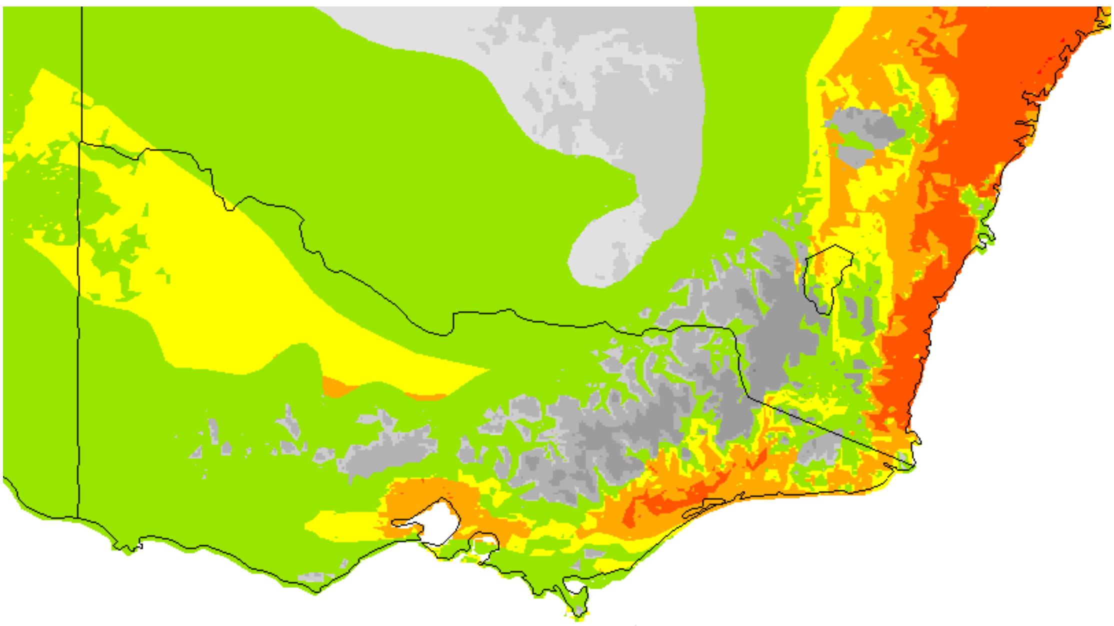
Figure 11b. *Bidens pilosa* A1 scenario (mid)



Baseline climate

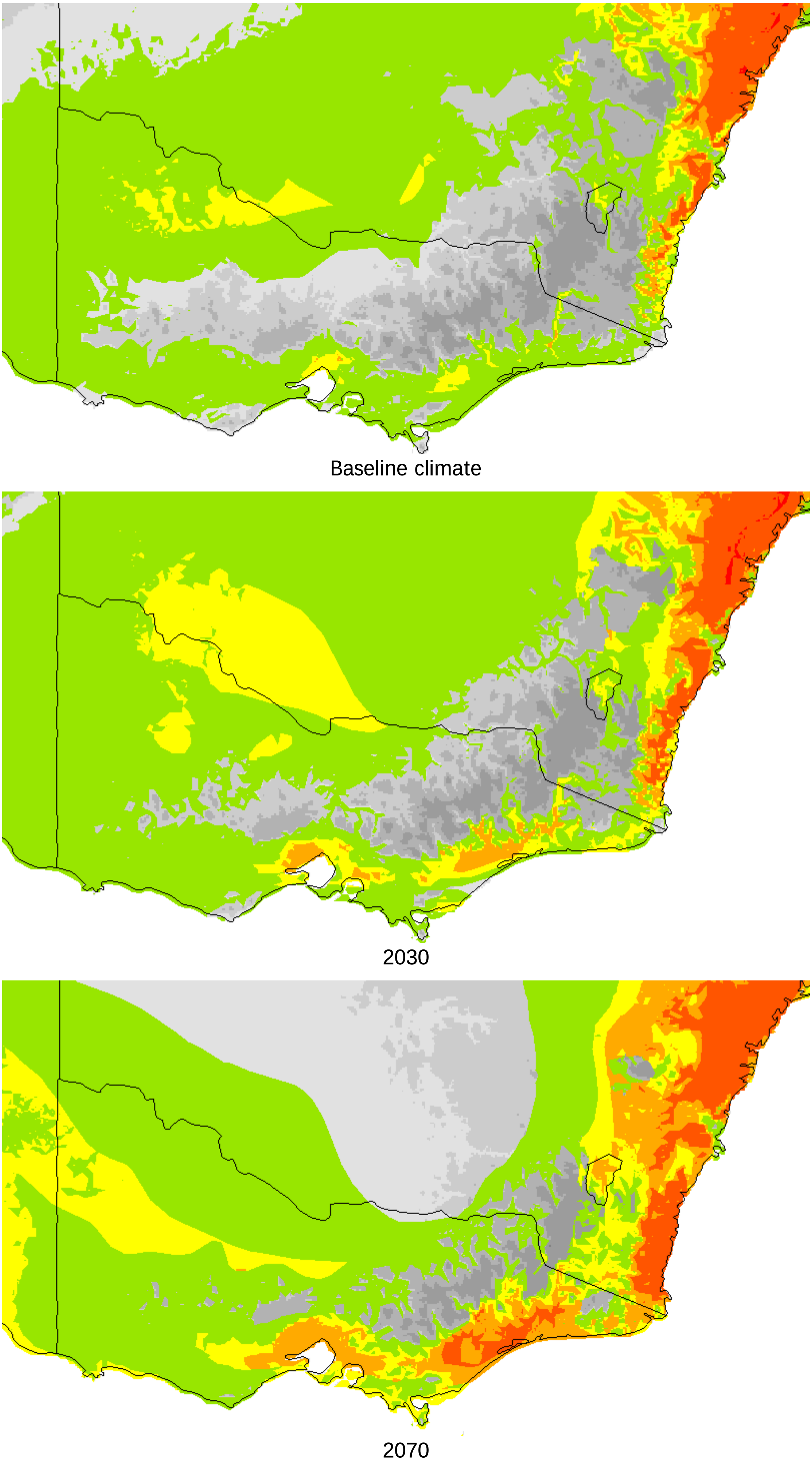


2030



2070

Figure 11c. ***Bidens pilosa*** A1F scenario (high)



Baseline climate

2030

2070

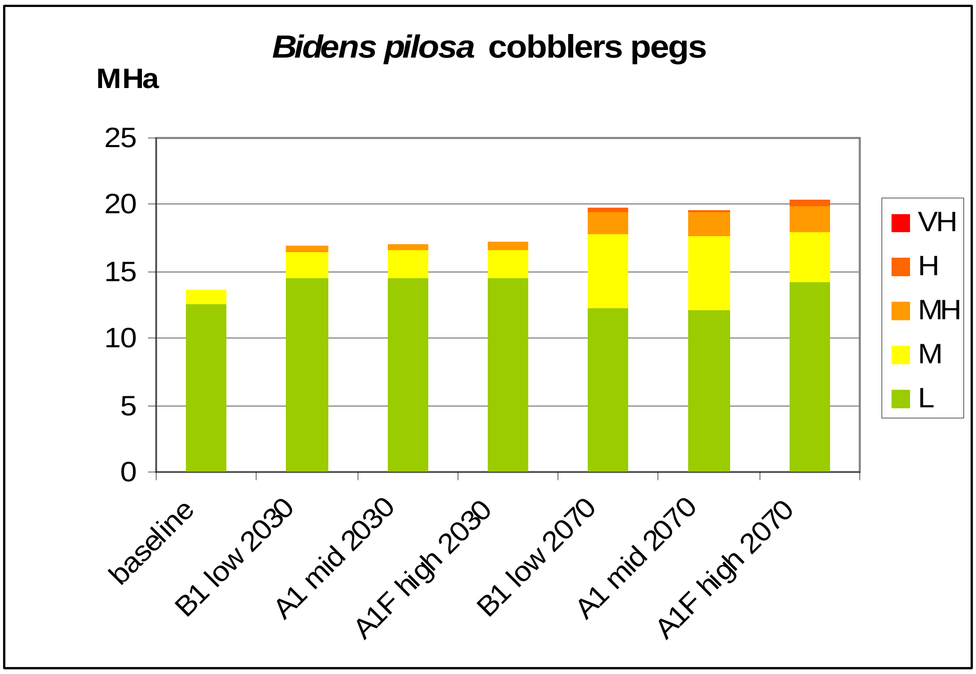


Figure 12. Area occupied by the climate envelope for *Bidens pilosa* under a range of climate scenarios over time

Results summary for *Bidens pilosa*

There was a general increase of climatic conditions likely to be suitable for *Bidens pilosa* over time under each climate change scenario. The degree of climatic suitability also increased, with larger areas of both moderate and moderately high climate suitability appearing at 2030 and high climatic suitability appearing at 2070 in all scenarios.

B1 (low)

2030

The climate envelope expanded to the south to occupy a greater area of north western Victoria. In the south of the state, the central and eastern parts of the climate envelope became more climatically suitable, with much larger areas of moderate climate match, and some moderately high climate appeared.

2070

The climate envelope expander further south to cover all of Victoria except for areas higher than 1000m above sea level. Climatic suitability increased over large areas, with a high climate match appearing in the West Gippsland region.

A1 scenario (mid)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

There was little difference between this scenario at 2070 and the changes observed under the B1 low scenario.

A1F scenario (high)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario, however the climate envelope was slightly larger.

2070

The climate envelope expanded in a similar way as observed under A1 mid, however it occupied a slightly larger area. There were also larger areas of high climate match in West Gippsland, when compared with the other scenarios at 2070. The degree of climate match in the north-west part of the state was noticeably decreased from the northern edge, when compared with the other scenarios at 2070.

Billardiera heterophylla Lindl. *sens. lat.*

blue-bell creeper

syn. *Sollya heterophylla*

B. heterophylla is a climber from Western Australia that now invades forest, woodland, grassland, scrub, thicket, heathland, and riparian and coastal communities where of south-eastern Australia (Carr et al 1992, White 2007)

Parameters previously used to model this species (White, in press) included effective rainfall (mean annual rainfall less mean annual evaporation); mean monthly minimum temperature for July; mean monthly maximum temperature for February and annual incident solar radiation.

White (in press) also found that the species occurs in moderate rainfall zones (450mm to 850mm mean annual rainfall) and that access to sufficient light and drought appear to limit the species at margins of its range.

The parameters chosen to model this species were 1, 6, 10, 21 & 31.

The baseline climate match for this species (Fig. 13) was fairly good with more than 95% of current distribution data points captured by the climate envelope.

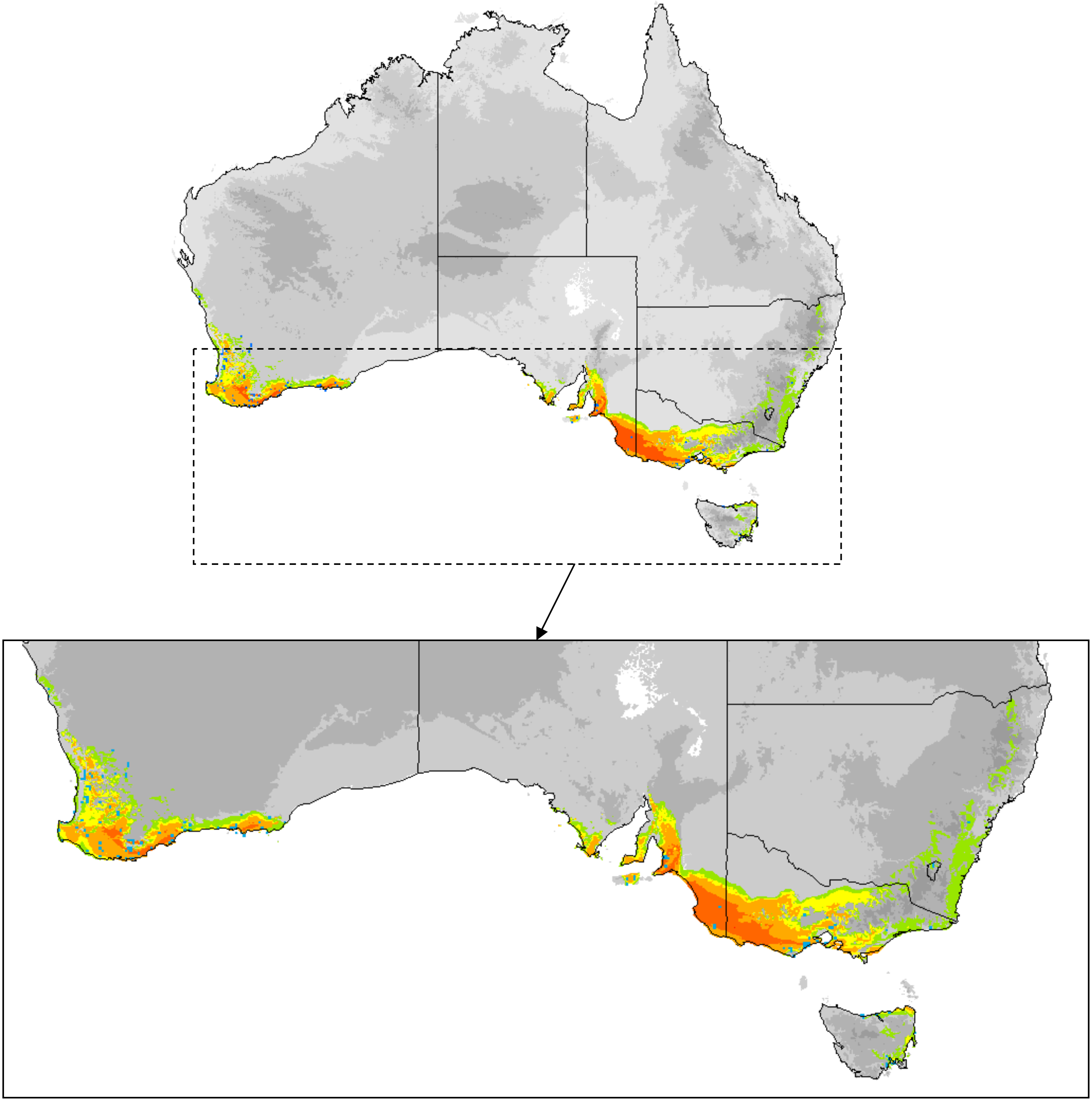
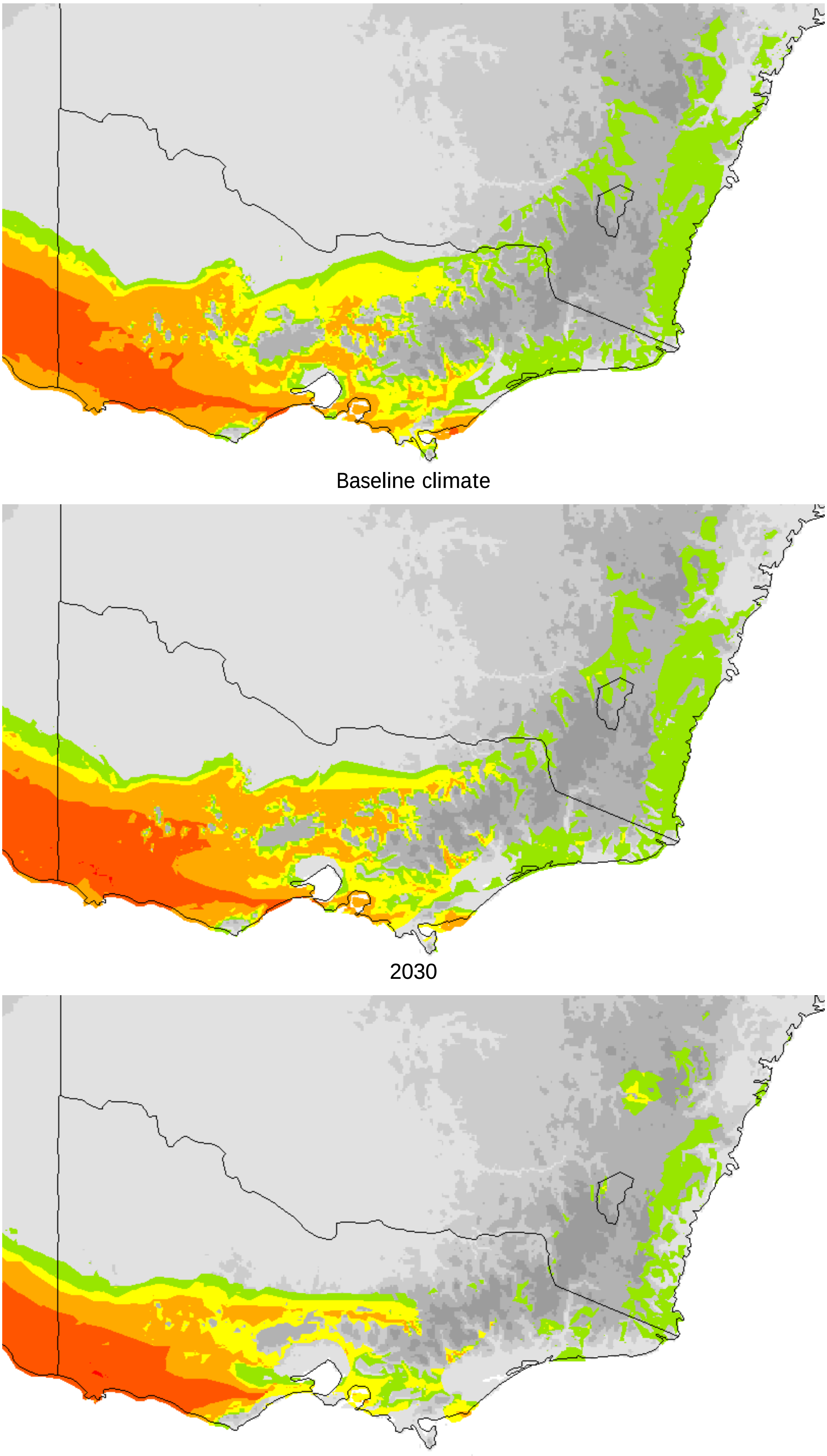


Figure 13. Comparison of current distribution with the baseline climate match

Figure 14a. *Billardiera heterophylla* B1 scenario (low)

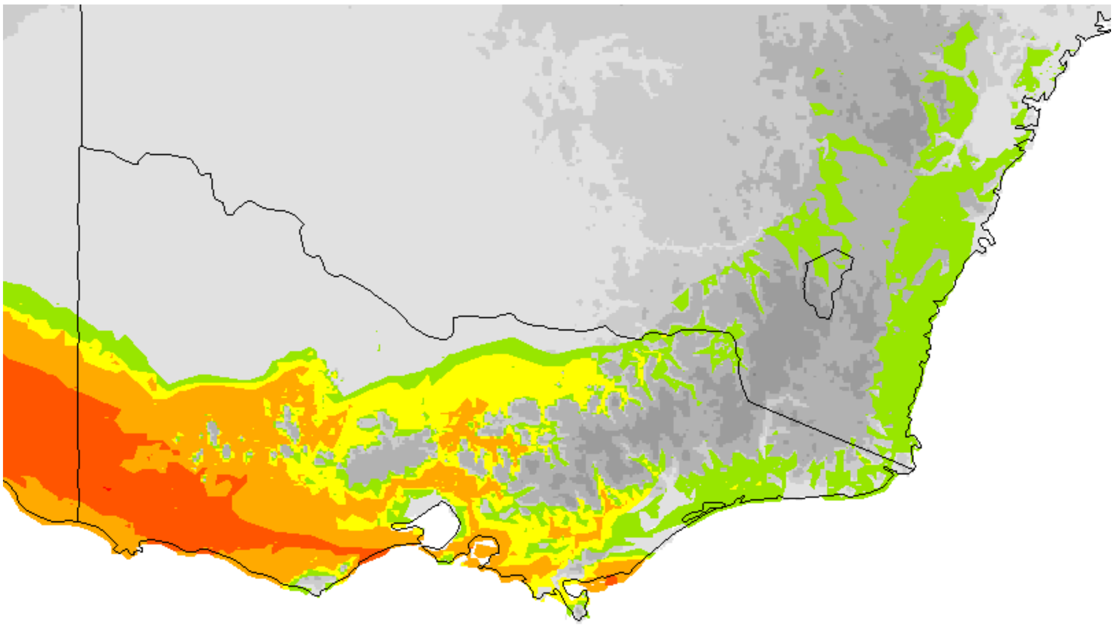


Baseline climate

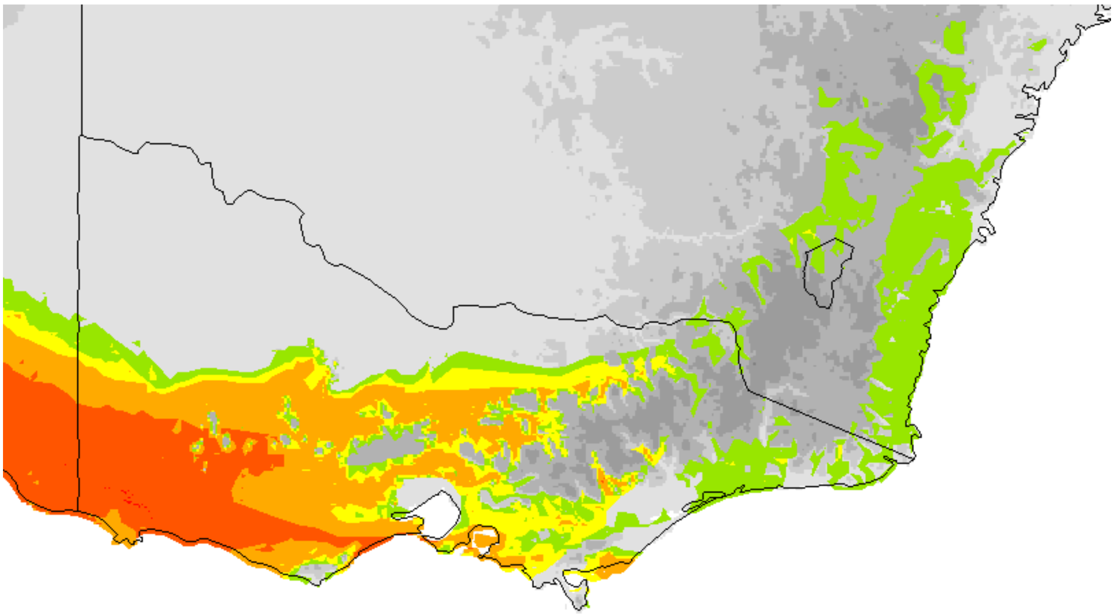
2030

2070

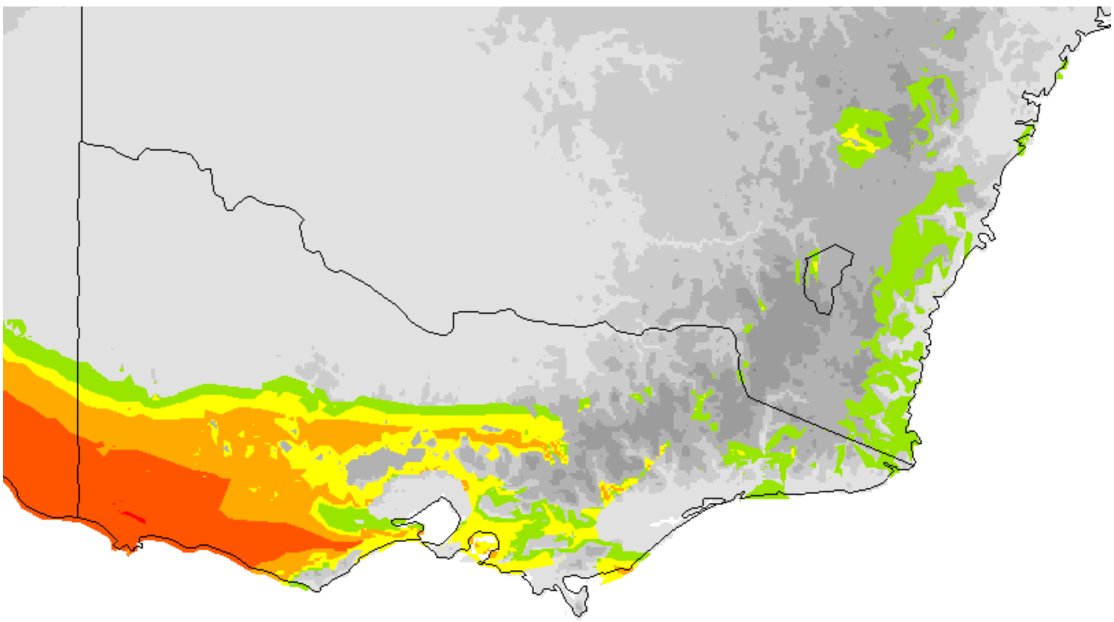
Figure 14b. *Billardiera heterophylla* A1 scenario (mid)



Baseline climate

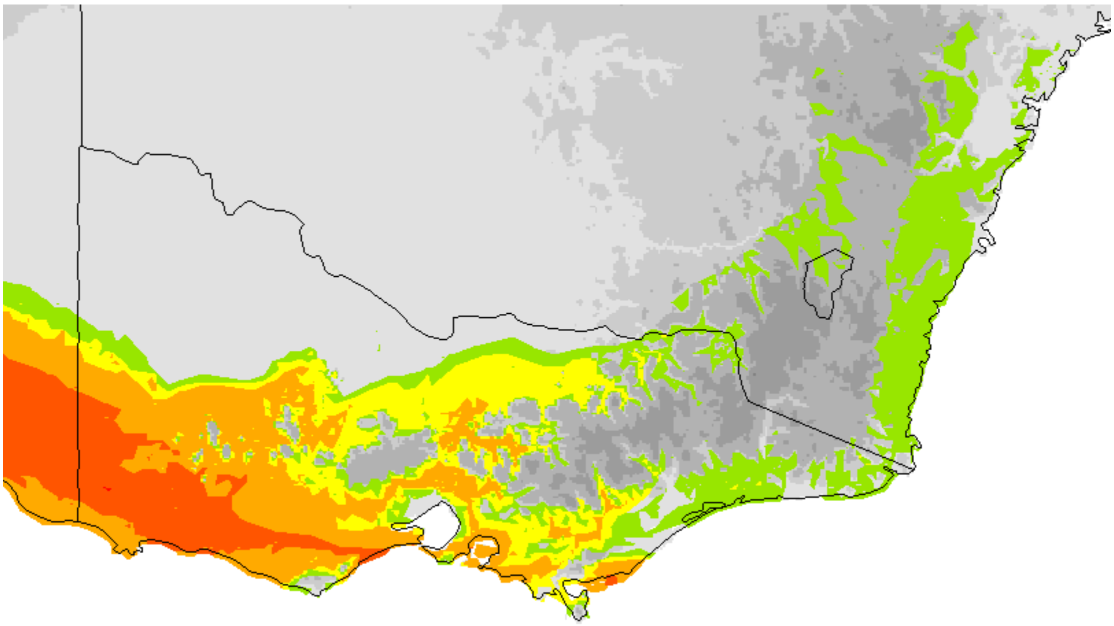


2030

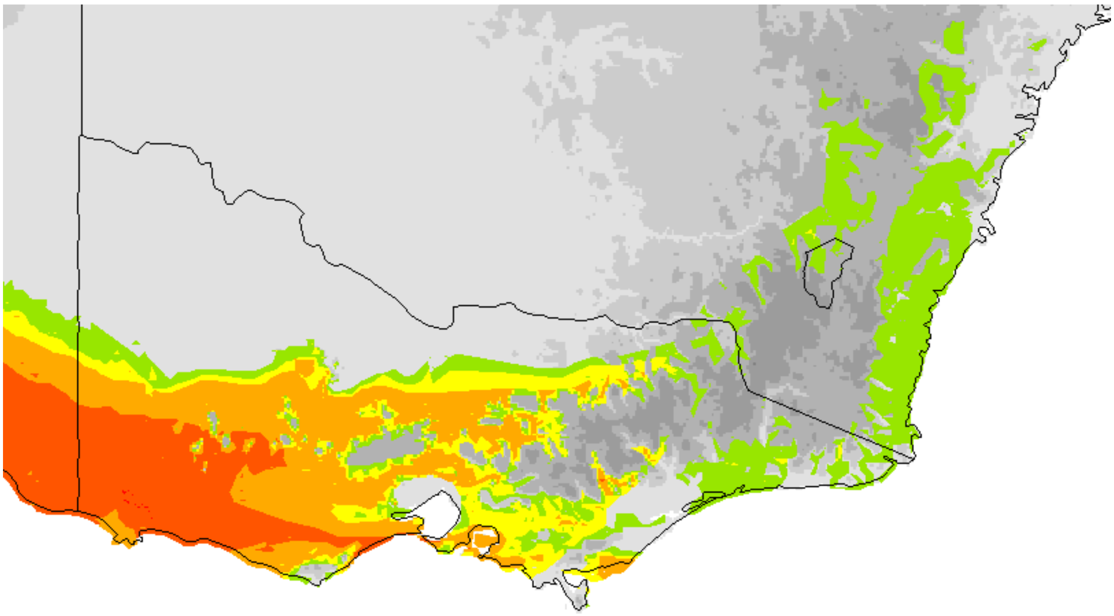


2070

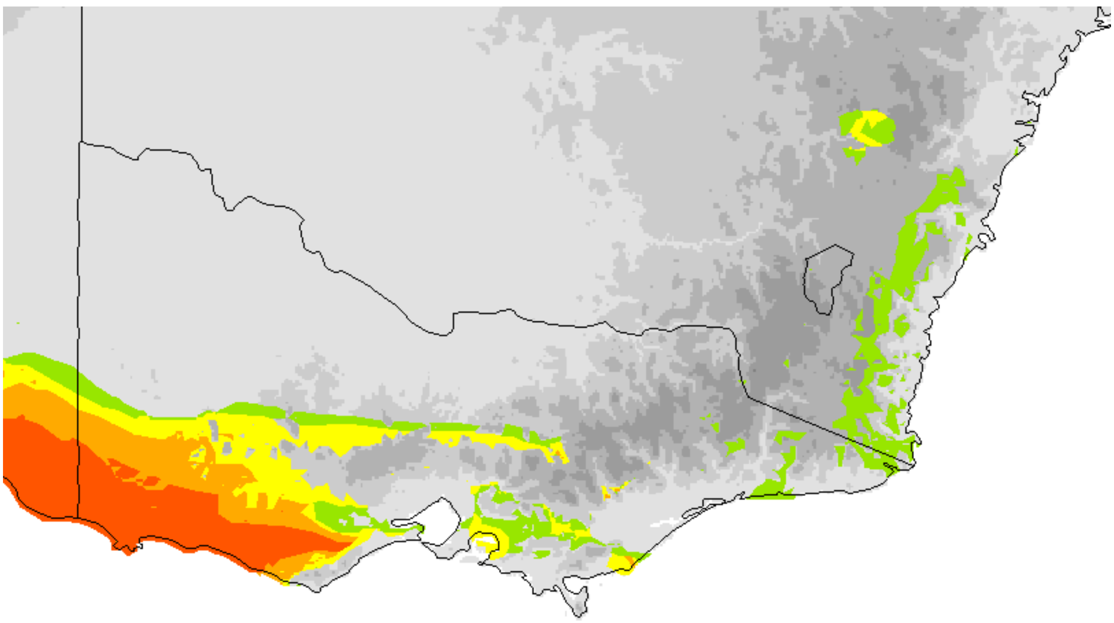
Figure 14c. *Billardiera heterophylla* A1F scenario (high)



Baseline climate



2030



2070

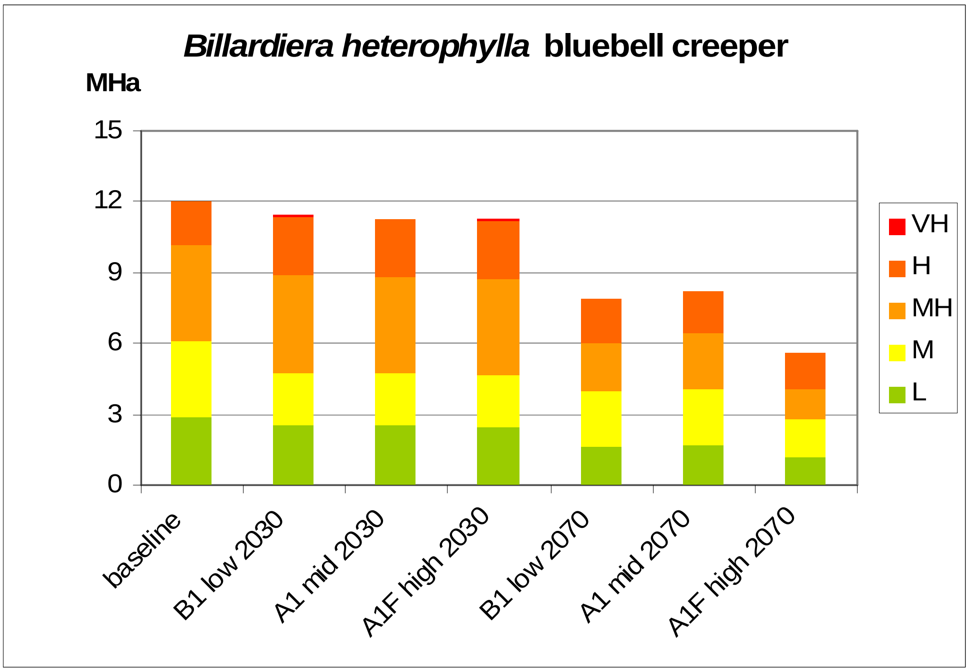


Figure 15. Area occupied by the climate envelope for *Billardiera heterophylla* under a range of climate scenarios over time

Results summary for *Billardiera heterophylla*

There was a general decline in suitable area of climate under all scenarios, most obviously in 2070, and particularly under the A1F high (+5.8^{o}C) scenario.

B1 (low)

2030

The climate envelope contracted slightly to the south but the high and very high climate matches increased in area, with more of south west Victoria appearing climatically suitable. There was some in-filling of the climate envelope, associated with climatically suitable areas appearing at higher altitudes.

2070

There was a further contraction of the climate envelope from the east and to the south, still leaving thousands of hectares of south west Victoria as highly to very highly climatically suitable.

A1 scenario (mid)

2030

Under this scenario the climate envelope showed a similar pattern to that under B1 low.

2070

Under this scenario the climate envelope showed a similar pattern to that under B1 low.

A1F scenario (high)

2030

Under this scenario the climate envelope showed a similar pattern to that under B1 low.

2070

Under this scenario, at 2070, the climate envelope was at its smallest area; less than half of the area as that under baseline conditions. The very high climate match also only disappeared under these climatic conditions. In the west of the state several areas at higher altitude became climatically suited to this species.

Cenchrus ciliaris

buffel grass

Cenchrus ciliaris is native to tropical and subtropical Africa, Asia and Indonesia. It is used for cattle fodder and was planted for erosion control but also invades native vegetation (CSIRO nd) and has naturalised in Qld, NSW, SA, WA & NT (Richardson & Richardson 2007).

It is drought resistant, but not tolerant of flooding or waterlogging (CSIRO nd) and is recommended for areas receiving a minimum average annual rainfall of 180 mm (McCormick & McGufficke 2004). It is mainly summer growing and tolerates frost (Partridge 2003), recovering with the onset of warmer weather (CSIRO nd).

The parameters chosen to model this species were 1, 23 & 25.

The baseline climate match for this species (Fig. 16) was very poor with no climate match appearing around the largest concentration of records in NT. It is possible that this taxon is two species (Hussey *et al*. 1997).

Cenchrus ciliaris

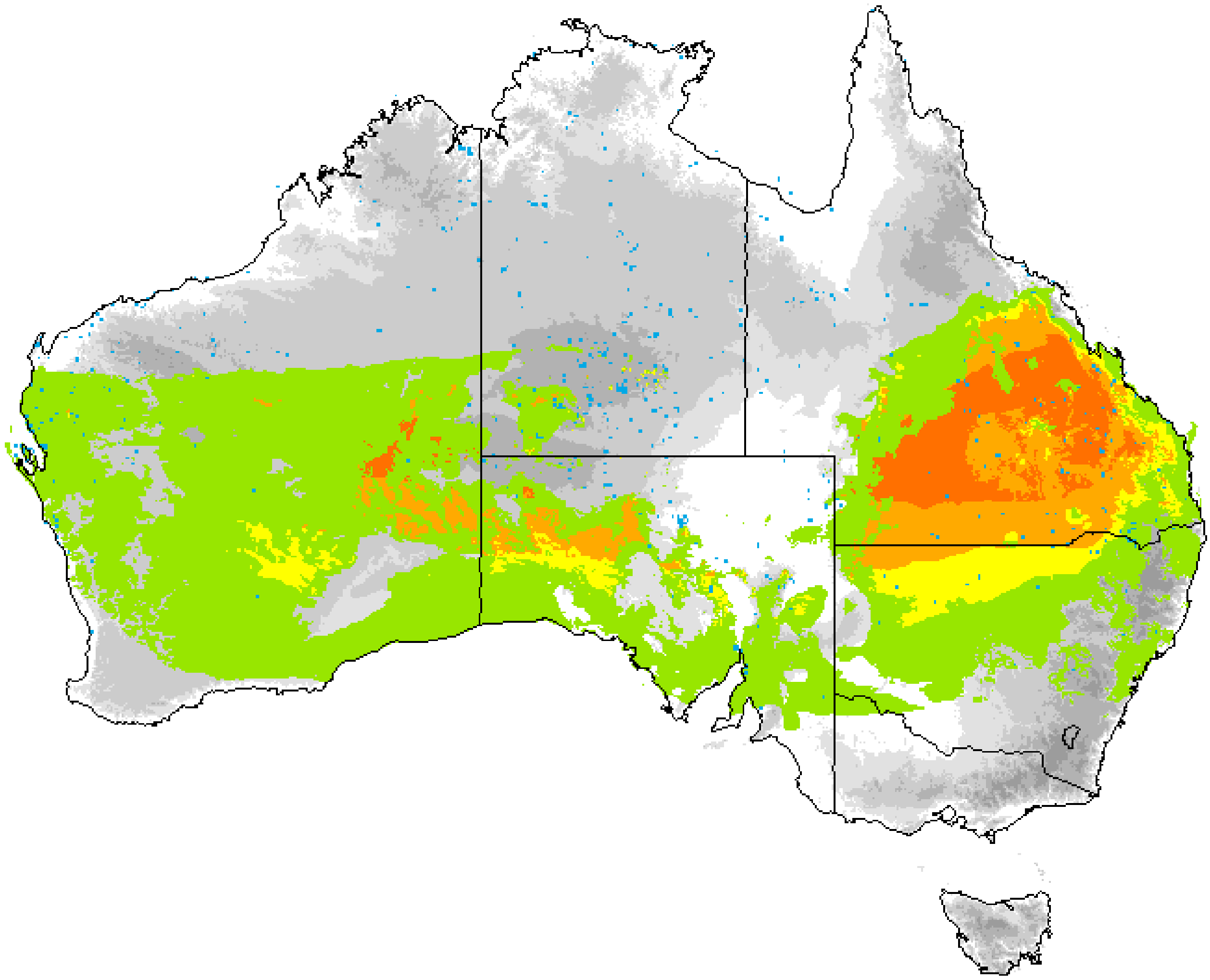


Figure 16. Comparison of current distribution with baseline climate match

Figure 17a. *Cenchrus ciliaris* B1 scenario (low)

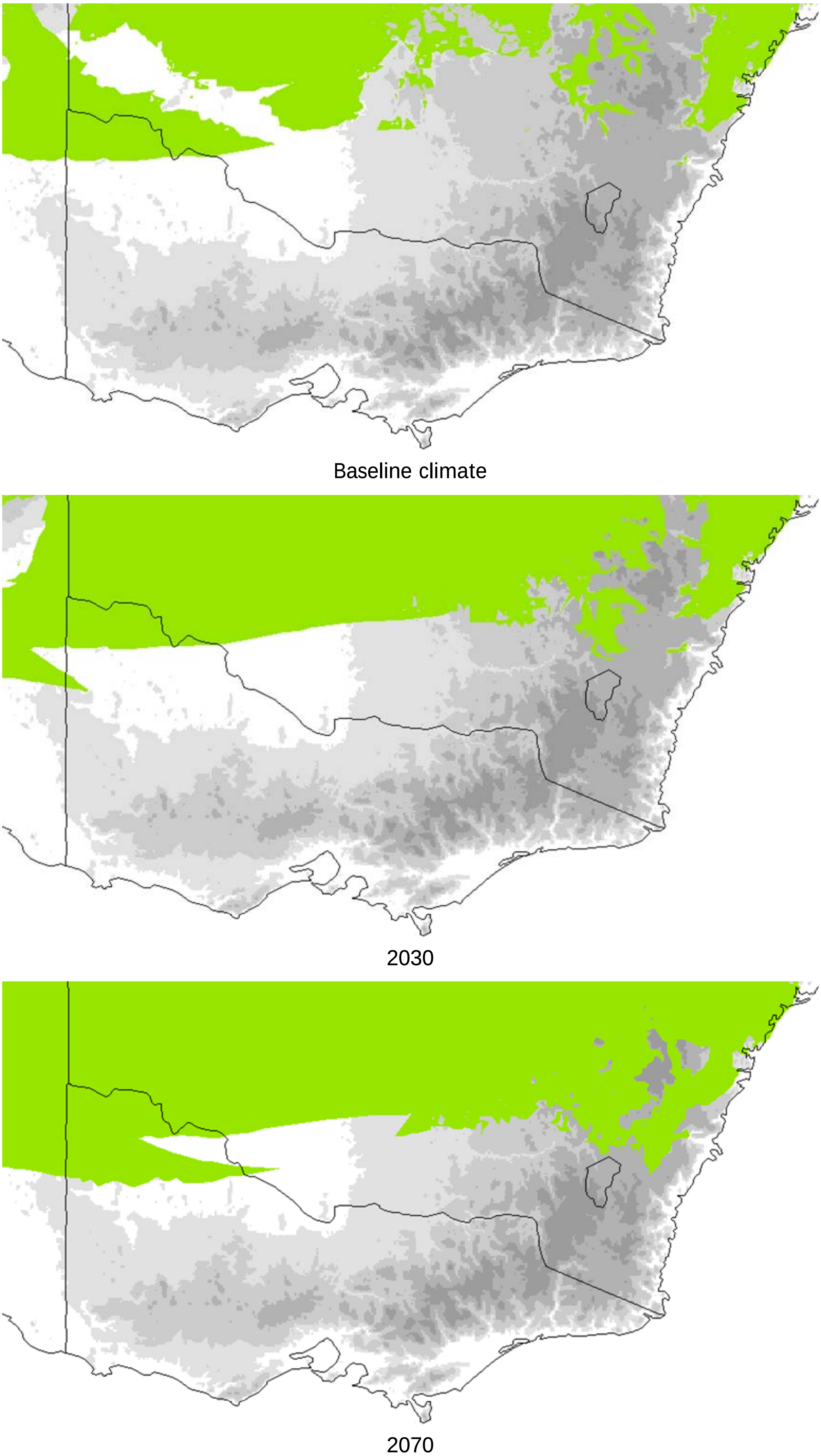
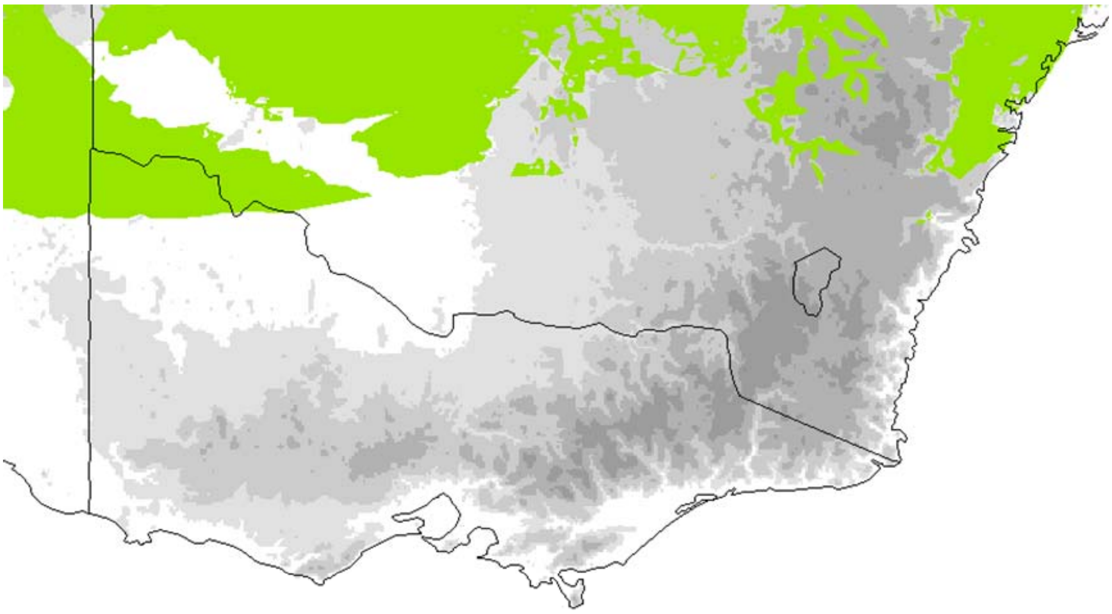
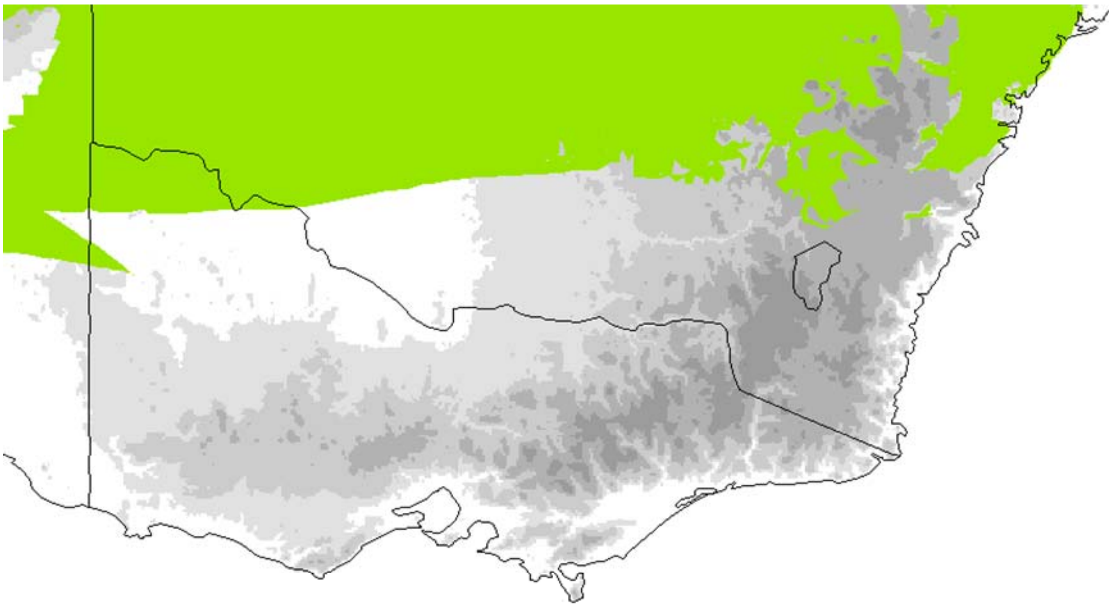


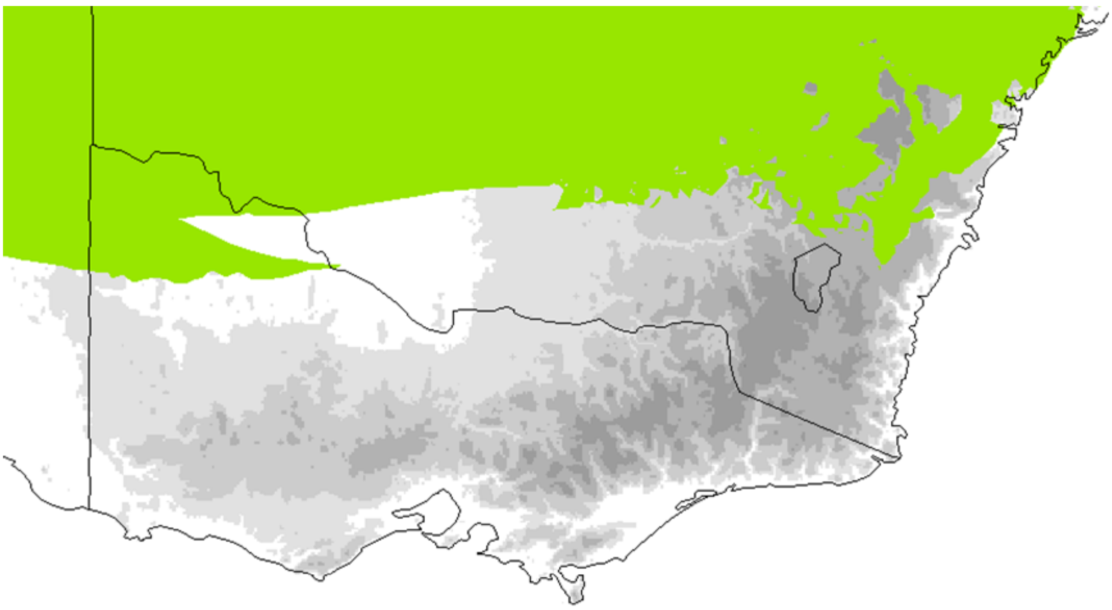
Figure 17b. *Cenchrus ciliaris* A1 scenario (mid)



Baseline climate

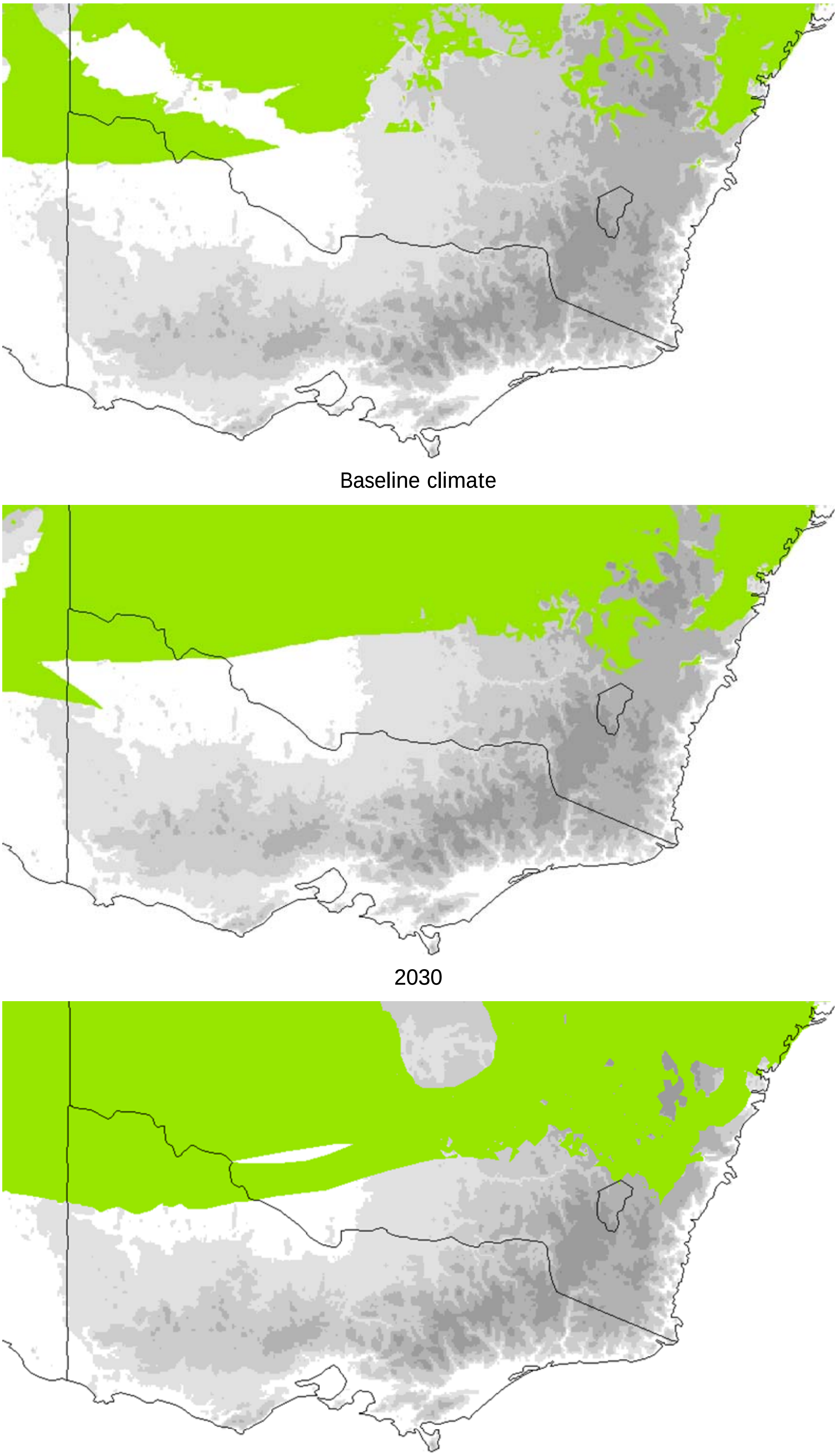


2030



2070

Figure 17c. *Cenchrus ciliaris* A1F scenario (high)



Baseline climate

2030

2070

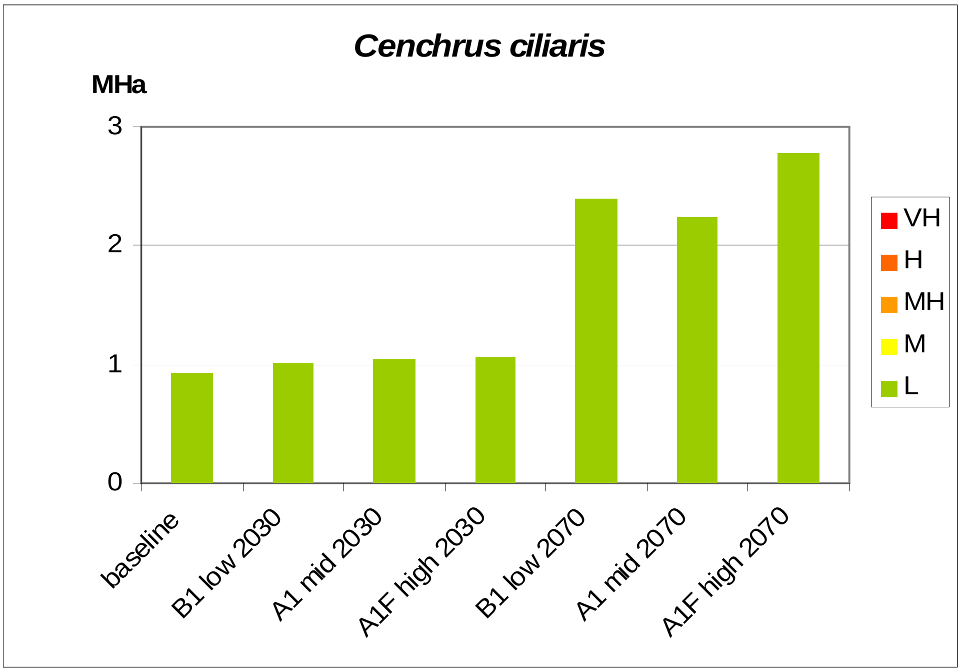


Figure 18. Area occupied by the climate envelope for *Cenchrus ciliaris* under a range of climate scenarios over time

Results summary for *Cenchrus ciliaris*

Whilst the climate envelope increased under climate change the poor baseline climate match reduced the usefulness of the following projections.

Global average surface warming +1.5°C

2030 for B1 low, A1 mid & A1F high

The climate envelope increased in size very slightly but there was very little difference in the potential distribution at 2030 when compared to baseline conditions under any scenario. The increase was slightly larger under each higher emission scenario than under B1 low.

2070 for B1 low, A1 mid & A1F high

The climate suitability remained at likely, but the size of the envelope was more than double the baseline area under B1 low and A1 mid, and more than three times the size under A1F high.

Cotoneaster glaucophyllus Franch.

large-leaf cotoneaster

This species, originally from China, has become a weed in NZ, USA and, in Australia: ACT, NSW, TAs, Vic and WA (Blood 2001).

It occurs as a weed in wasteland, scrub, gullies and gardens (Webb *et al.* 1988) and can invade heathland; heathy and dry woodland; lowland grassland; grassy woodland; dry, damp and wet sclerophyll forest; rock outcrop and riparian vegetation; and freshwater wetland (seasonal) (Carr *et al.* 1992) .

Cotoneaster glaucophyllus is tolerant of frost, cold or hot weather, and seasonally dry conditions (Muyt 2001).

The parameters chosen to model this species were 7, 10, 22, 28 & 31.

IN the baseline climate match (Fig. 19) outlying points in SA, Tas and northern NSW were not captured by the climate envelope, but more than 99% of the points were still within its boundaries.

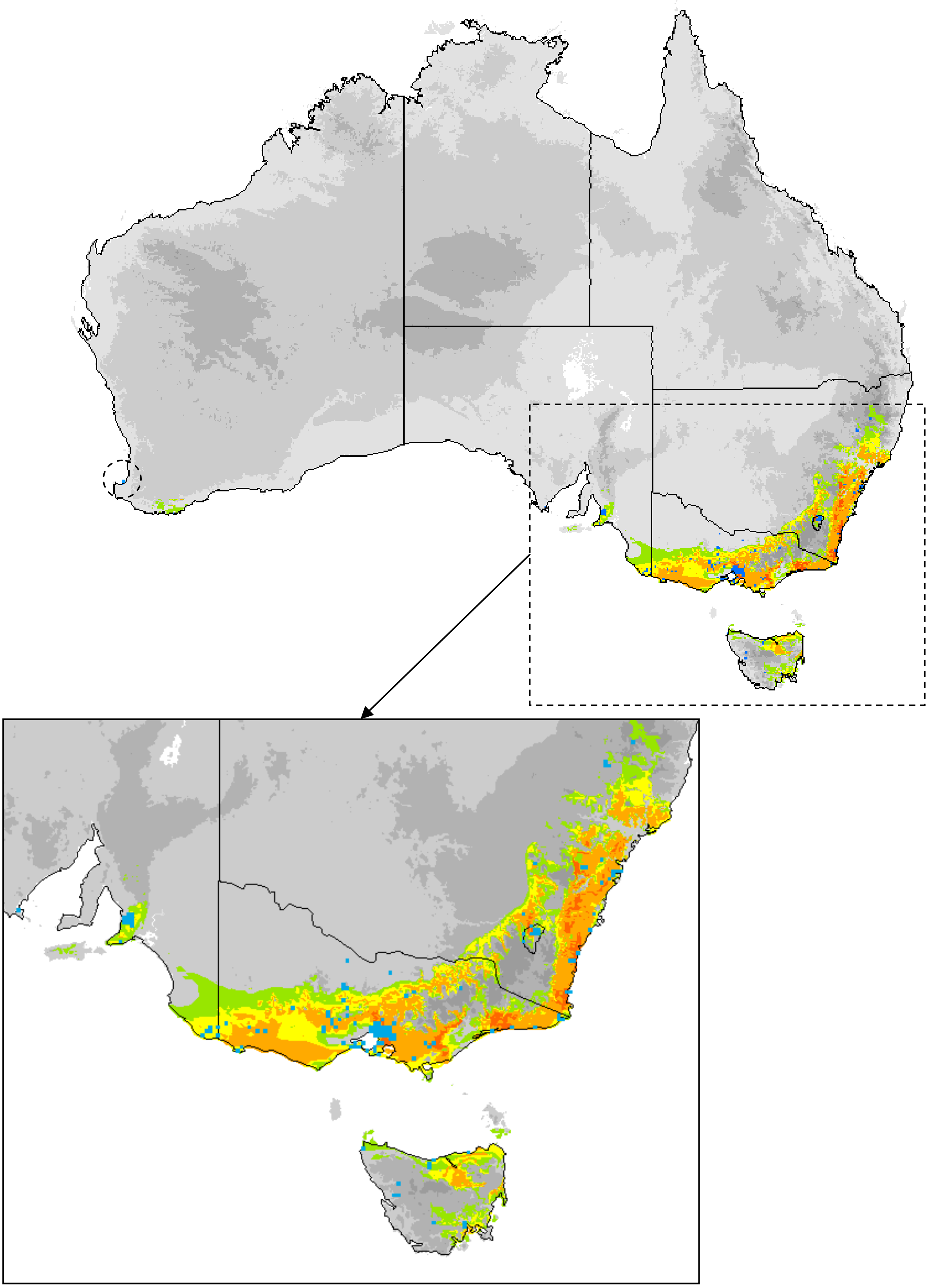
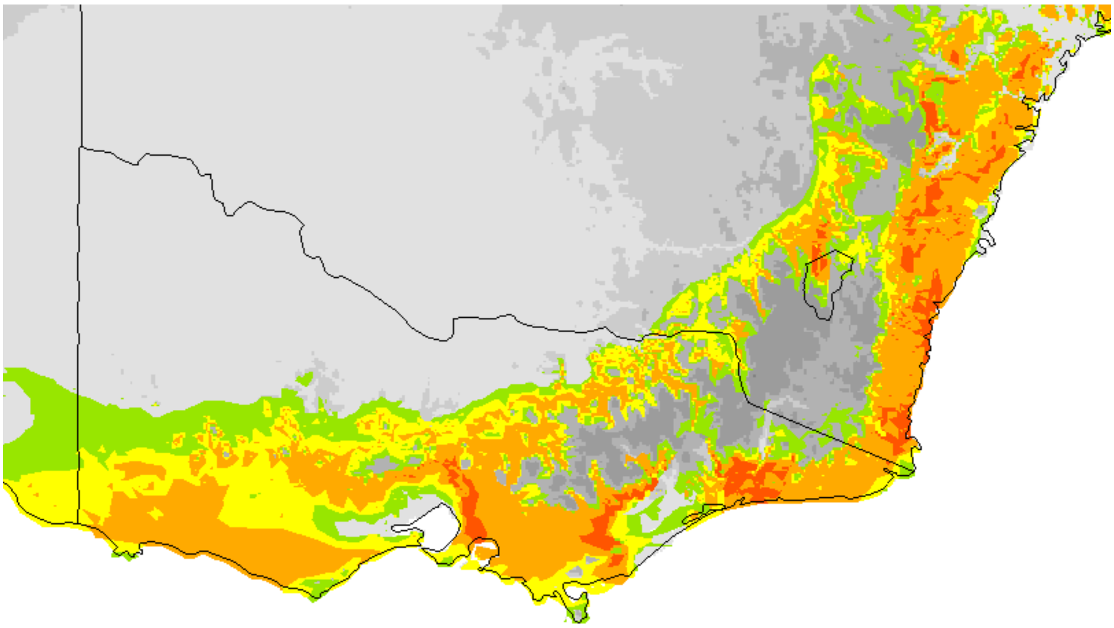
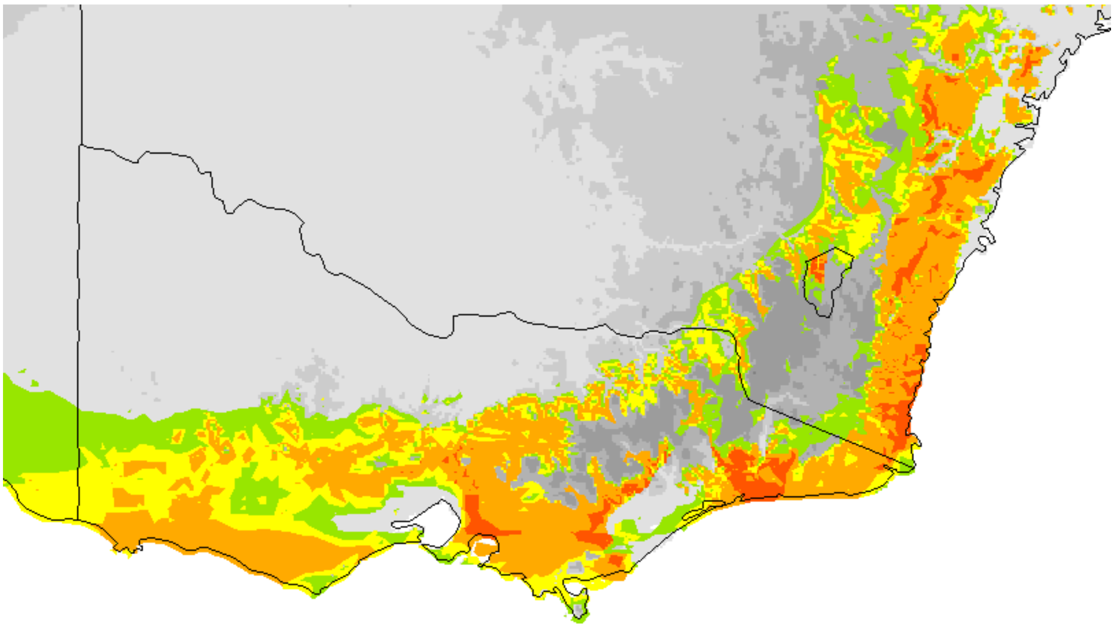


Figure 19. Comparison of current distribution with the baseline climate match

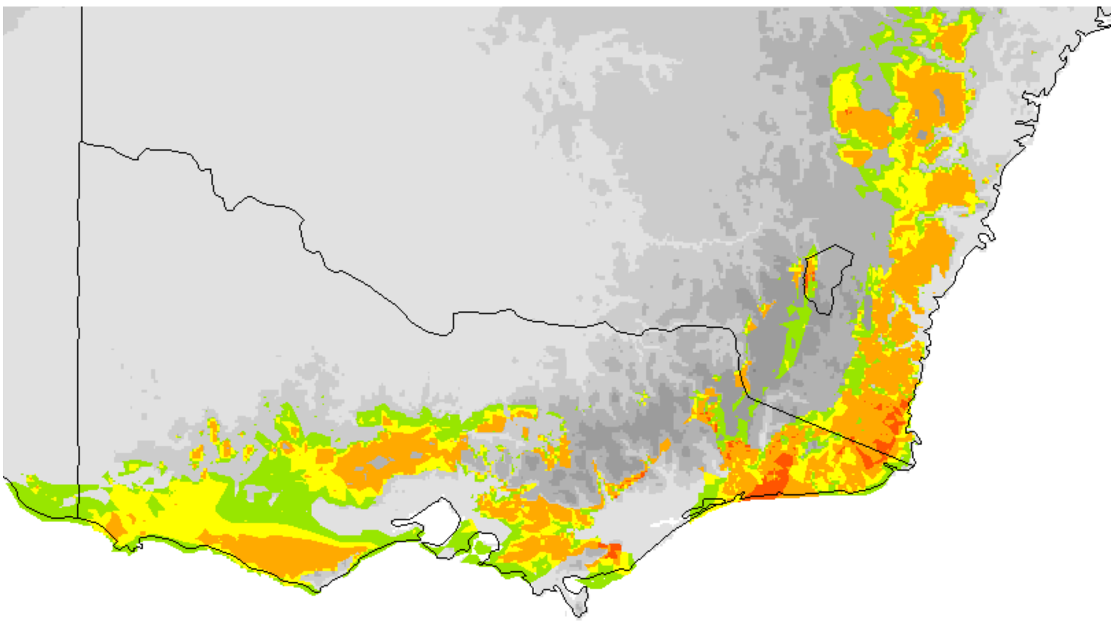
Figure 20a. ***Cotoneaster glaucophyllus*** B1 scenario (low)



Baseline climate

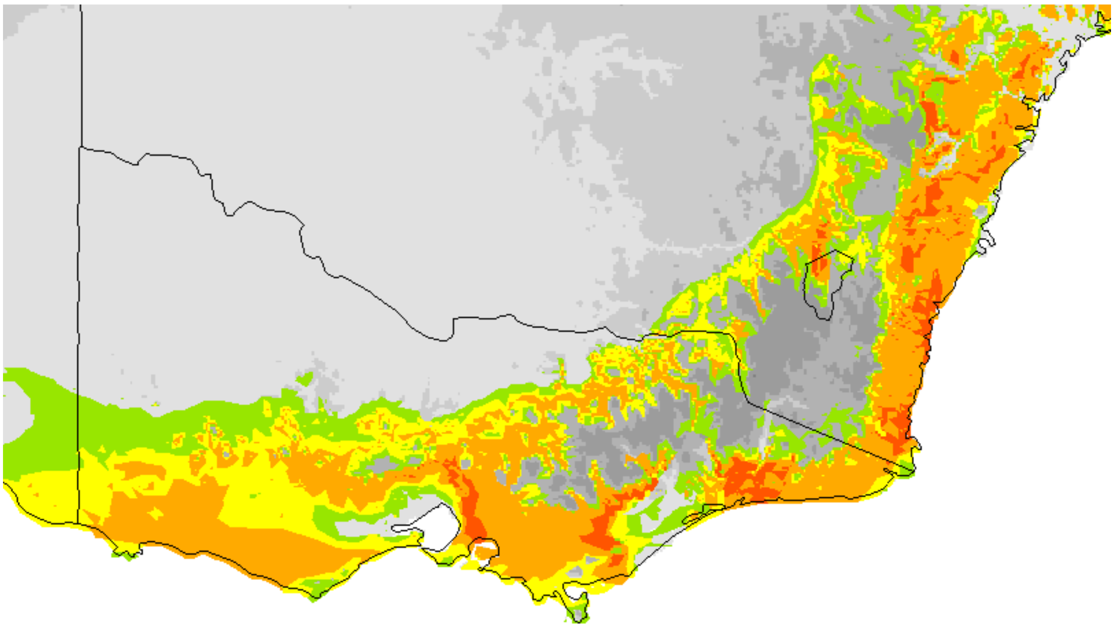


2030

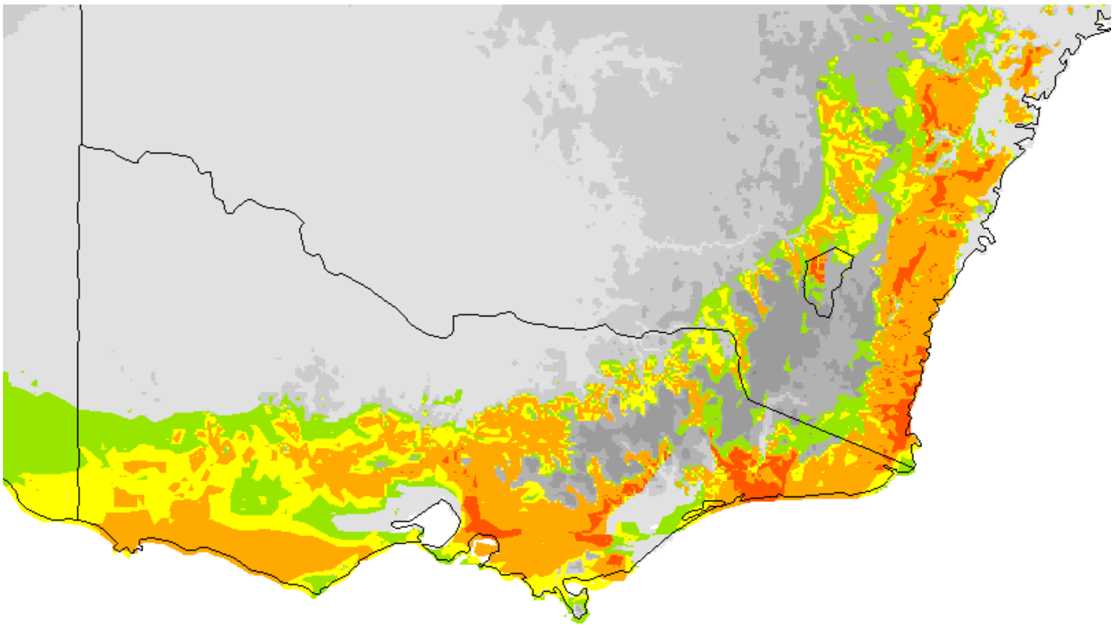


2070

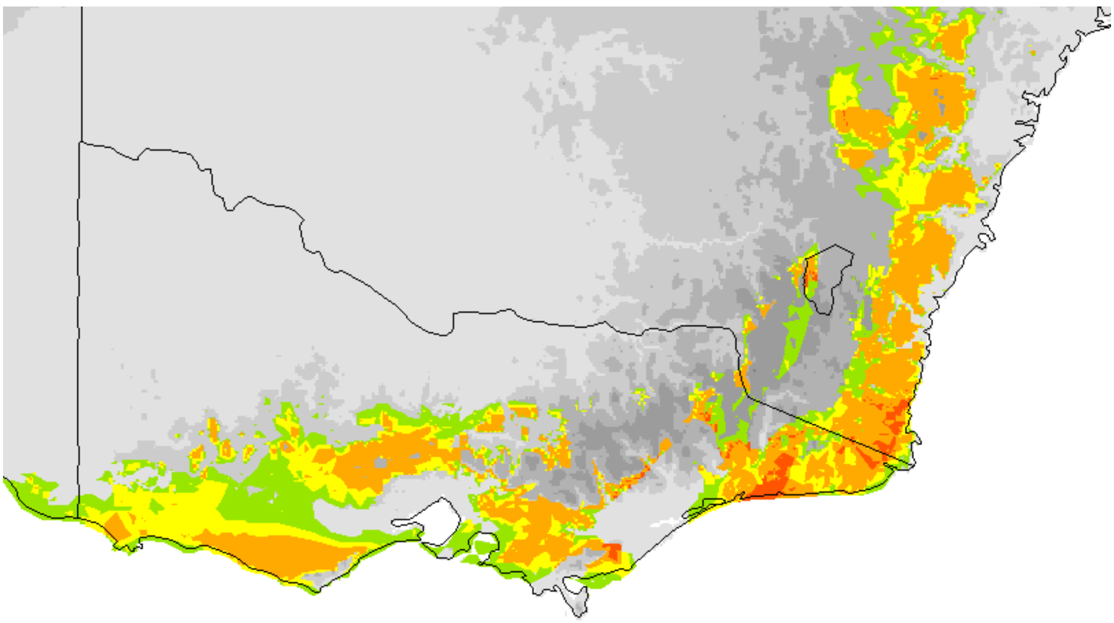
Figure 20b. *Cotoneaster glaucophyllus* A1 scenario (mid)



Baseline climate

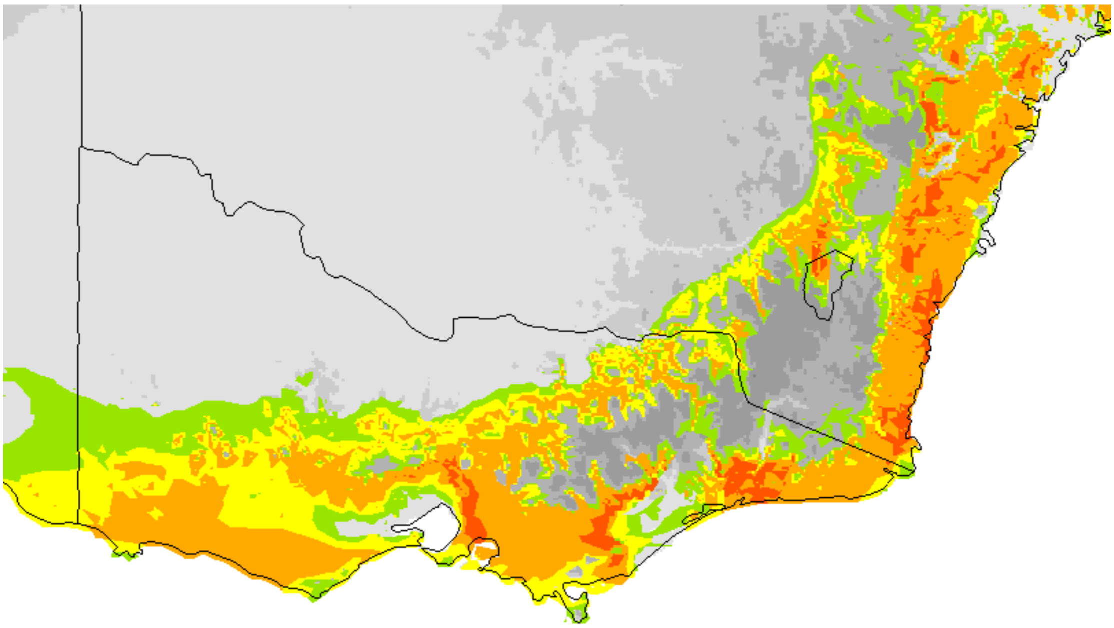


2030

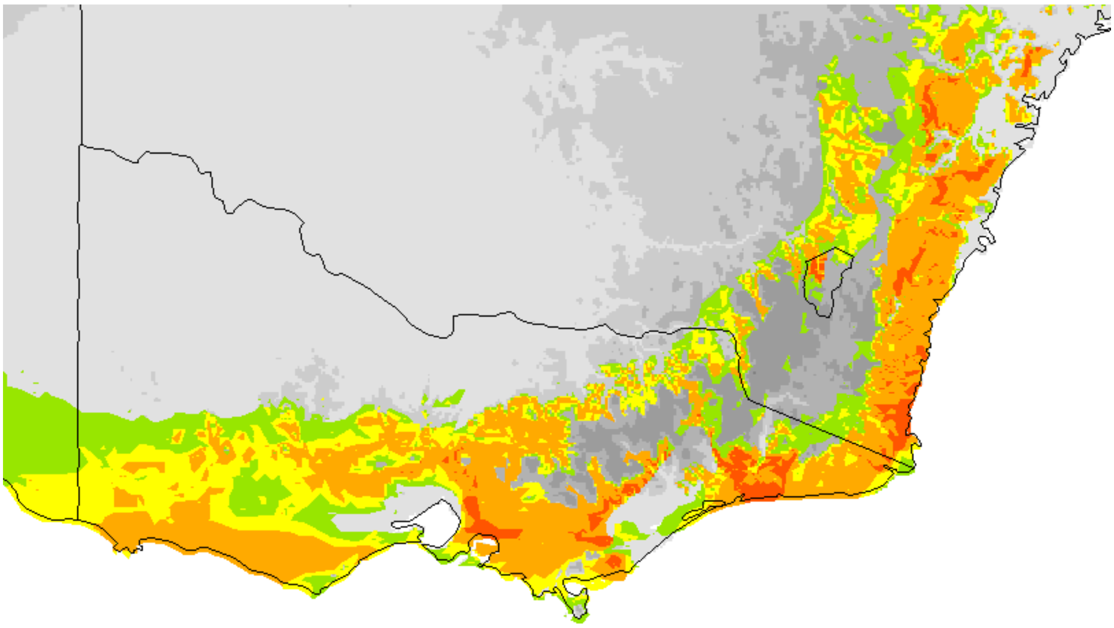


2070

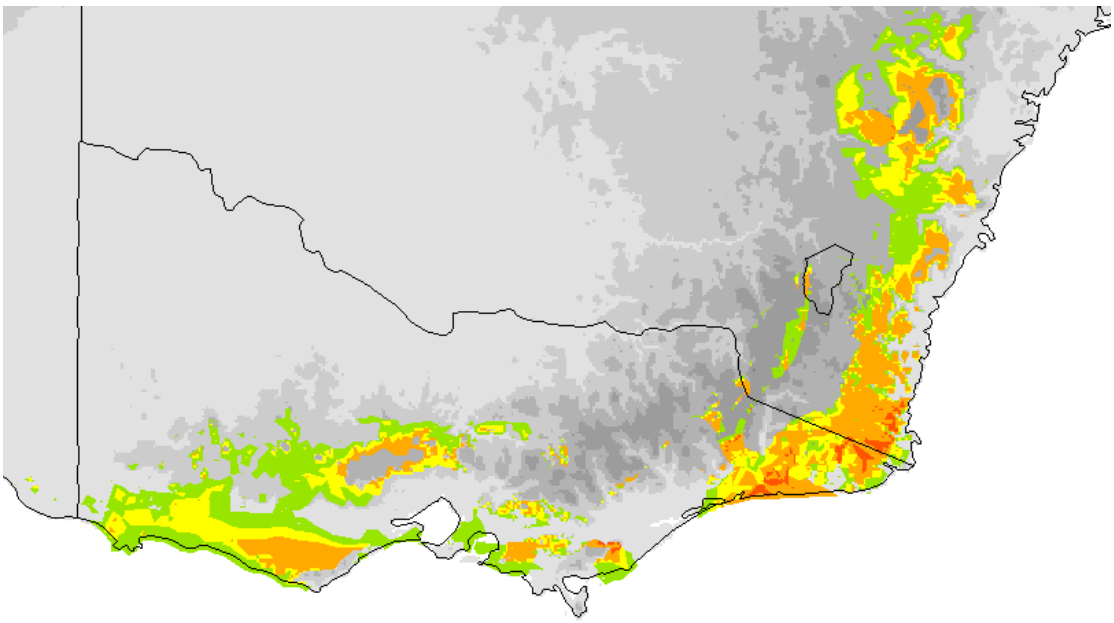
Figure 20c. ***Cotoneaster glaucophyllus*** A1F scenario (high)



Baseline climate



2030



2070

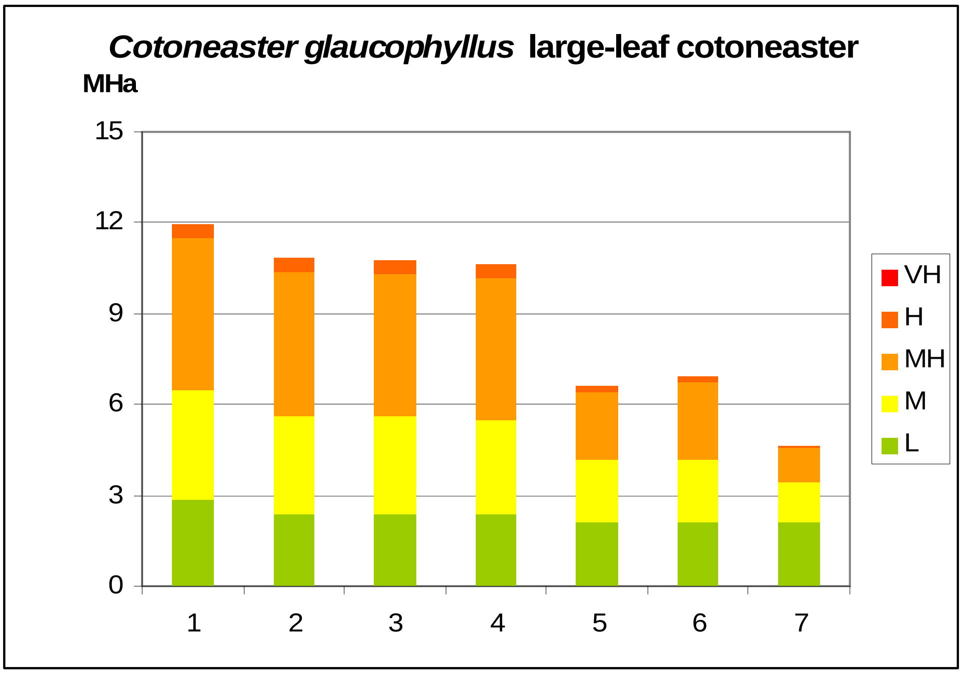


Figure 21. Area occupied by the climate envelope for *Cotoneaster glaucophyllus* under a range of climate scenarios over time

Results summary for *Cotoneaster glaucophyllus*

There was a general decline in the size of the climate envelope under climate change for this species, however the degree of climate match did not alter much, with some areas of the state showing a high climate match, even at 2070 under the A1F (+5.8^{o}C) scenario. Whilst less of the state may be suitable for the growth and spread of *C. glaucophyllus*, parts of the state will still be highly suitable under all climate change scenarios.

B1 (low)

2030

The northern boundary of the climate envelope contracted slightly to the south. There were smaller areas of likely, moderate and moderately high climate match, but the area of high climate match became larger.

2070

There was a further contraction of the climate envelope from the north and it became more fragmented. The areas of high climate match remained only in the Gippsland region.

A1 scenario (mid)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

There was little difference between this scenario at 2070 and the changes observed under the B1 low scenario.

A1F scenario (high)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

The climate envelope reduced dramatically under this scenario at 2070, occupying less than half the area that it did under baseline conditions. It contracted further south and away from the coast. It fragmented into many small, discrete patches, remaining only in the south and elsewhere generally at higher altitudes.

***Echium plantagineum* L.**

Paterson's curse

Paterson's curse is a winter annual that grows in warm-temperate regions, principally in areas with a dominant winter rainfall (Parsons & Cuthbertson, 2001), where it is found on a wide range of soils. Its distribution is limited by aridity (Morley & Stapleton, 1999), daylength and cold temperatures, for vernalisation (Tom Morley pers. Comm.).

In Australia, it has become a common weed of degraded pastures, roadsides and neglected areas. It sometimes occurs in crops if sowing is early and/or land preparation is poor. Paterson's curse will also invade mallee shrubland, lowland grassland and grassy woodland, dry sclerophyll forest and woodland riparian vegetation (Carr *et al*, 1992).

Dense stands of Paterson's curse occur where annual rainfall is less than 1270mm; and where, in the warmest month: rainfall is greater than 63.5mm, mean temperature is 21.1-26.7^{o}C, and daily temperature range is 13.9^{o}C; and in the coldest month: rainfall is greater than 25.4mm, mean temperature is 4.4-10.0^{o}C, and daily range is 8.3-13.9^{o}C. It also grows in north-east NSW and south-east Qld where rainfall and daylengths are more even.

Short photoperiods and high temperatures retard flowering and germination is probably inhibited by low winter temperatures. Emergence is abundant after rainfalls in summer, autumn and winter, when temperatures are high (Piggin & Sheppard, 1995).

The climatic parameters used to model this species were: 1, 5, 6, 10, 11, 19 & 22.

The potential distribution under baseline climatic conditions (Fig. 22) enveloped more than 99% of the current distribution data points.

Echium plantagineum

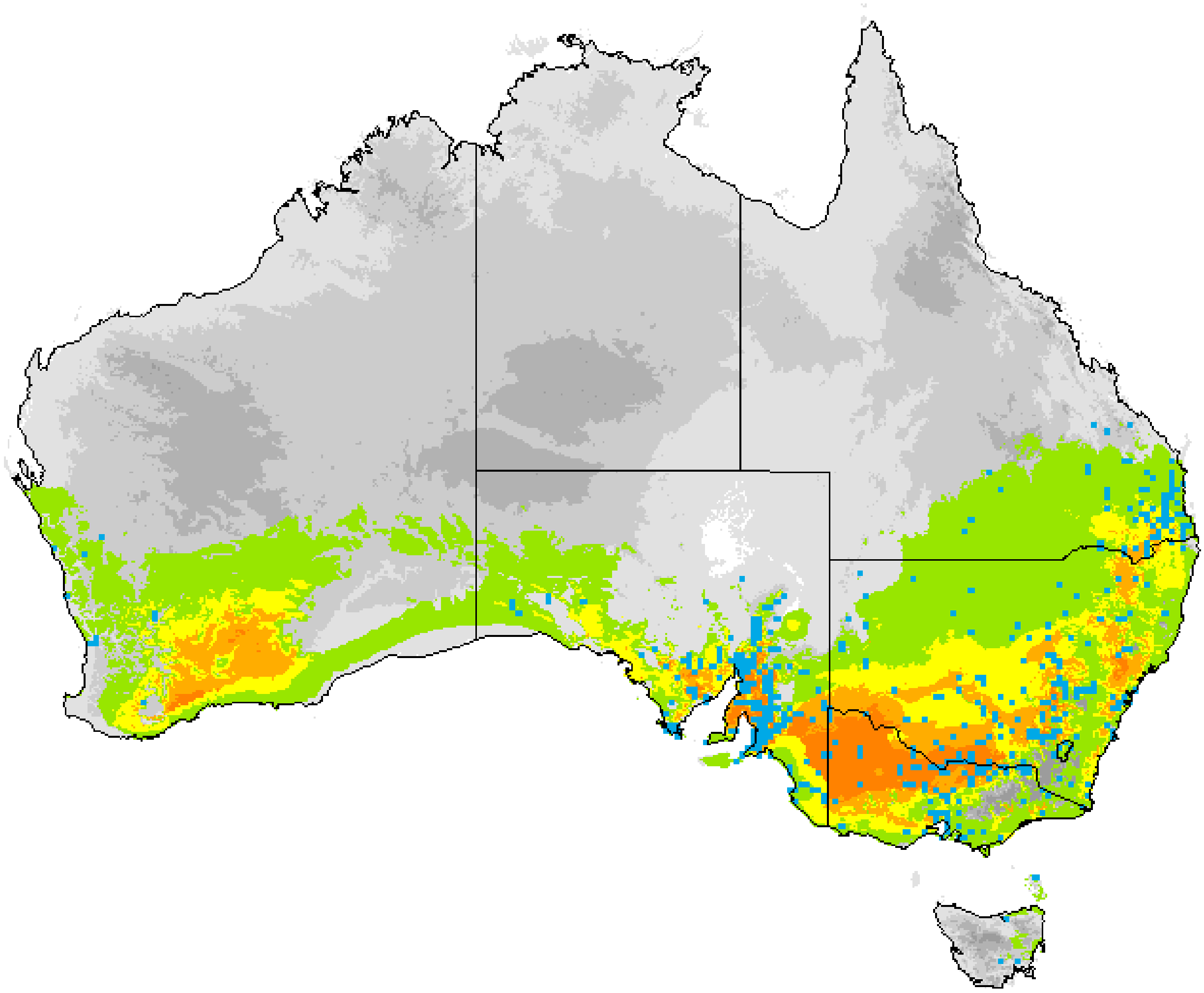
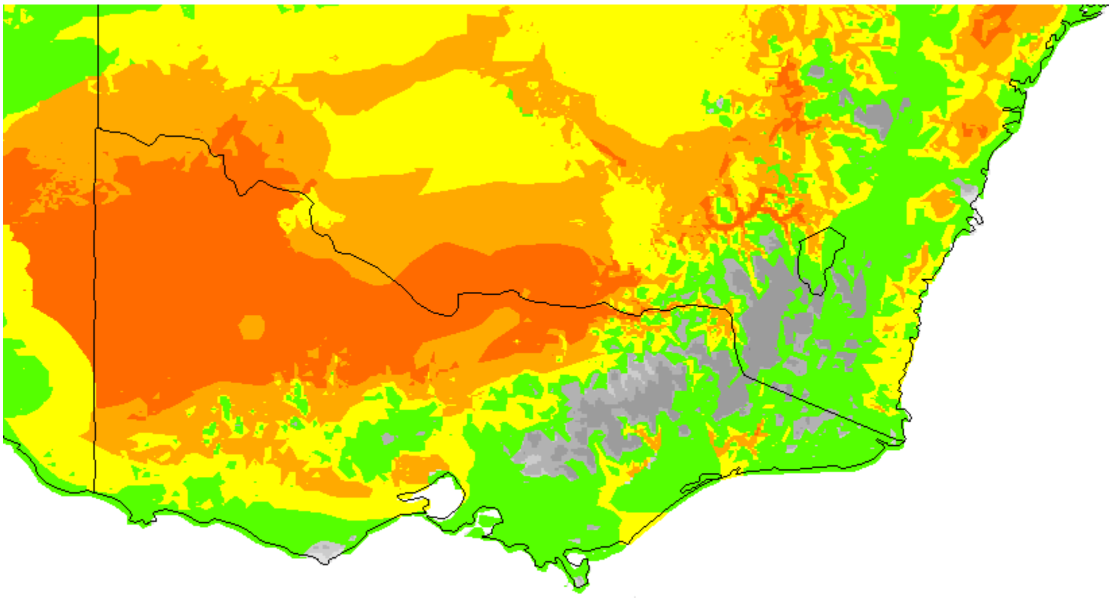
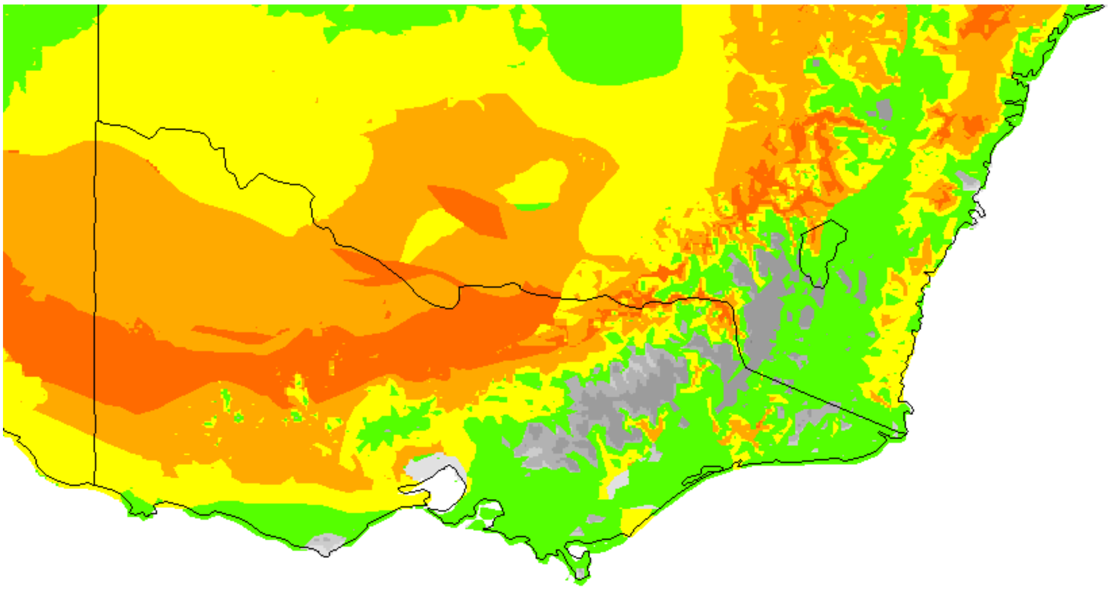


Figure 22. Comparison of current distribution with the baseline climate match

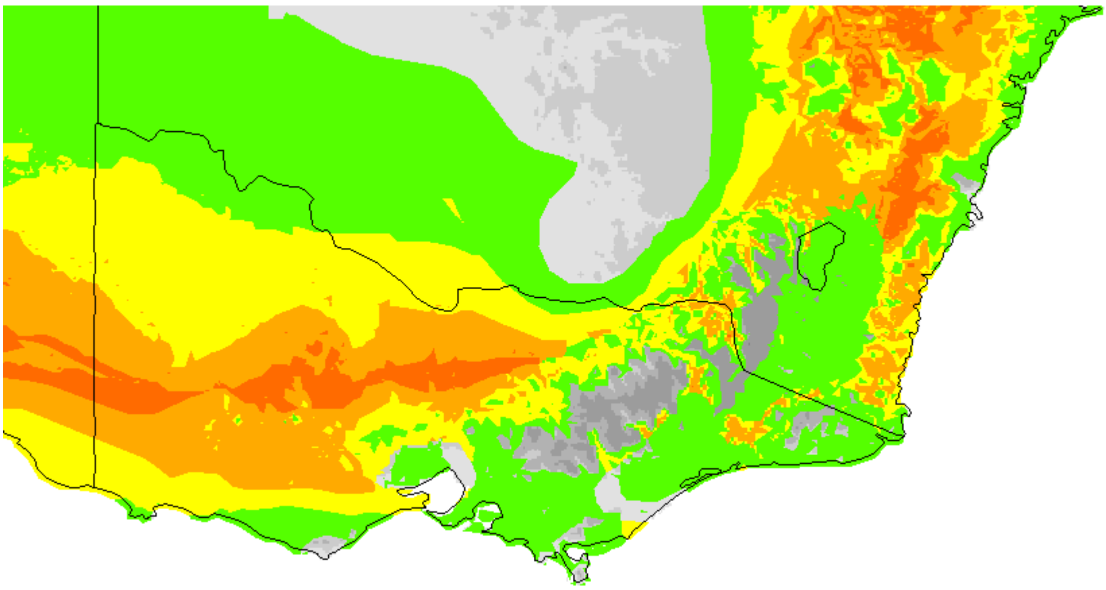
Figure 23a. ***Echium plantagineum*** B1 scenario (low)



Baseline climate

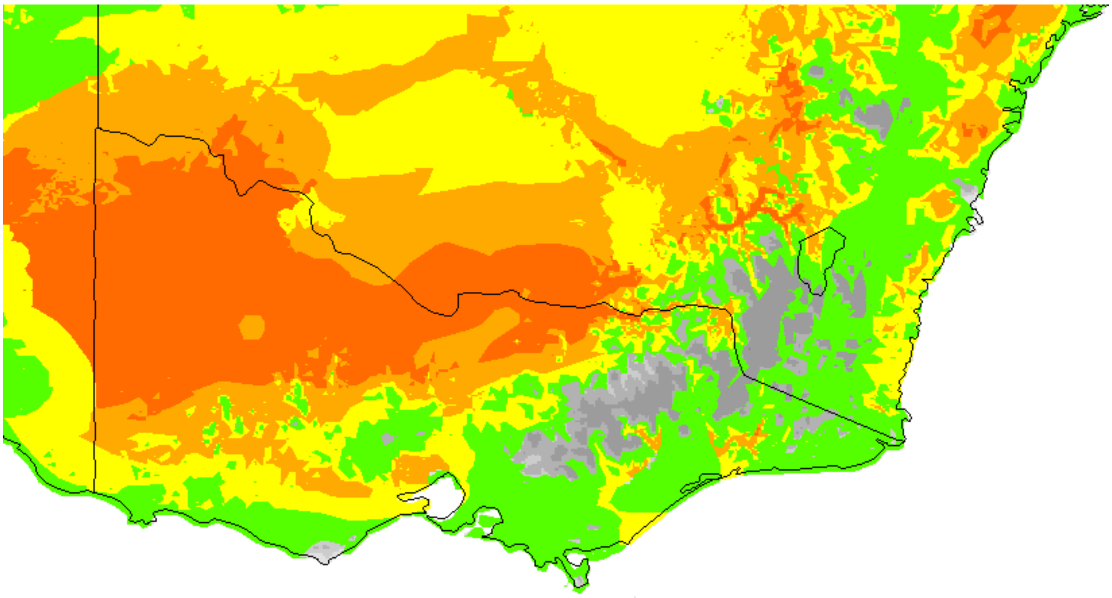


2030

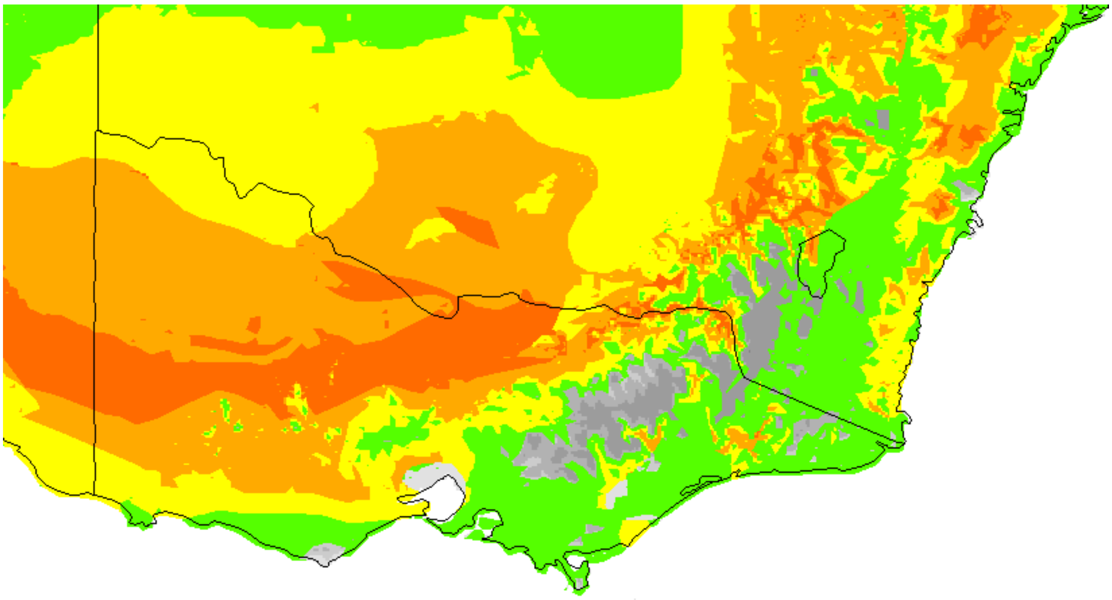


2070

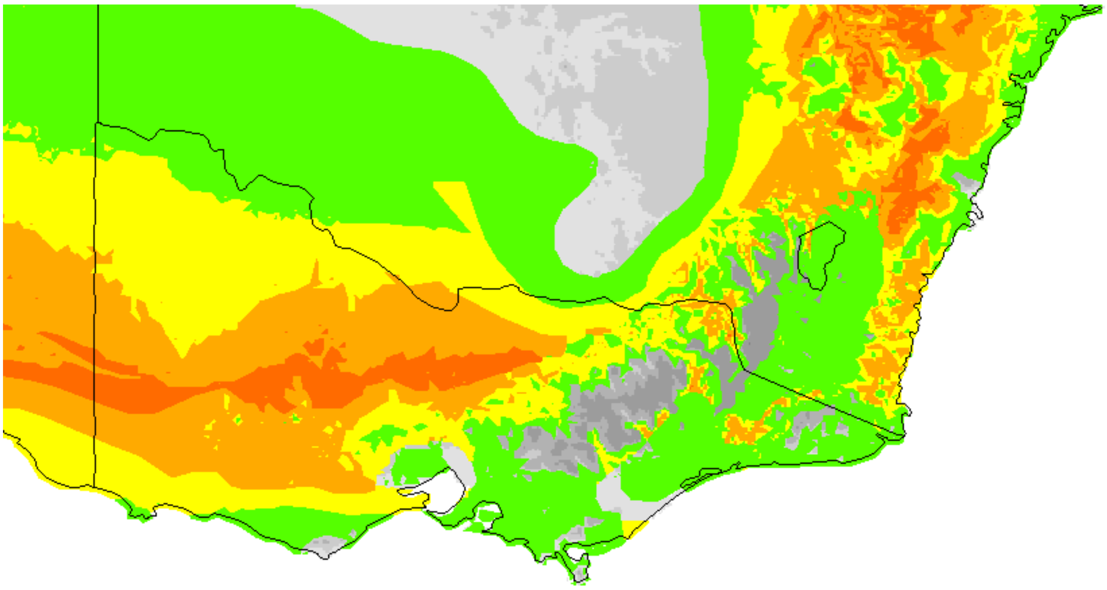
Figure 23b. ***Echium plantagineum*** A1 scenario (mid)



Baseline climate

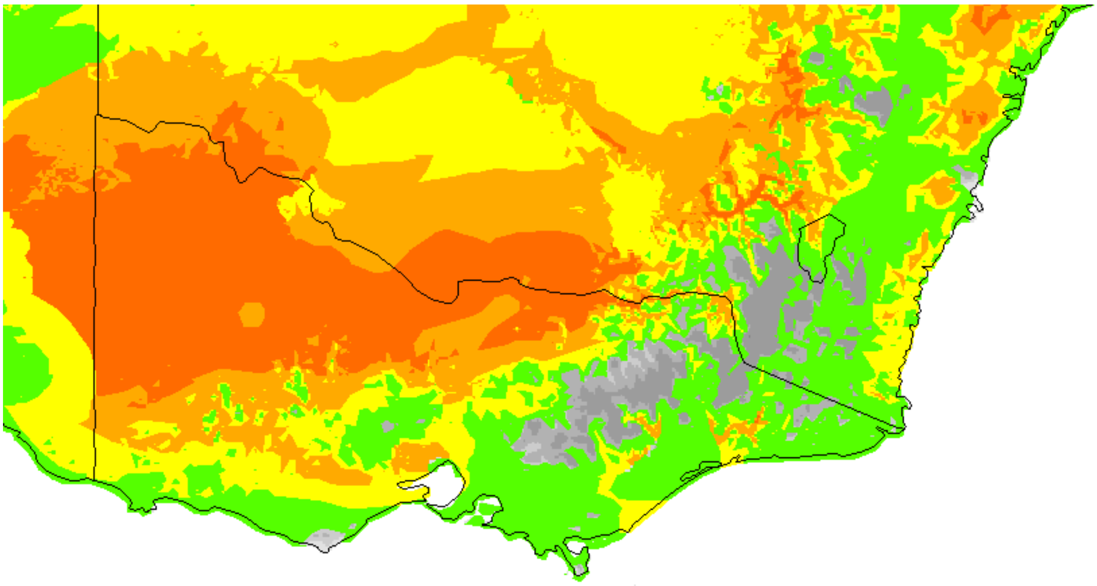


2030

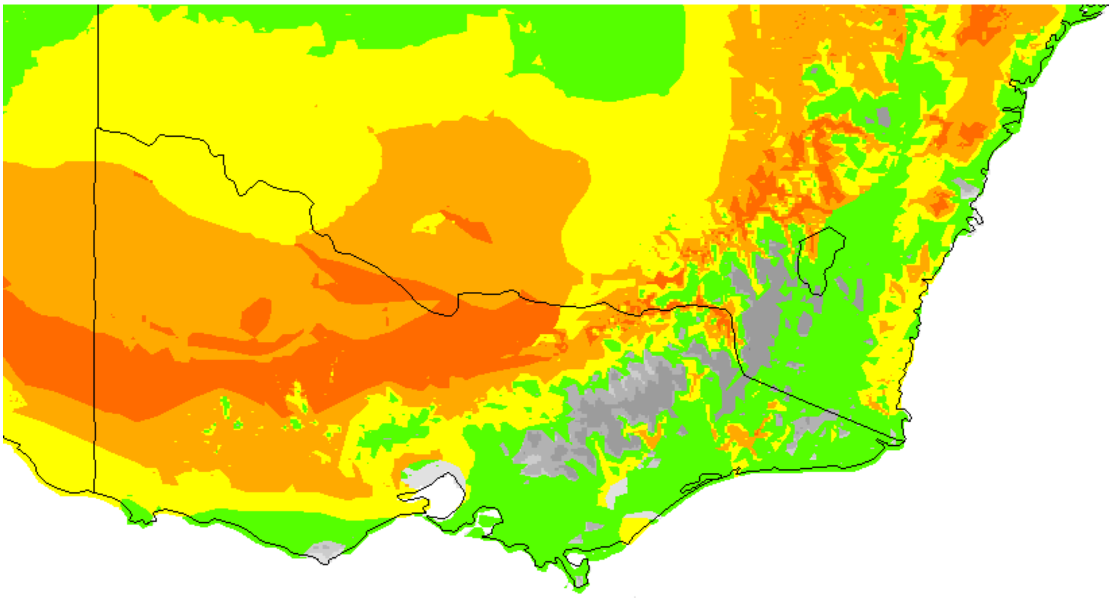


2070

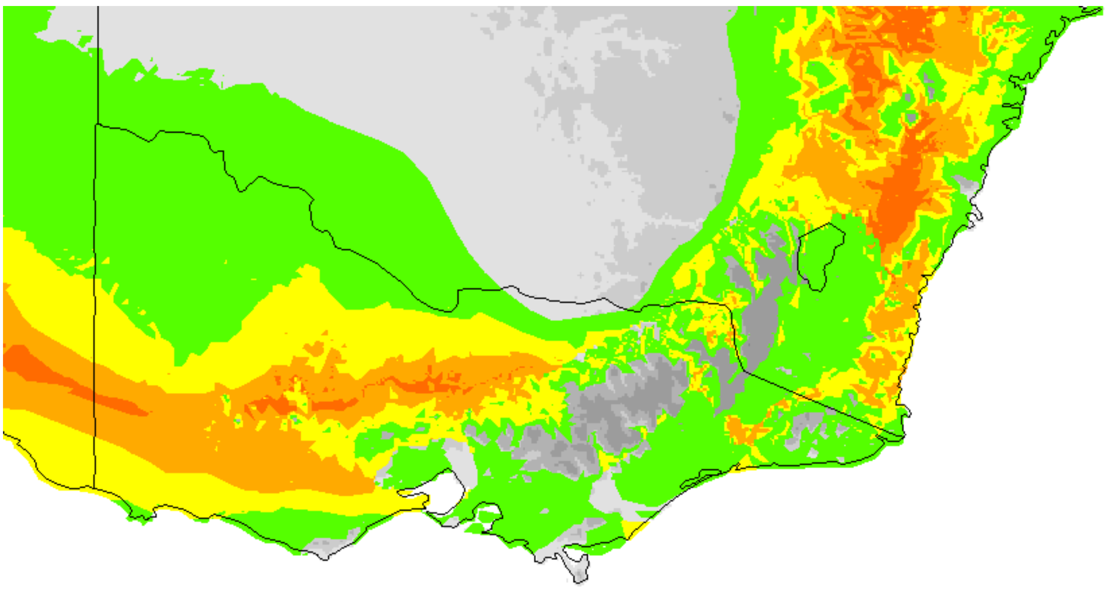
Figure 23c. *Echium plantagineum* A1F scenario (high)



Baseline climate



2030



2070

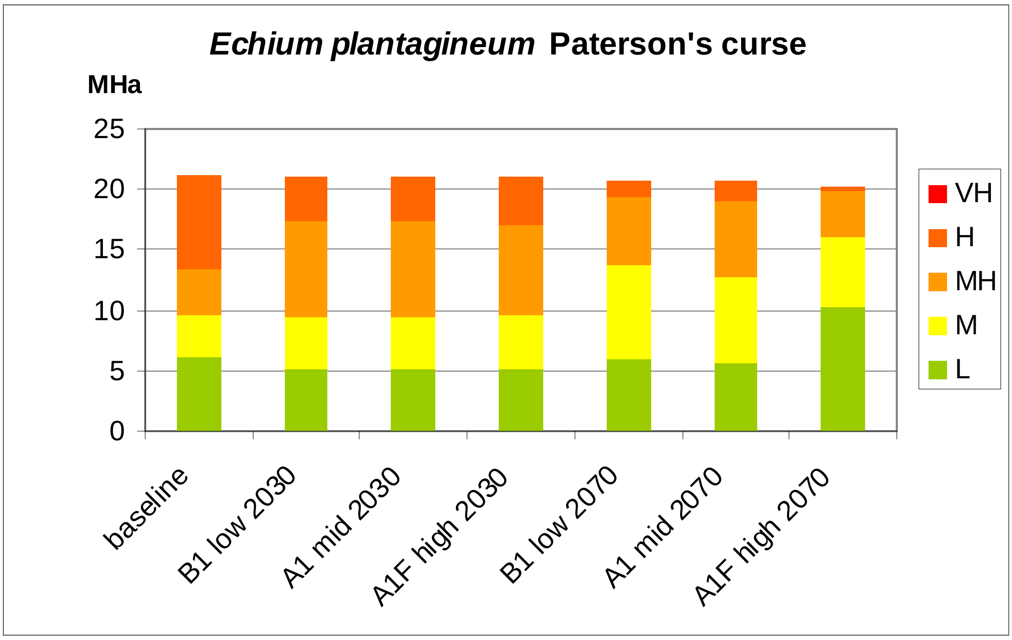


Figure 24. Area occupied by the climate envelope for *Echium plantagineum* under a range of climate scenarios over time

Results summary for *Echium plantagineum*

There was very little difference in the area of the climate envelope under climate change for this species; however the quality of the climate match declined over time, and with increased carbon environments.

B1 (low)

2030

As was the case in the baseline climate, the whole of Victoria, remained to some degree climatically suitable for Paterson's curse, with the exception of the Alps and some patches around Wilson's Promontory and at Cape Otway. The climate envelope also contracted from the coast around Melbourne. The areas of high climate match contracted from the north to a band running through Shepparton, Bendigo and Horsham.

2070

The whole of Victoria, with the exception of the Alps, remained to some degree climatically suitable for Paterson's curse (except some patches, around Wilson's Promontory and at Cape Otway and coastal areas near Melbourne). The climate envelope contracted from the coast around the Lakes district and inland to the Heyfield-Maffra area. The high climate match fragmented to some isolated patches within its former range.

A1 (mid)

2030

There was very little difference between the potential distribution in 2030 under this scenario when compared to the B1 low scenario.

2070

There was very little difference between the potential distribution in 2070 under this scenario when compared to the B1 low scenario.

A1F (high)

2030

There was very little difference between the three scenarios at 2030.

2070

Whilst the area of the climate envelope only reduced by a small amount, the quality of the climate match declined noticeably under this scenario at 2070. The area of high climate match contracted to become fragmented. The climate match over the Mallee dropped from mostly being moderate (under baseline and 2030 conditions under all scenarios) to only likely. Some areas south of the Vic-NSW border, from Cobram to Wodonga, appeared unsuitable climatically for Paterson's curse.

Eremophila sturtii R. Brin Sturt

narrow-leaf emu bush

Native to Australia, prevalent in NSW and considered a weed of pasture, however, considered at risk of disappearing from Victoria (Walsh & Stasjik 2007). Also present in Qld, SA & NT (Elliot & Jones 1984). It has been identified as an invasive scrub species that may be responding to changed fire and grazing conditions since European settlement (Science and Information Board 2004). This species is frost hardy and tolerant of extended dry periods and not usually found on flood plains (Elliot & Jones 1984).

The parameters chosen to model this species were 1, 3 & 8.

The baseline climate match for this species (Fig. 25) was poor and only encompassed about half the current distribution points and some of the densest concentrations of records concurred with only a likely climate match.

Eremophila sturtii

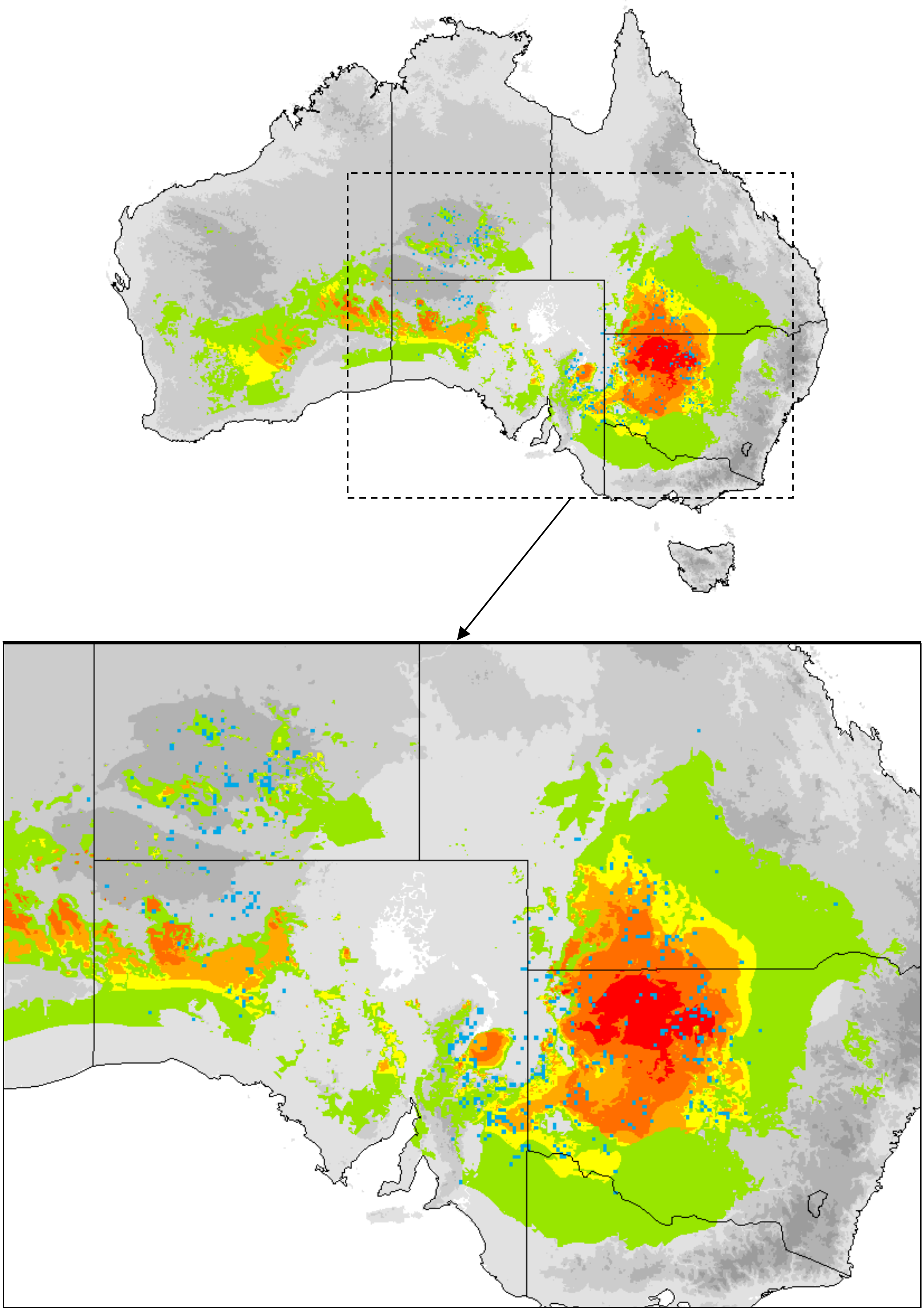
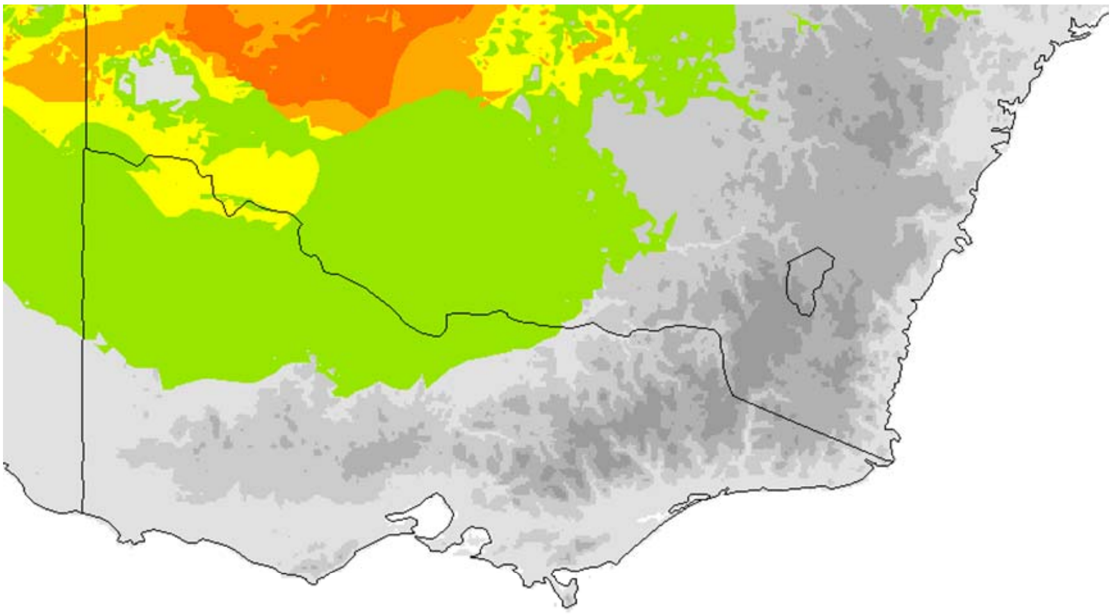
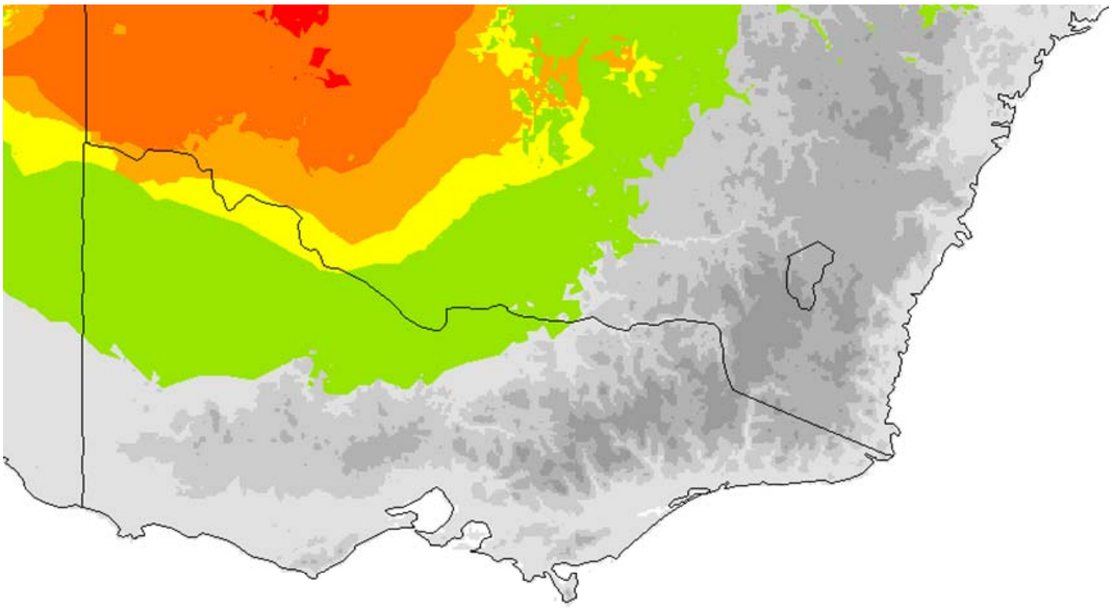


Figure 25. Comparison of current distribution with baseline climate match

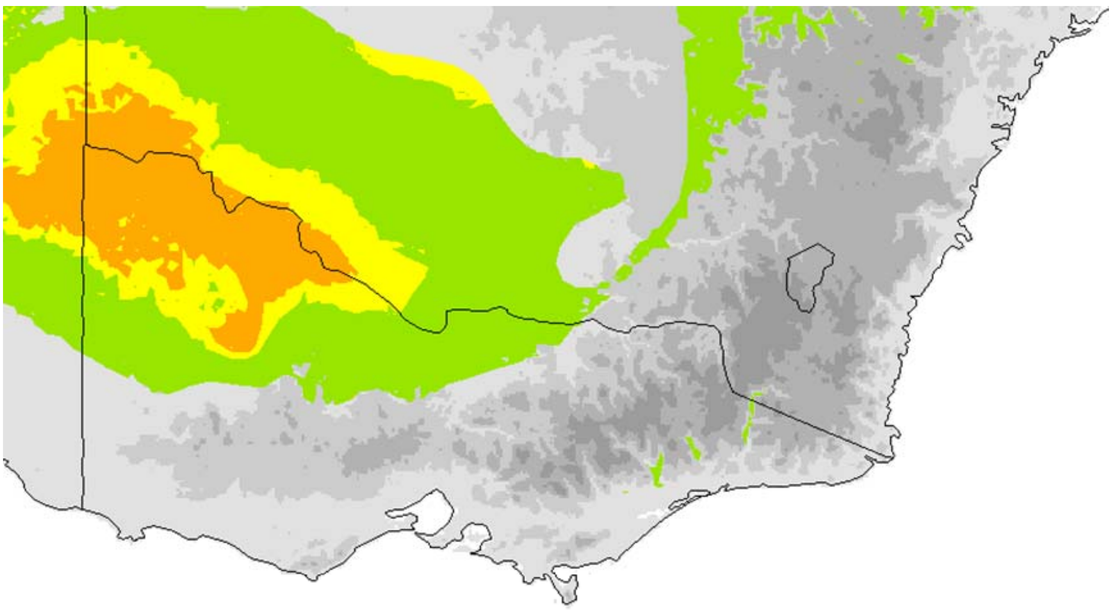
Figure 26a. *Eremophila sturtii* B1 scenario (low)



Baseline climate

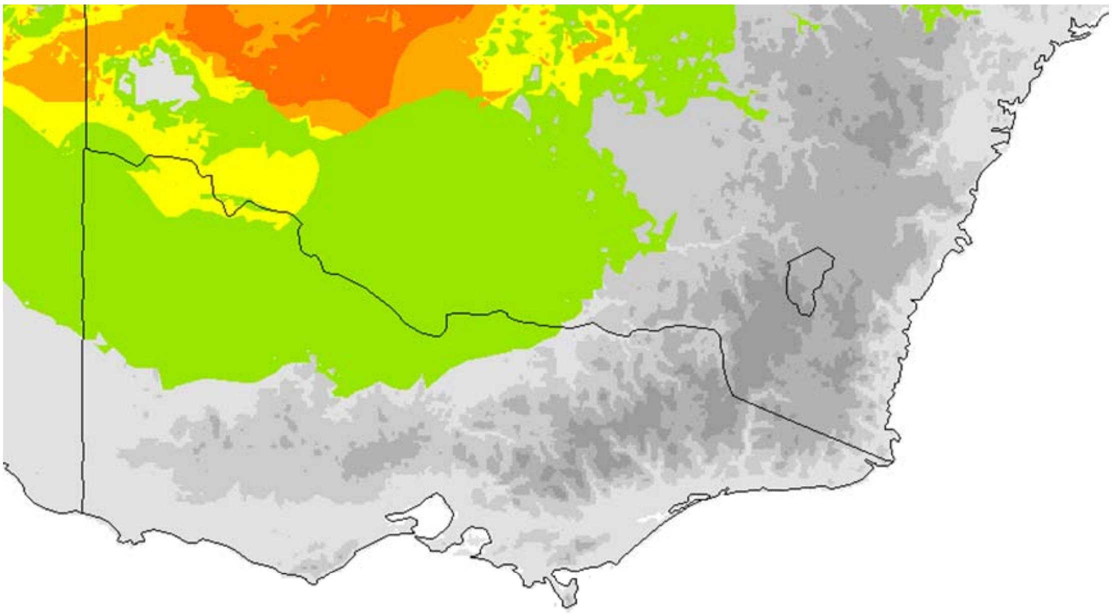


2030

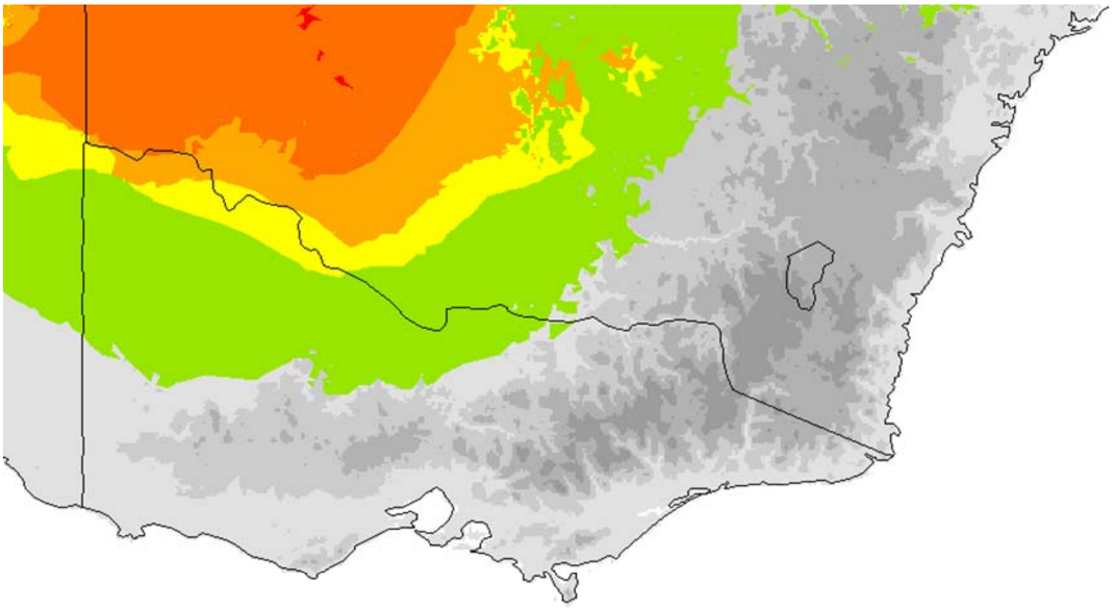


2070

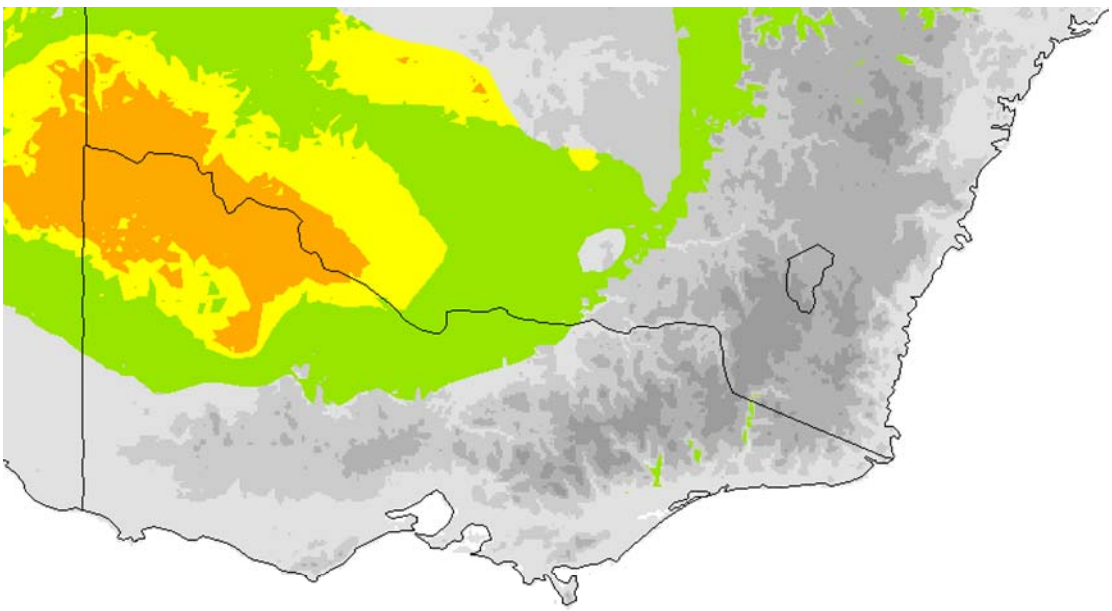
Figure 26b. ***Eremophila sturtii*** A1 scenario (mid)



Baseline climate

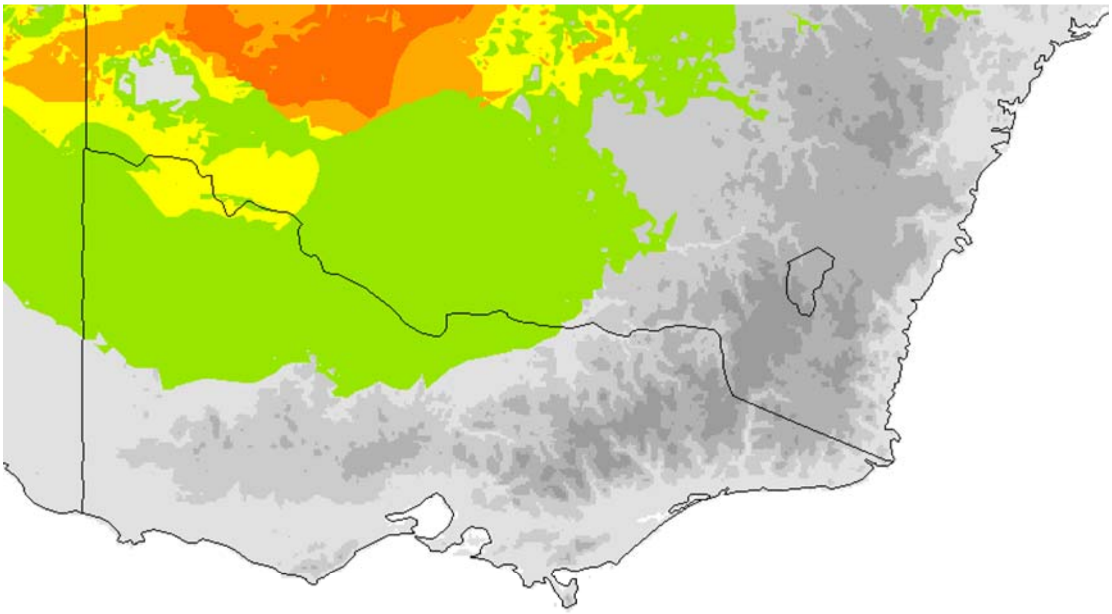


2030

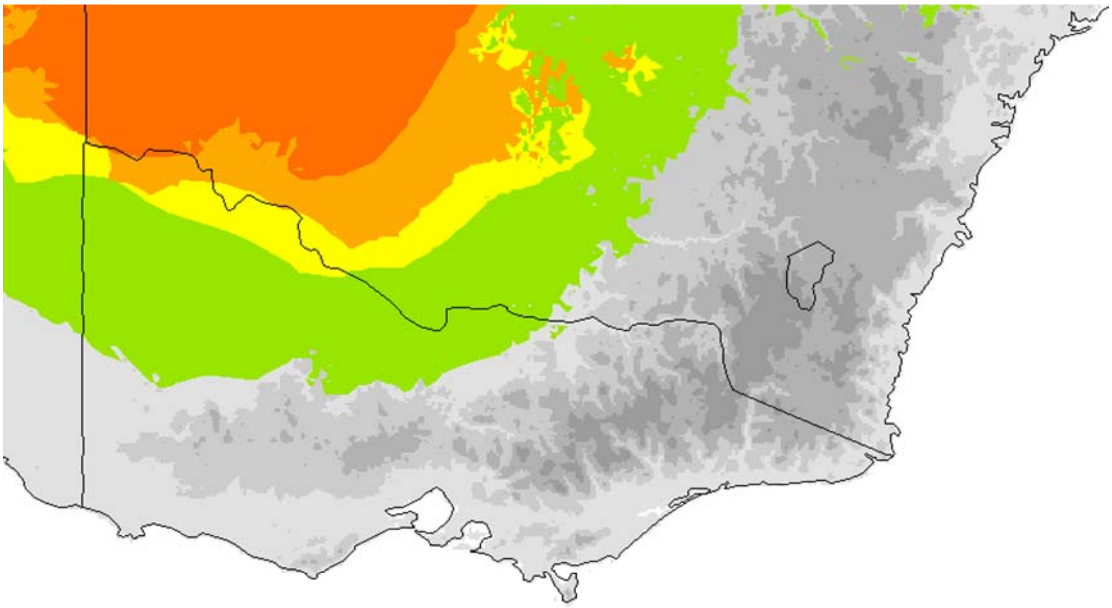


2070

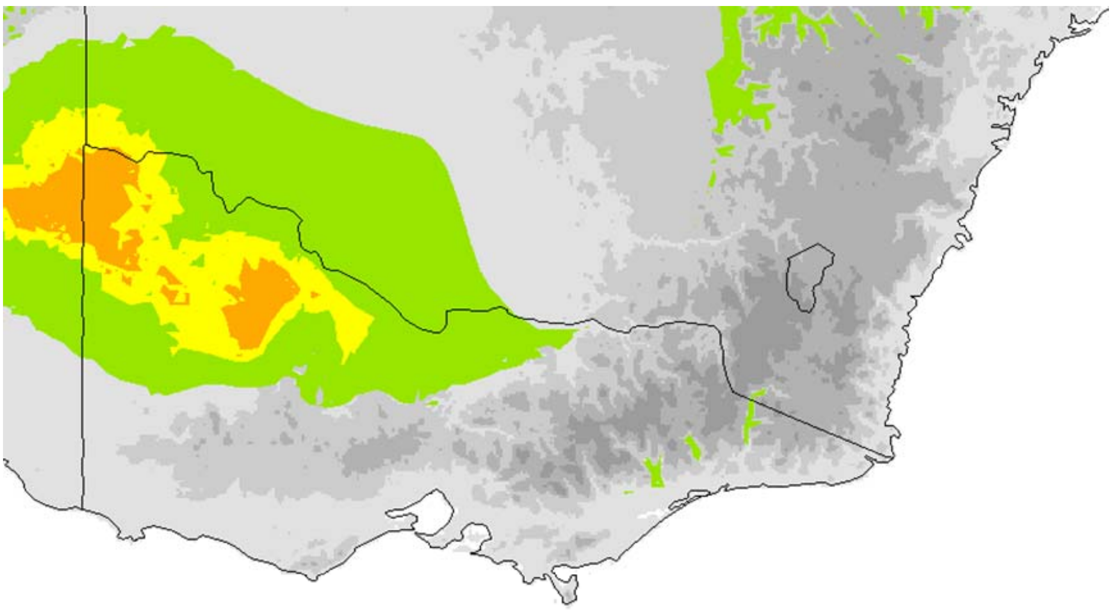
Figure 26c. *Eremophila sturtii* A1F scenario (high)



Baseline climate



2030



2070

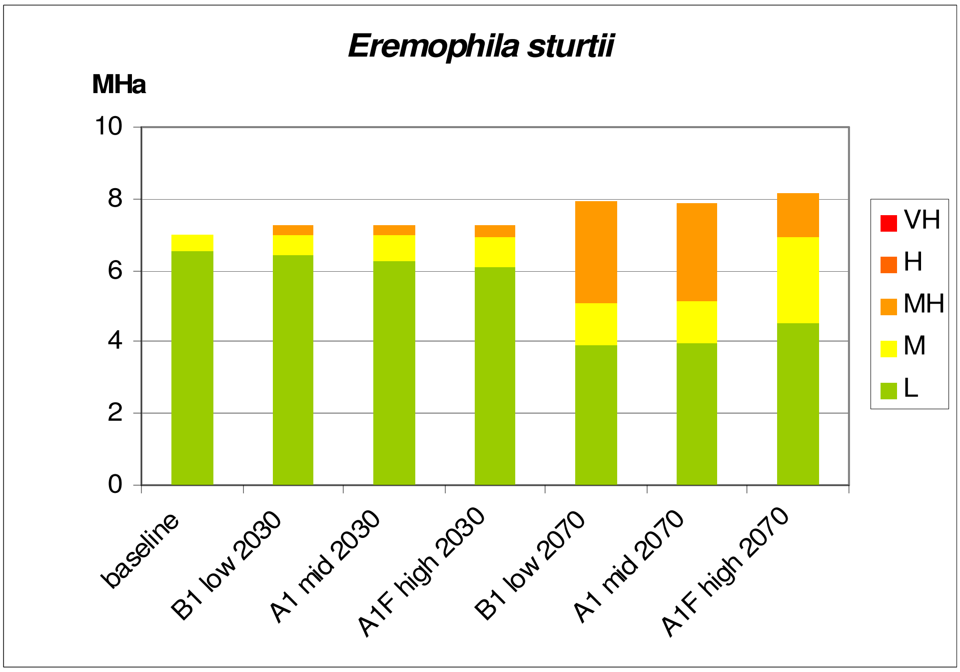


Figure 27. Area occupied by the climate envelope for *Eremophila sturtii* under a range of climate scenarios over time

Results summary for *Eremophila sturtii*

There was little change in the area of the climate envelope within Victoria but the climatic suitability for the establishment and growth of this species generally increased over time.

2030 for B1 low, A1 mid and A1F high

The climate envelope at 2030 appeared to be very similar under all scenarios. There was a slight increase in the climate envelope, compared to baseline conditions, but more obviously, a greater area of moderate climate match and the appearance of some moderately high climate match in the north-west corner of the state.

2070

Under the B1 low and A1 mid scenarios the climate envelope expanded to the south and climatic suitability increased to moderately high in most of the north-west. Under the A1F high scenario the climate envelope reached its largest size but the climatic suitability was somewhat reduced. Much of the area occupied by a moderately high climate match under B1 low and A1 mid scenarios appeared as a moderate climate match under A1F high.

Euphorbia terracina L.

Terracina spurge

E. terracina is native to the Mediterranean region (Parsons & Cuthbertson 2001) but has become a weed of pasture, roadsides, bushland, coastal areas and disturbed sites in NSW, Vic, SA & WA (Richardson & Richardson 2006).

It occurs in warm-temperate regions principally with winter-dominated rain (Parsons & Cuthbertson 2001), can germinate any time water is available (Dixon 2000), whilst good summer rains and mild winters promote early seedling emergence (Randall & Brooks 2000); and tolerates drought (Orchard & O'Neil 1957).

The parameters chosen to model this species were 1, 8, 11, 15, 17, 18, 19, 20 & 21.

The baseline climate match (Fig. 28) was very good, with current distribution points outside the climate envelope at only four locations; the northern-most points in WA and NSW, near Perth in WA and at the northern-most part of the Murray River in SA.

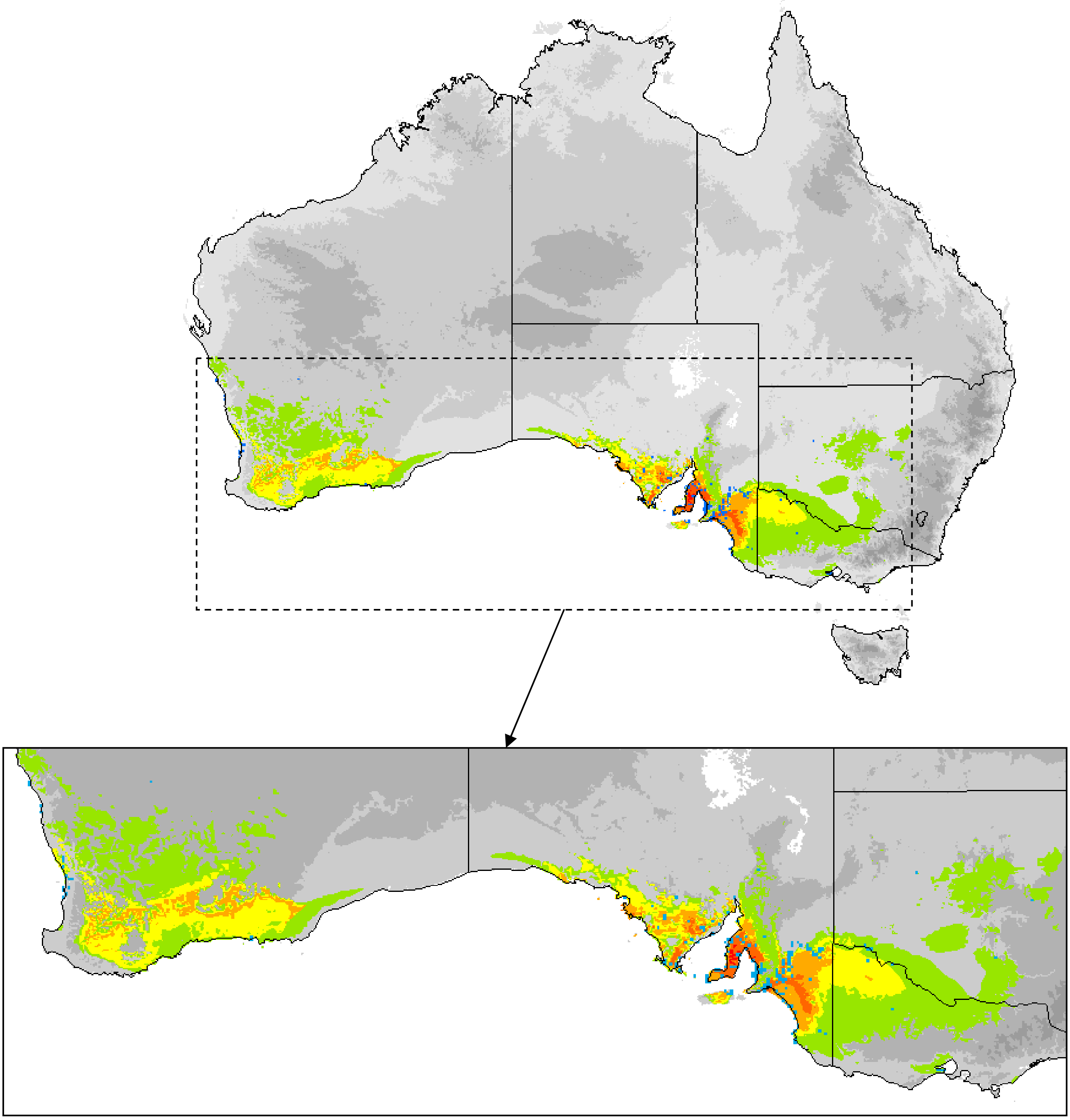


Figure 28. Comparison of current distribution with the baseline climate match

Figure 29a. ***Euphorbia terracina*** B1 scenario (low)

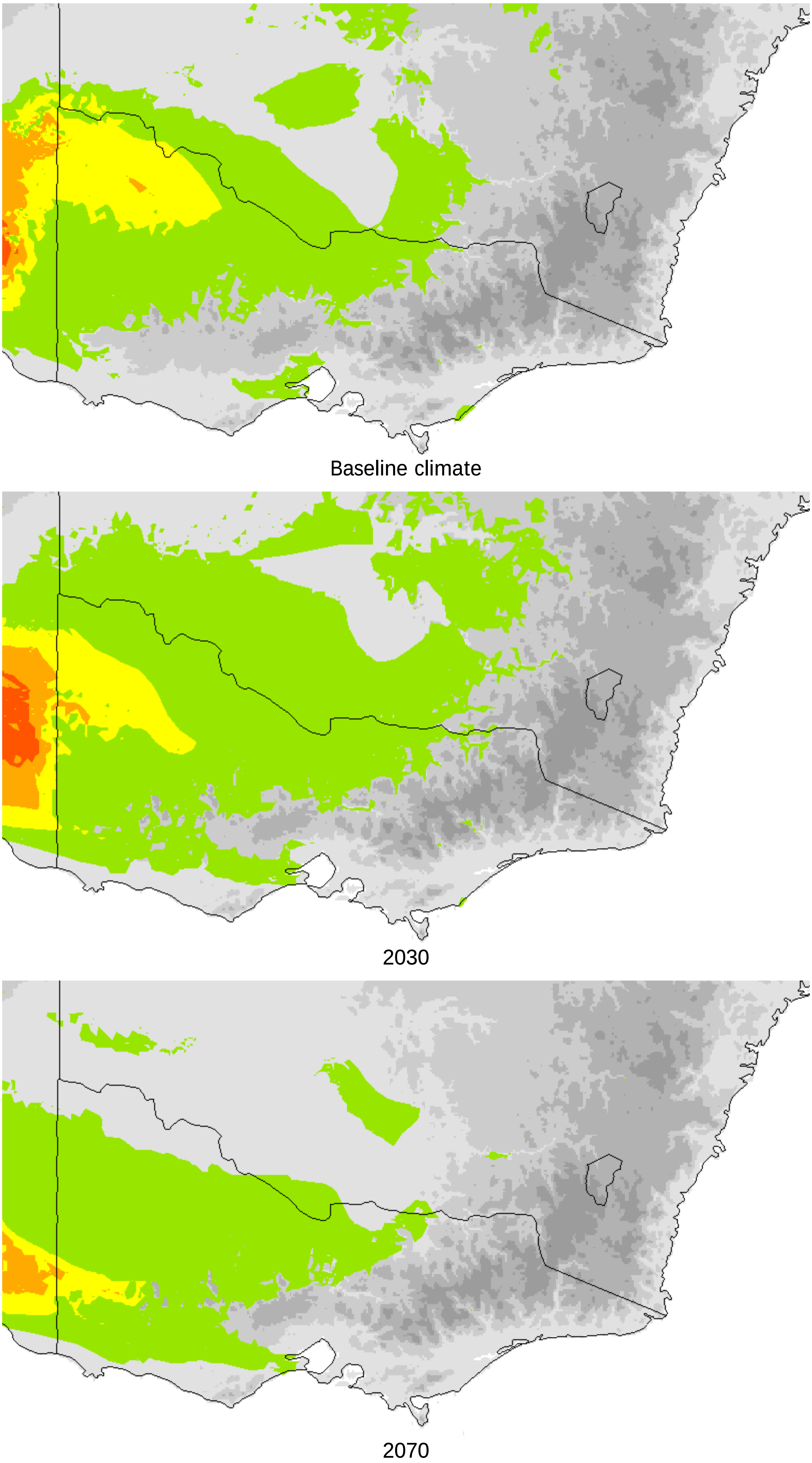
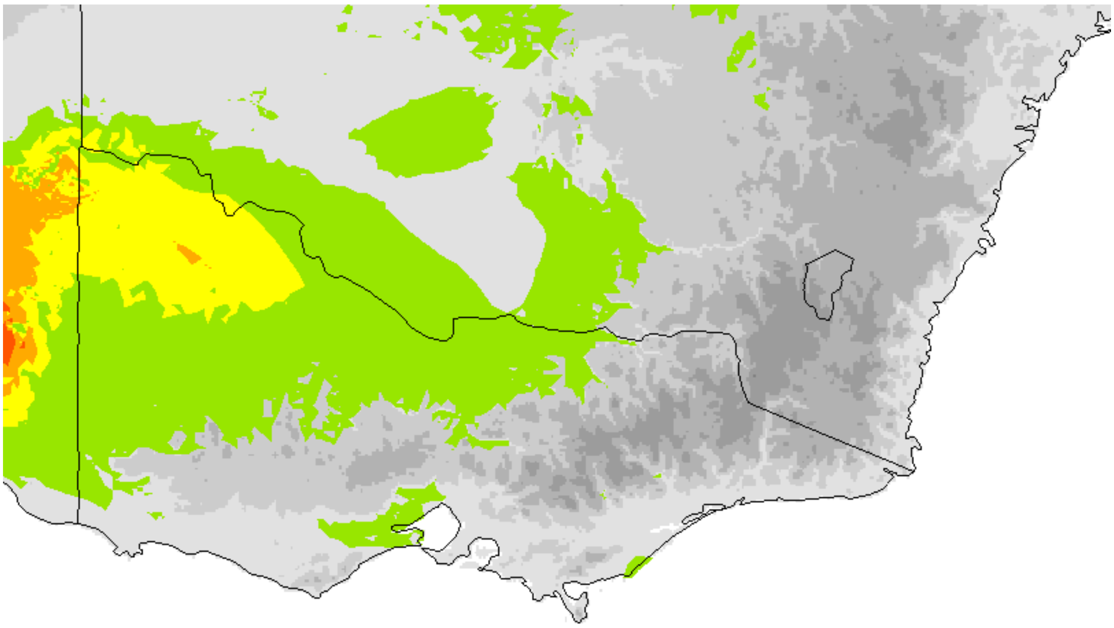
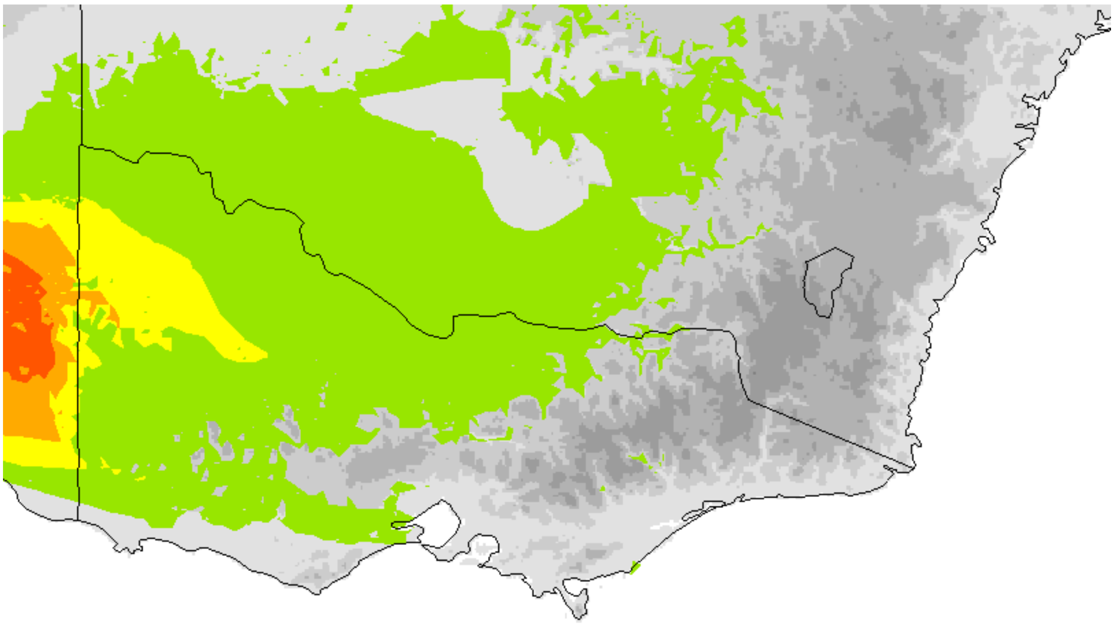


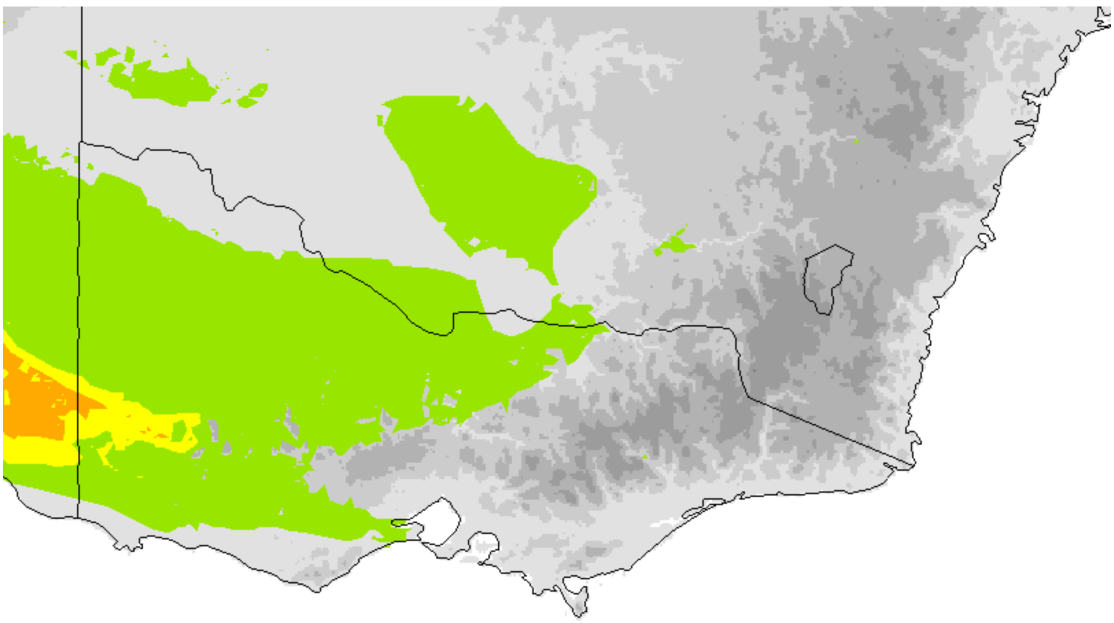
Figure 29b. *Euphorbia terracina* A1 scenario (mid)



Baseline climate

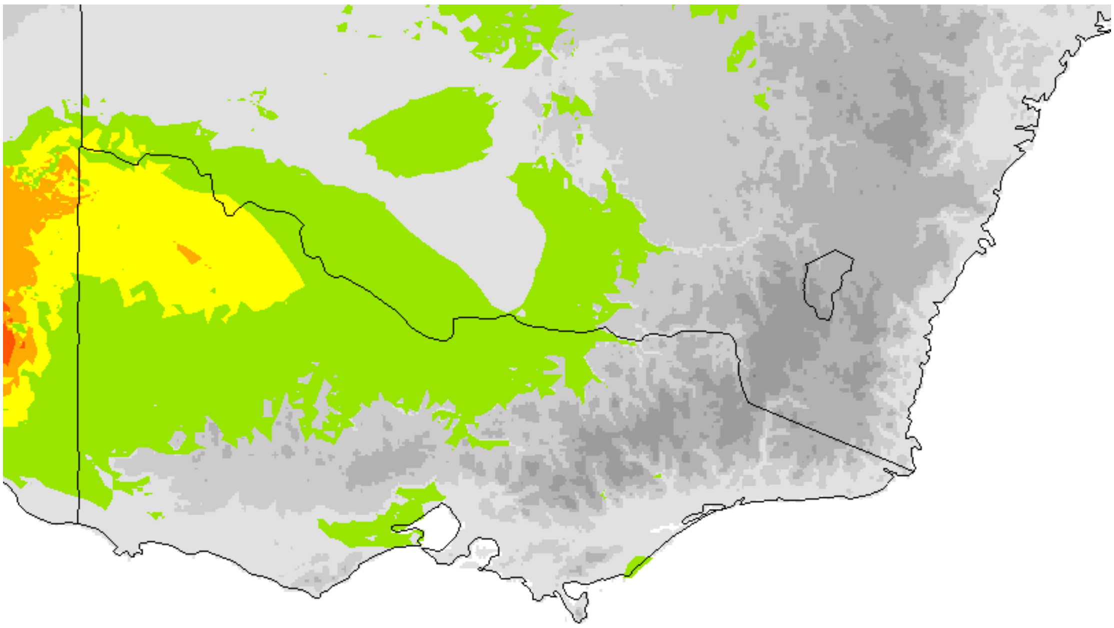


2030

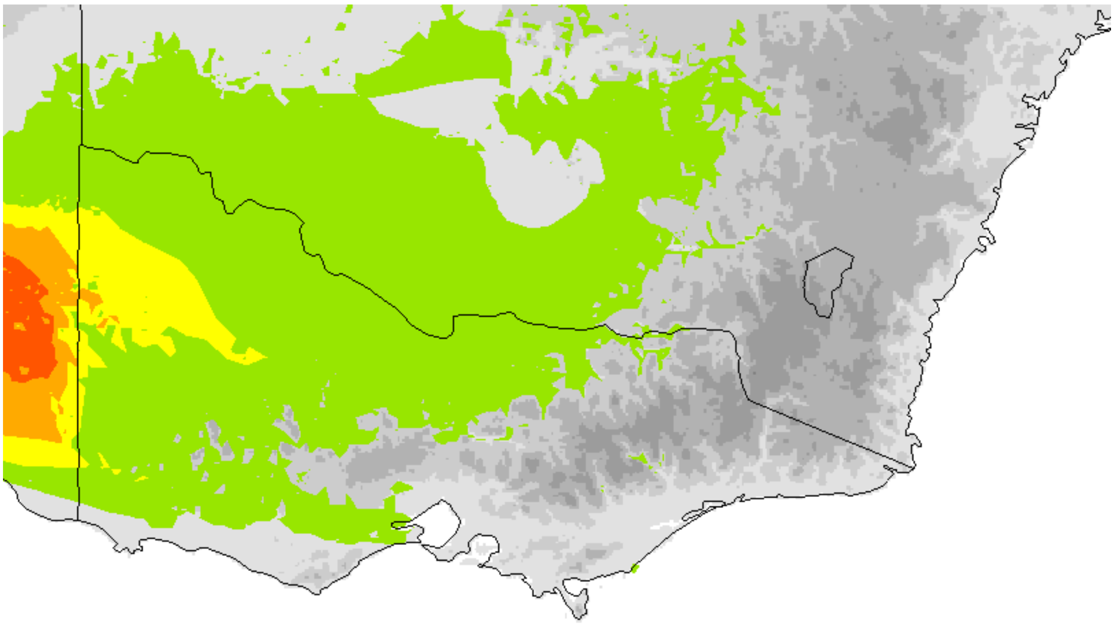


2070

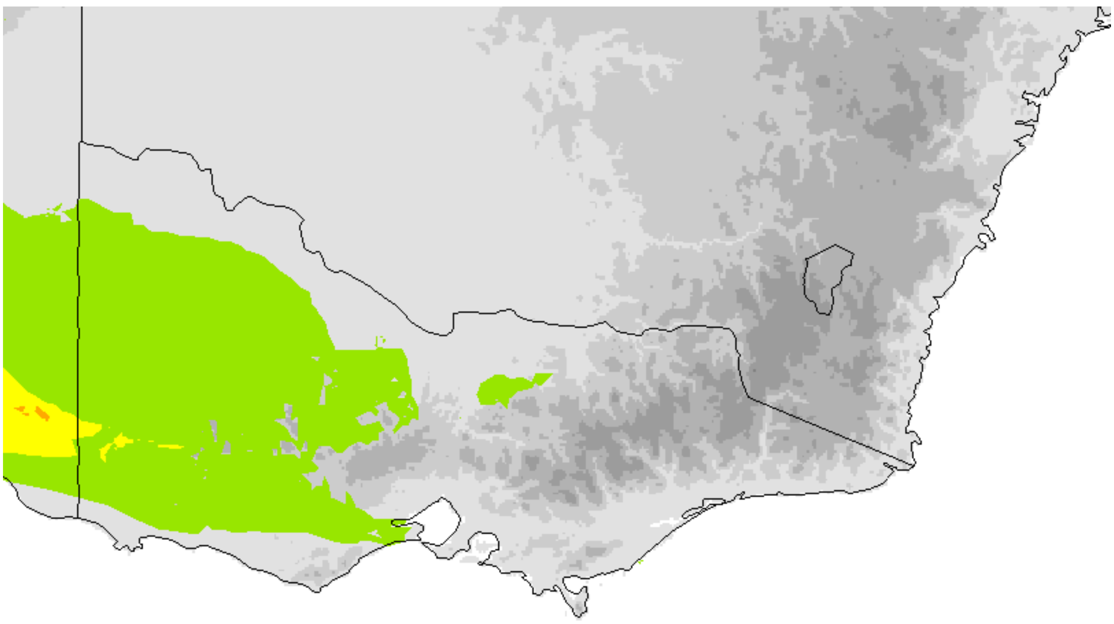
Figure 29c. *Euphorbia terracina* A1F scenario (high)



Baseline climate



2030



2070

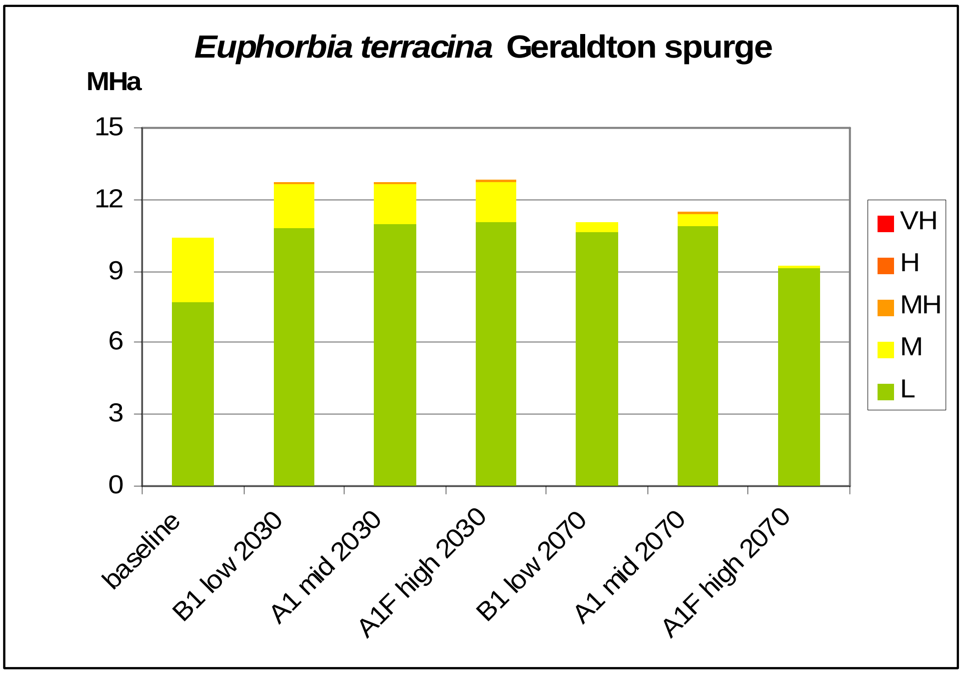


Figure 30 Area occupied by the climate envelope for *Euphorbia terracina* under a range of climate scenarios over time

Results summary for *Euphorbia terracina*

The climate envelope for this species increased under all climate change scenarios at both 2030 and 2070, except for A1F high at 2070, where the area of climate match decreased in both size and intensity. Climatic conditions under which *E. terracina* is likely to grow are likely to remain in Victoria.

B1 (low)

2030

The climate envelope expanded south and the areas showing higher climate matches appeared further south also.

2070

The climate envelope contracted from the north, however it still extended as far south as it did in 2030, resulting in a larger area than that observed under baseline climatic conditions. There were smaller areas of moderate and moderately high climate match when compared to both 2030 and baseline climates.

A1 scenario (mid)

2030

Under this climate change scenario the climate envelope was a similar shape to that observed under B1 low, but the climatic suitability was reduced, with the moderate and moderately high climate matches occupied slightly smaller areas.

2070

The northern boundary of the climate match contracted more under this scenario than under B1 low, but the area it occupied was still larger than that under both B1 low, and baseline conditions.

A1F scenario (high)

2030

Under A1F high the climate envelope expanded to a similar size and shape as that observed under the other two scenarios, but the climate match was less intense, with a greater proportion of likely, rather than moderate or moderately high climate match.

2070

The climate envelope contracted to the west with a much smaller area of moderate climate match, and them moderately high climate match did not appear. The climate envelope was smaller than that under baseline conditions only at this time and under this scenario.

Heliotropium amplexicaule Vahl

blue heliotrope

Blue Heliotrope (*H. amplexicaule*) is a summer growing (predominantly), prostrate perennial herb (Parsons & Cuthbertson 2001). Native to Southern America; Brazil, Argentina, Bolivia & Uruguay (GRIN 2007) and now a weed in NSW, Vic, SA & Qld (Richardson & Richardson 2007).

A weed of arable land in Mauritius (Rochecouste & Vaughan 1963), it is often found along roadside reserves, in waterways, on non-arable country, in degraded pastures, and on fallowed cultivation (Dellow *et al*. 2004). In Australia it is a weed of cultivated land, pastures and forests (Newell 1997) and occurs in woodlands, roadsides and pasture habitats (Benson & von Richter 2007), wasteland and disturbed areas (Richardson & Richardson 2007).

Major infestations occur in areas receiving more than 500mm of rainfall per year, but it is also established in lower rainfall areas. It is "a highly persistant perennial, adaptable to a wide range of soil and climatic types." Extremely drought hardy but "frost-susceptible, dying off in Winter and regenerating from the vigorous root system the following Spring" (Dellow *et al*. 2004).

Seeds germinate throughout summer usually with a major flush in late summer or autumn if moisture is available (Parsons & Cuthbertson 2001).

The parameters chosen to model this species were 1, 11, 12 & 13.

The baseline climate match for this species (Fig. 31) encompassed more than 95% of the current distribution points. There was a strong degree of climate match around the largest concentrations of data points in NSW and Qld, but the likely match in SA did not reflect the concentrated nature of the distribution of *H. amplexicaule* in that state.

Heliotropium amplexicaule

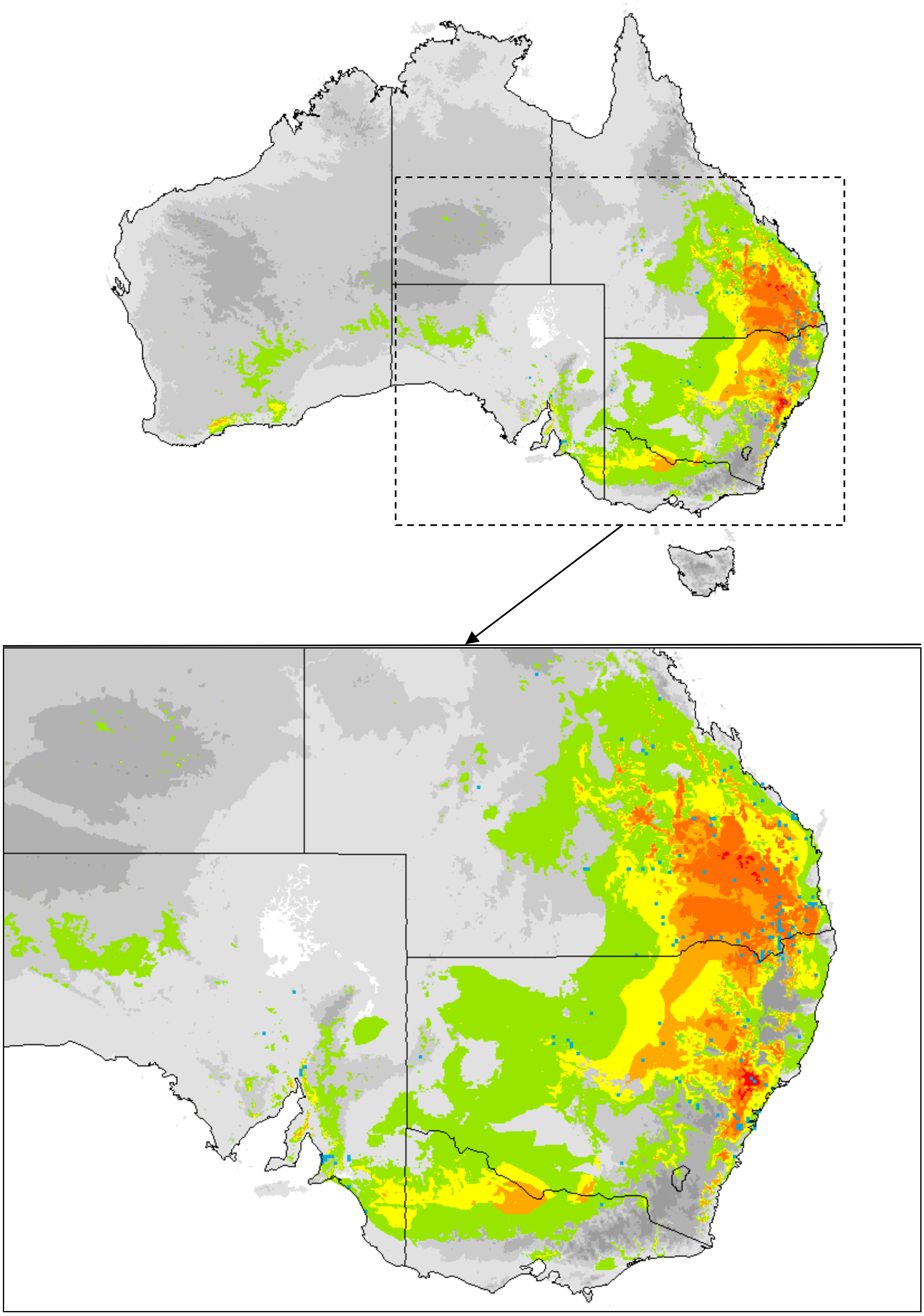
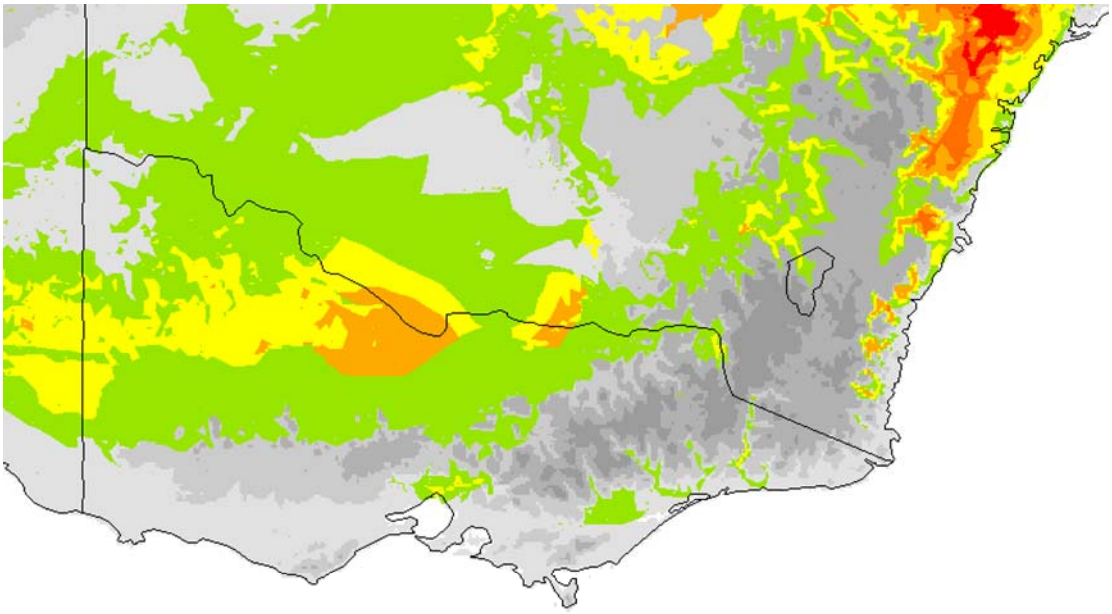
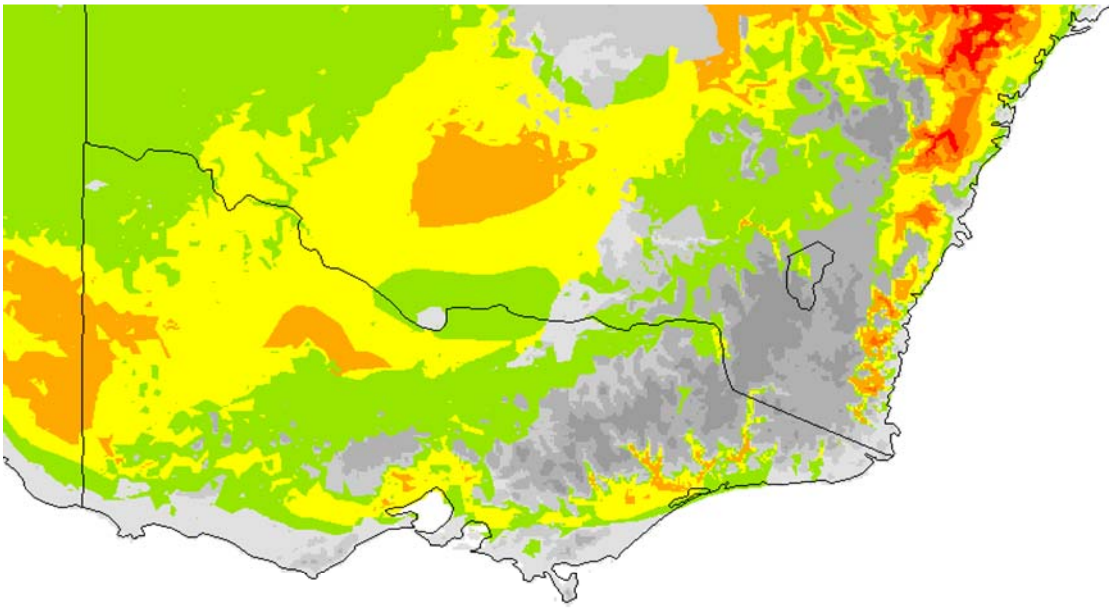


Figure 31. Comparison of current distribution with the baseline climate match

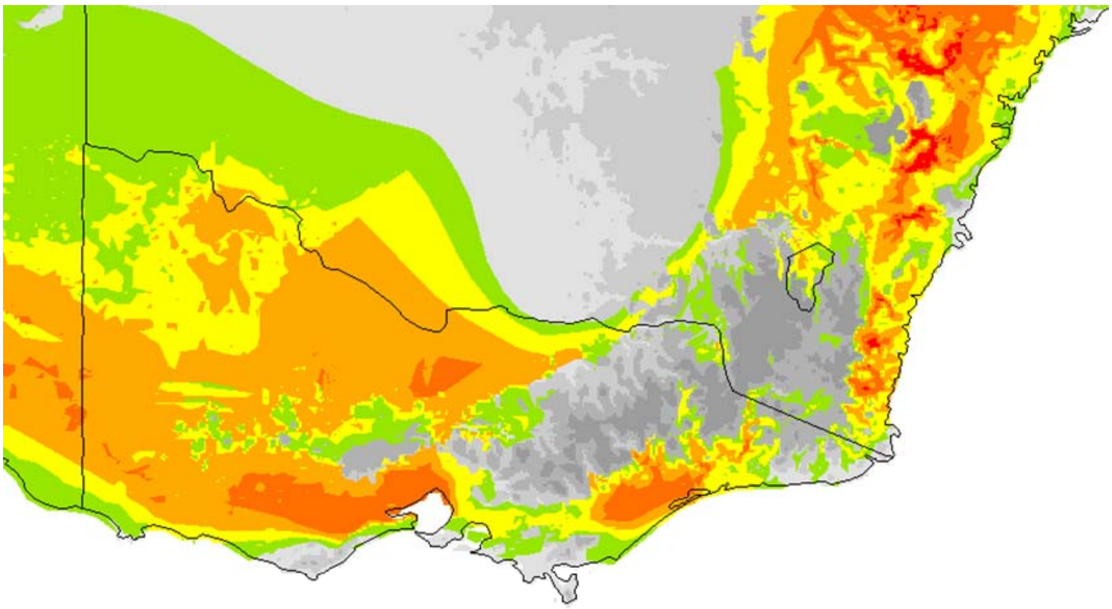
Figure 32a. *Heliotropium amplexicaule* B1 scenario (low)



Baseline climate

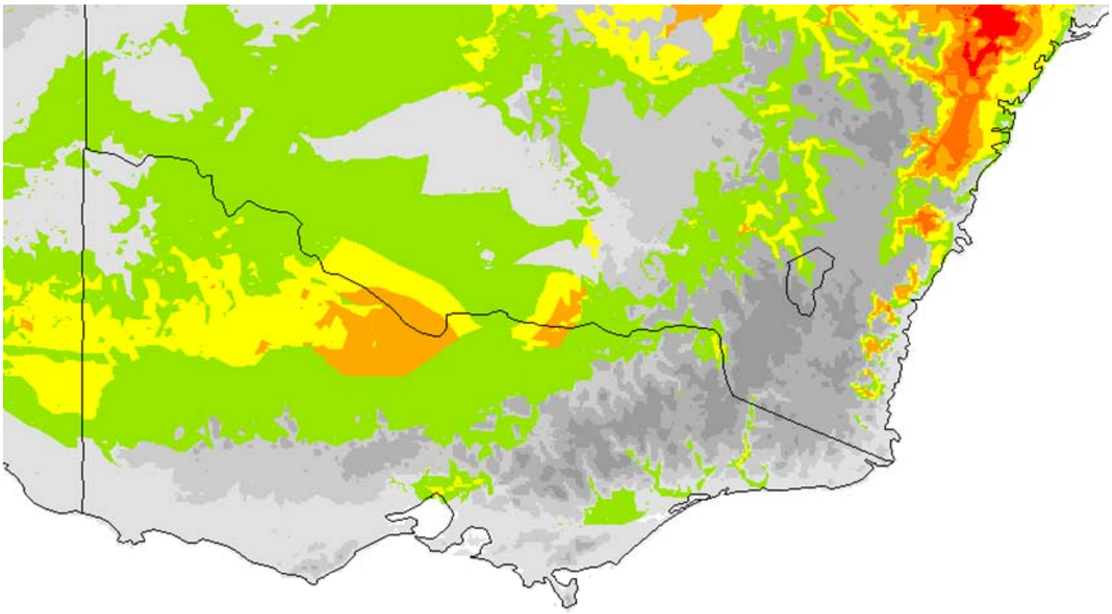


2030

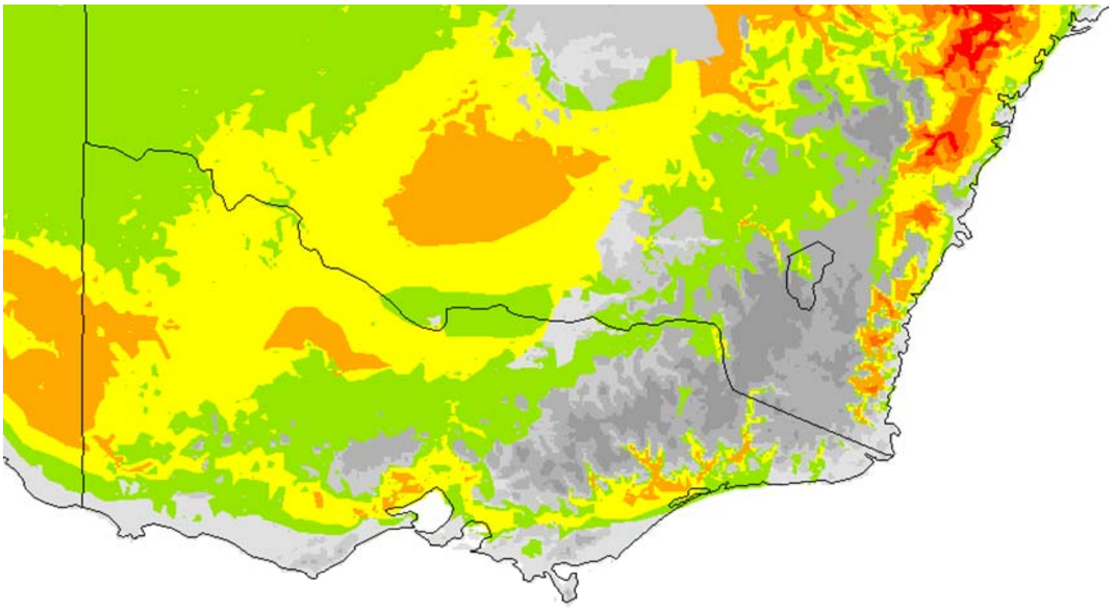


2070

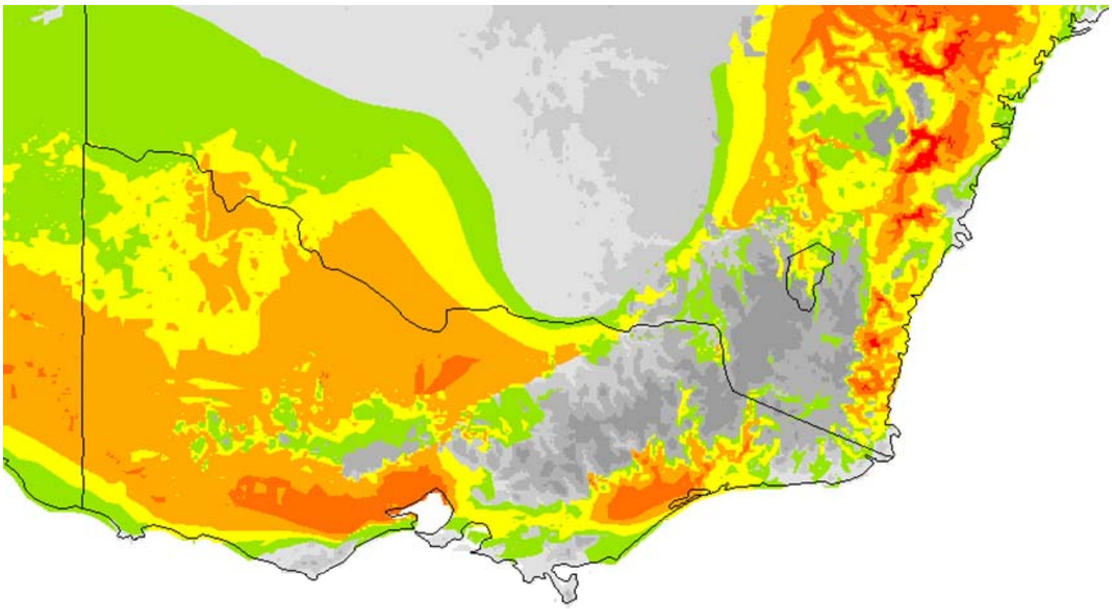
Figure 32b. *Heliotropium amplexicaule* A1 scenario (mid)



Baseline climate

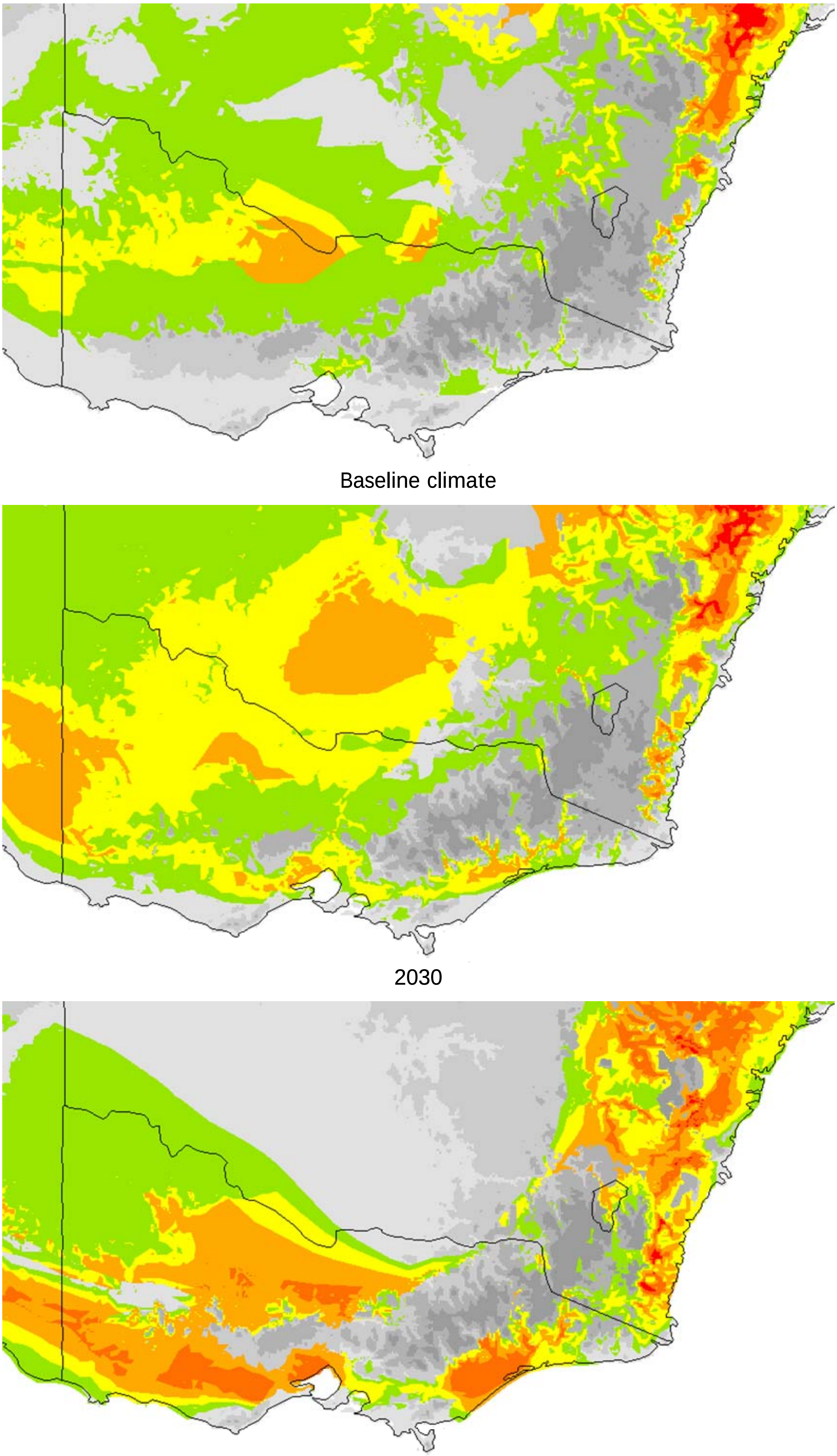


2030



2070

Figure 32c. *Heliotropiium amplexicaule* A1F scenario (high)



Baseline climate

2030

2070

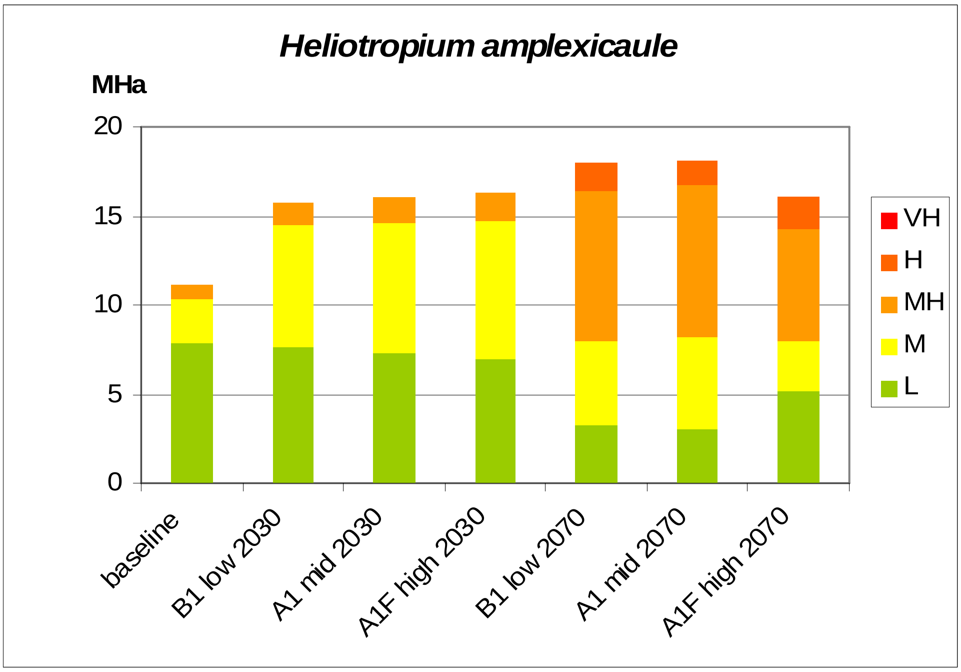


Figure 33. Area occupied by the climate envelope for *Heliotropium amplexicaule* under a range of climate scenarios over time

Results summary for *Heliotropium amplexicaule*

Across the timescale there was a general trend towards a larger climate envelope with greater degree of climatic suitability for this species.

B1 (low)

2030

There was a noticeable increase in the size of the climate envelope, expanding to the south of the state and also filling most of the Mallee region. Much of the north-west also became more climatically suited, increasing from likely to a moderate climate match.

2070

The climate envelope expanded further south to cover all but the Great Dividing Range and the most southern coast promontories: the Otways, Mornington Peninsula, and Wilson's Promontory and surrounds. Large areas of high climate match appeared and the moderately high areas expanded greatly.

A1 (mid)

2030

There was very little difference in the climate envelope under this scenario when compared with B1 low.

2070

There was very little difference in the climate envelope under this scenario when compared with B1 low.

A1F (high)

2030

There was very little difference in the climate envelope under this scenario when compared with B1 low.

2070

At 2070 there was a slight contraction of the climate envelope under this scenario, although it remained large than that observed under baseline conditions. The contraction occurred as a sliver of land from near Ballarat to the west of the state became climatically unsuited to the establishment and growth of this species.

Hordeum glaucum Steud.

blue barley-grass

syn. *Critesion murinum* ssp. *glaucum*

Hordeum glaucum is native to the dry parts of the east of: Europe, western Asia, and North Africa and inhabits 'steppe and sub-desert, dry foothill pastures, waste places, fields, etc.'

In New Zealand it is restricted to areas with rainfall less than 550 mm, and more than 6 months where evapotranspiration exceeds rainfall.

In Australia it is a component of annual pastures and provides useful early feed but is considered undesirable because its sharp seeds enter the skin, eyes, and wool of sheep with a resulting loss in productivity. It occurs in the semiarid zone of the southern States (<425 mm of rain), and in wetter regions in northern New South Wales and southern Queensland (Cocks, Boyce & Kloot 1976).

The parameters chosen to model this species were 1, 5, 6, 10, 11, 20, 22, 27 & 31.

The baseline climate match for this species (Fig. 34) encompassed more than 90% of the current distribution points, however it did not concur with a cluster of points in NT, and some in Qld, WAS and SA fell north of its northern boundary. The SA climate match showed a high concentration of records concurring with the climate match, but the match was not as good in WA.

Hordeum glaucum

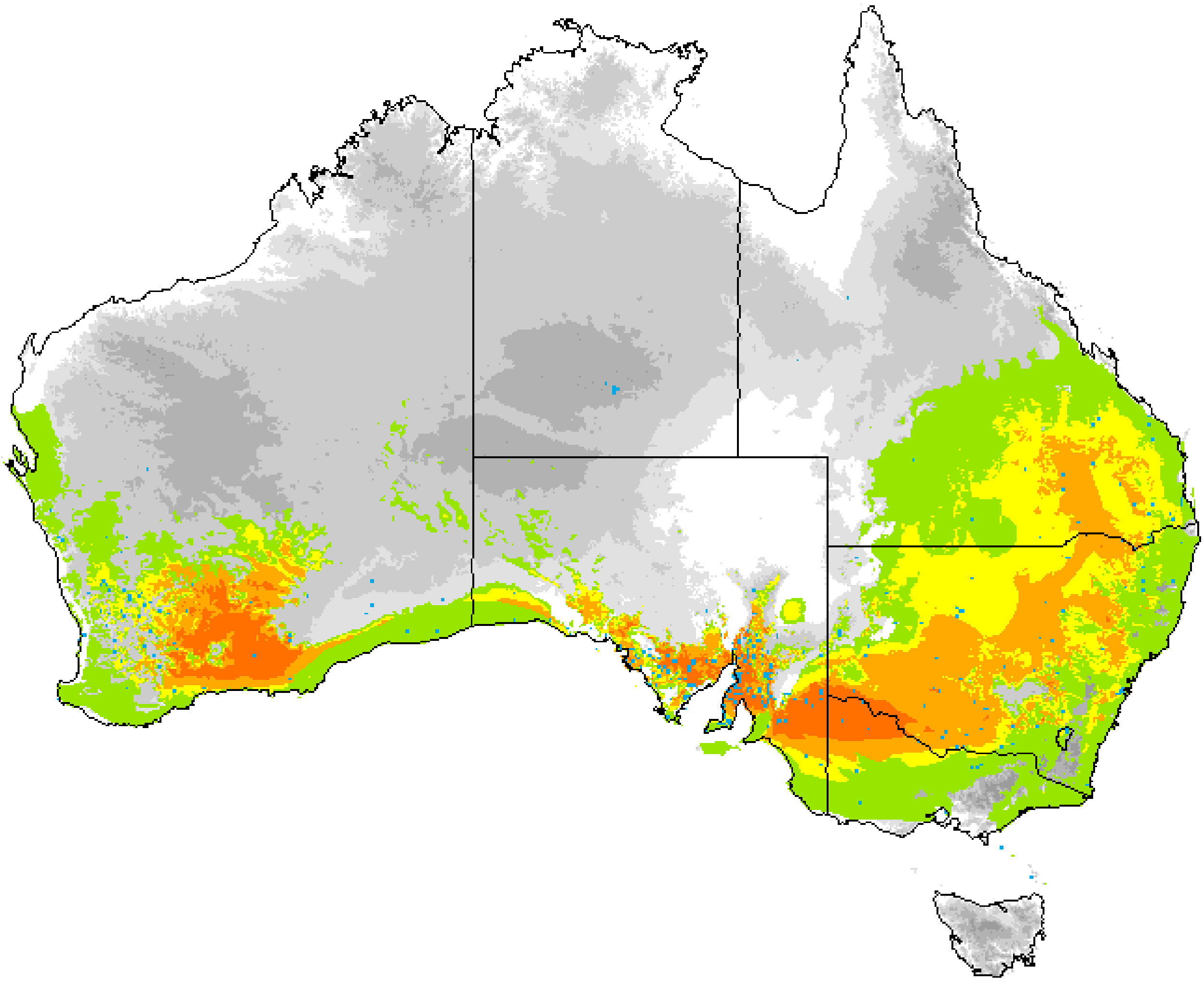
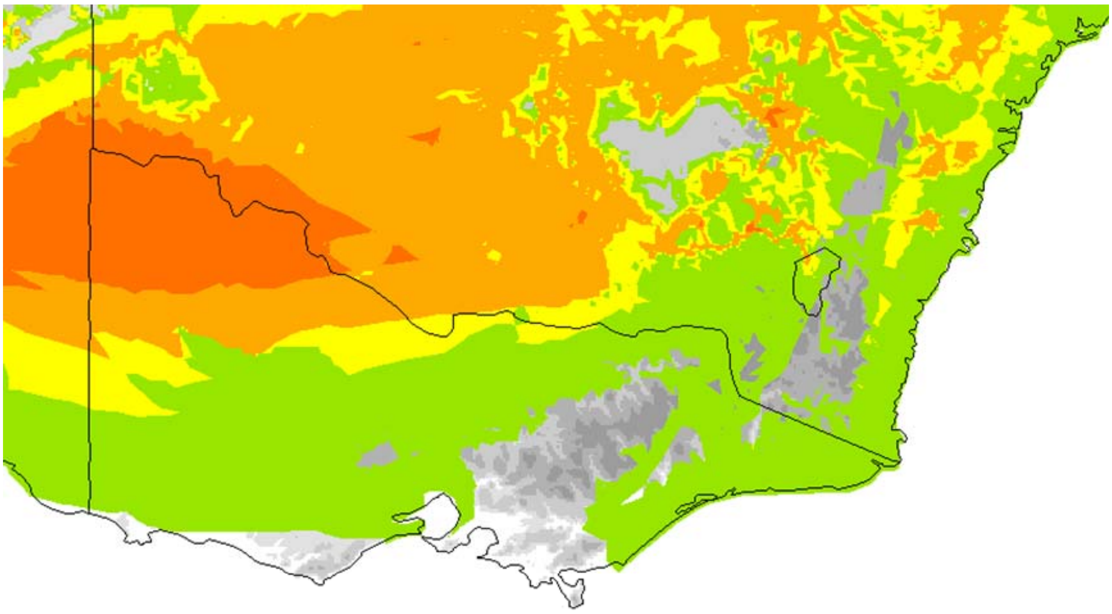
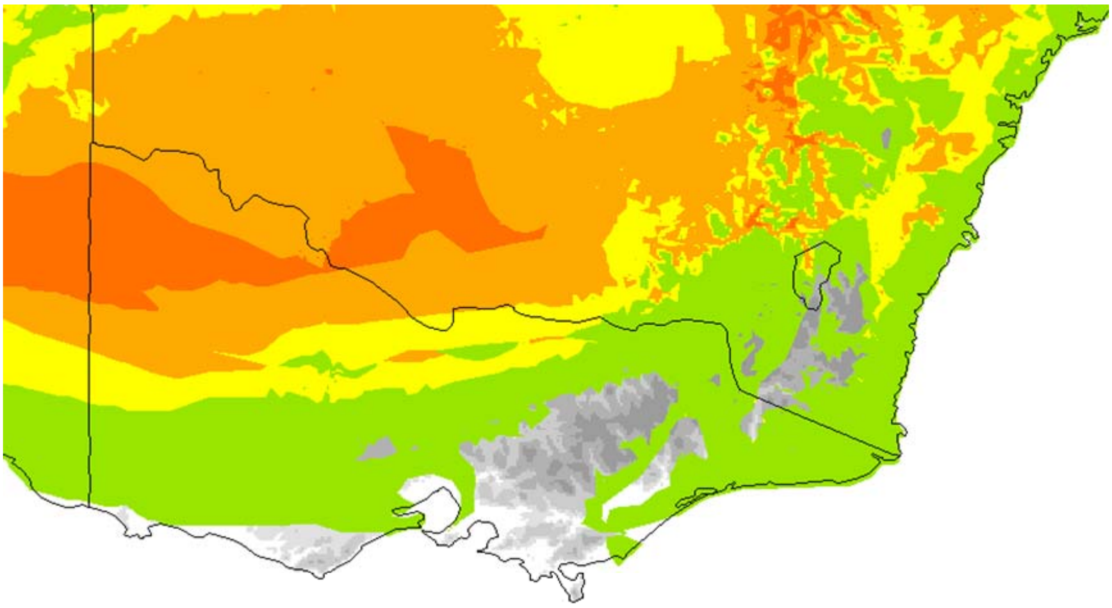


Figure 34. Comparison of current distribution with the baseline climate match

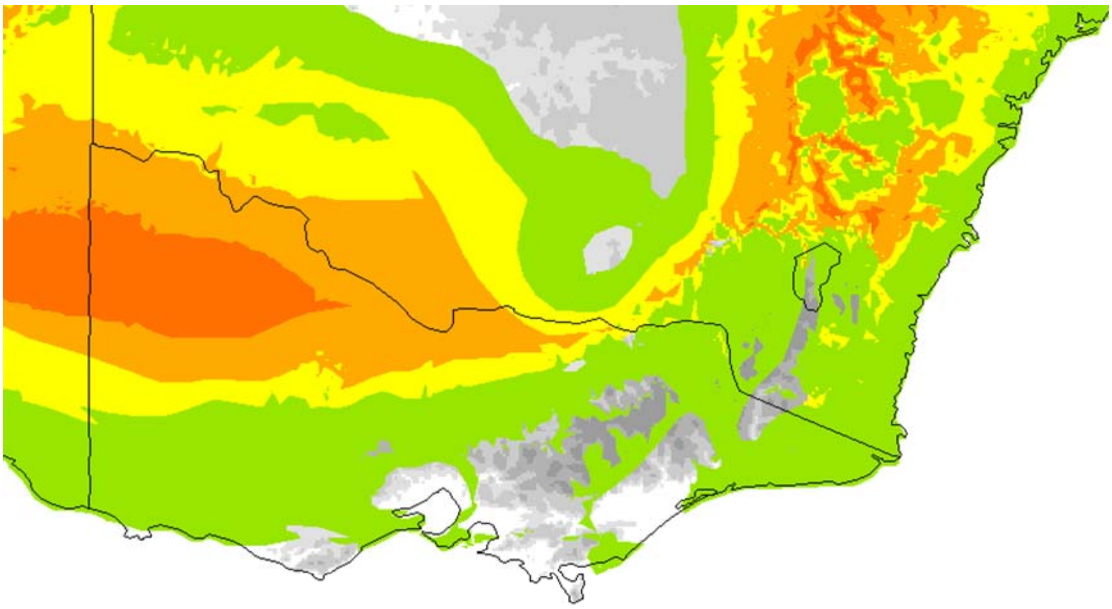
Figure 35a. *Hordeum glaucum* B1 scenario (low)



Baseline climate

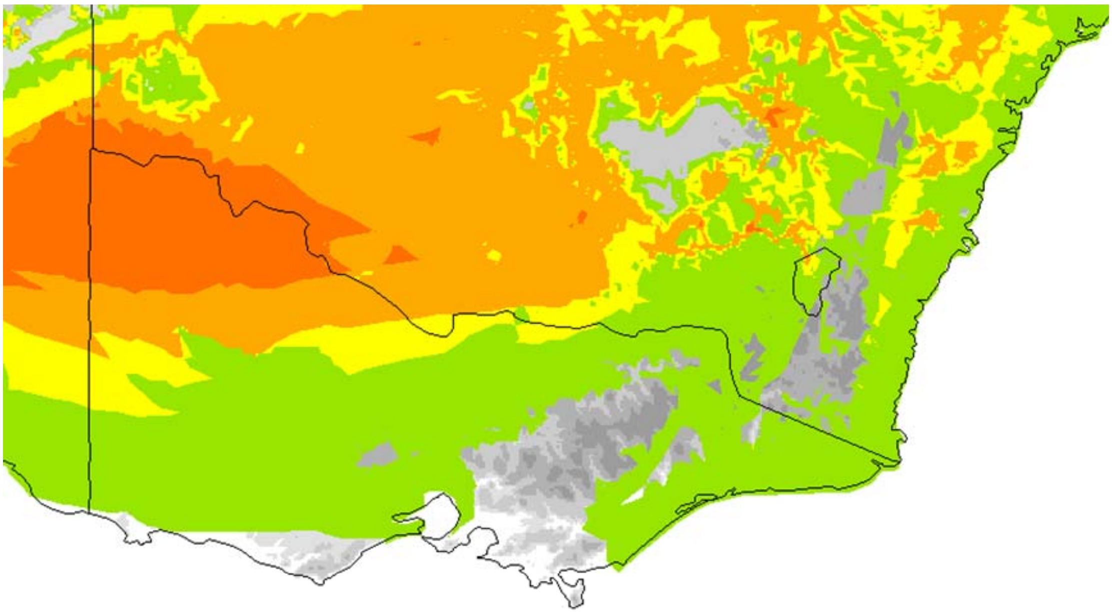


2030

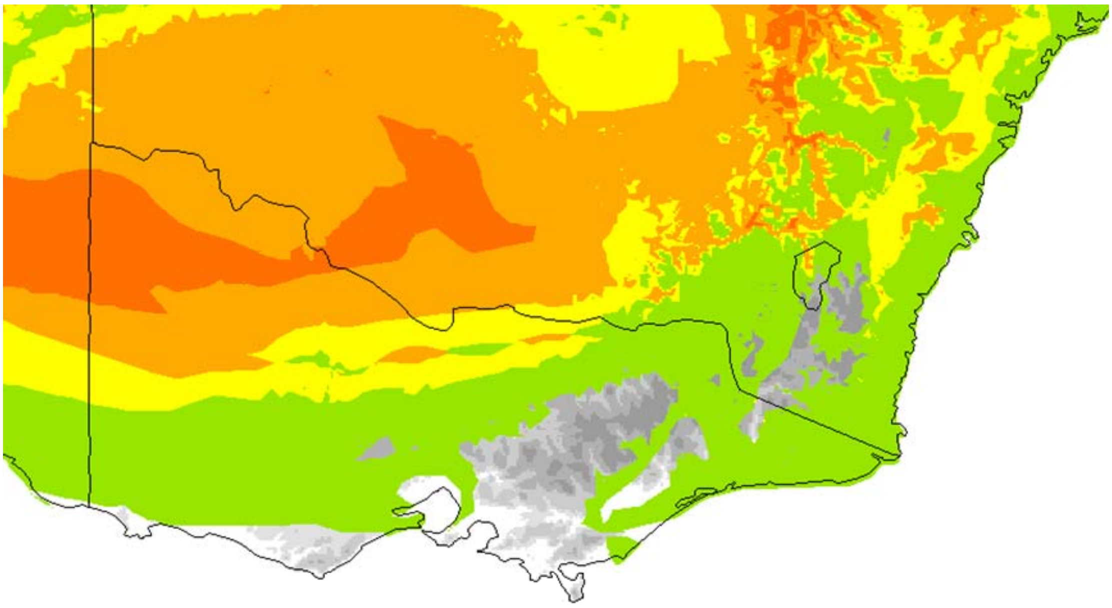


2070

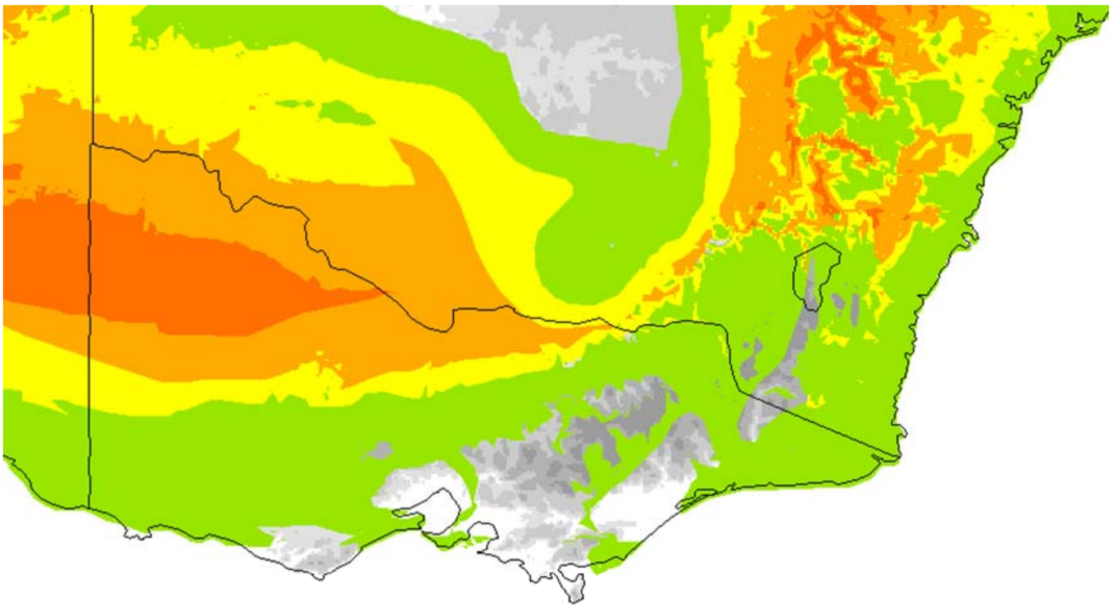
Figure 35b. *Hordeum glaucum* A1 scenario (mid)



Baseline climate

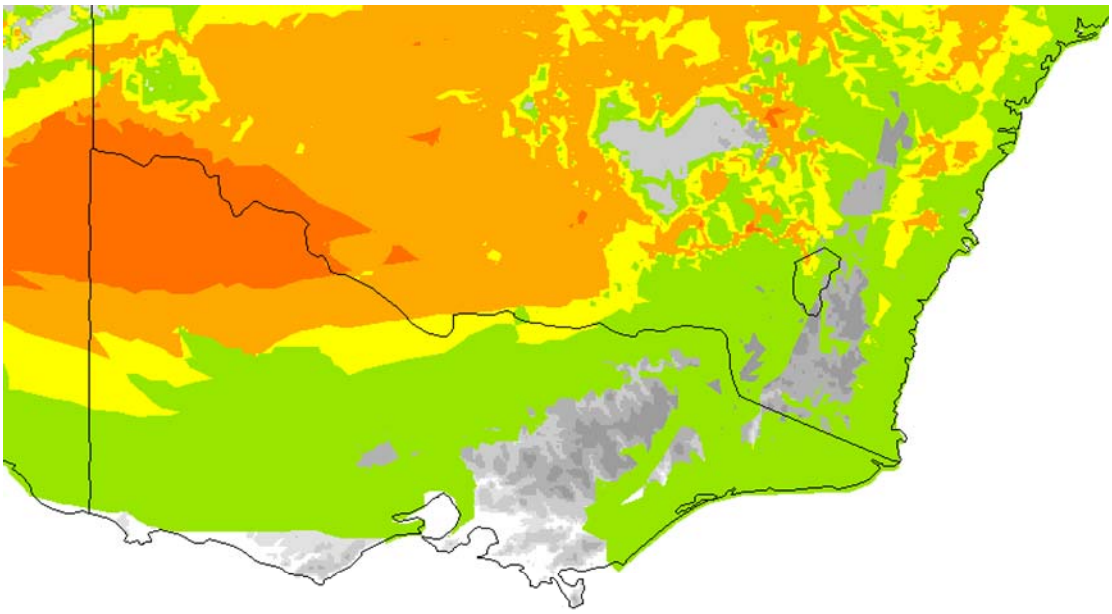


2030

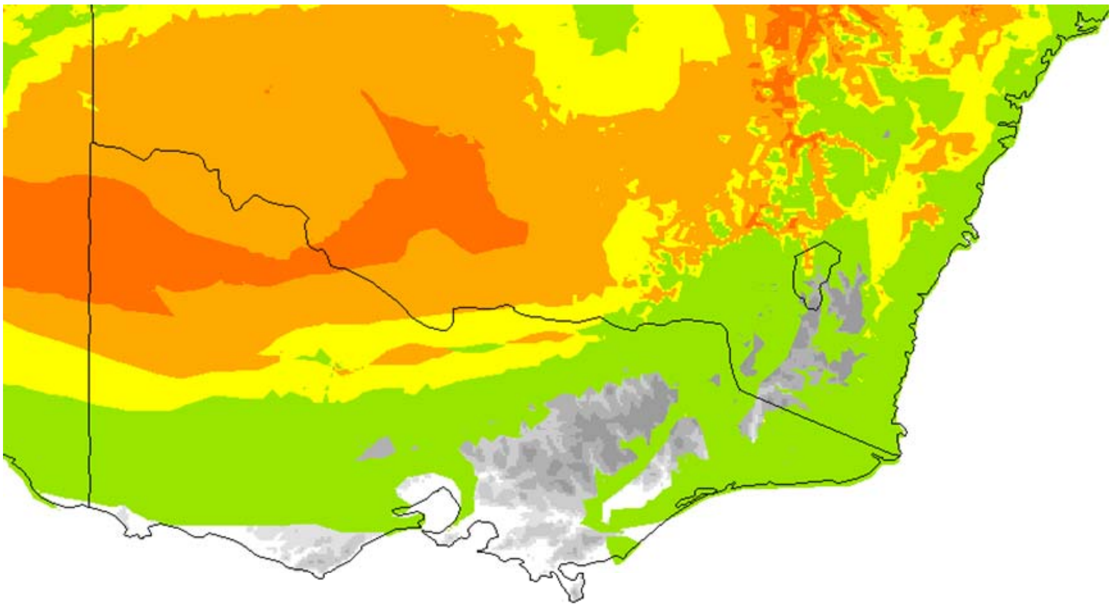


2070

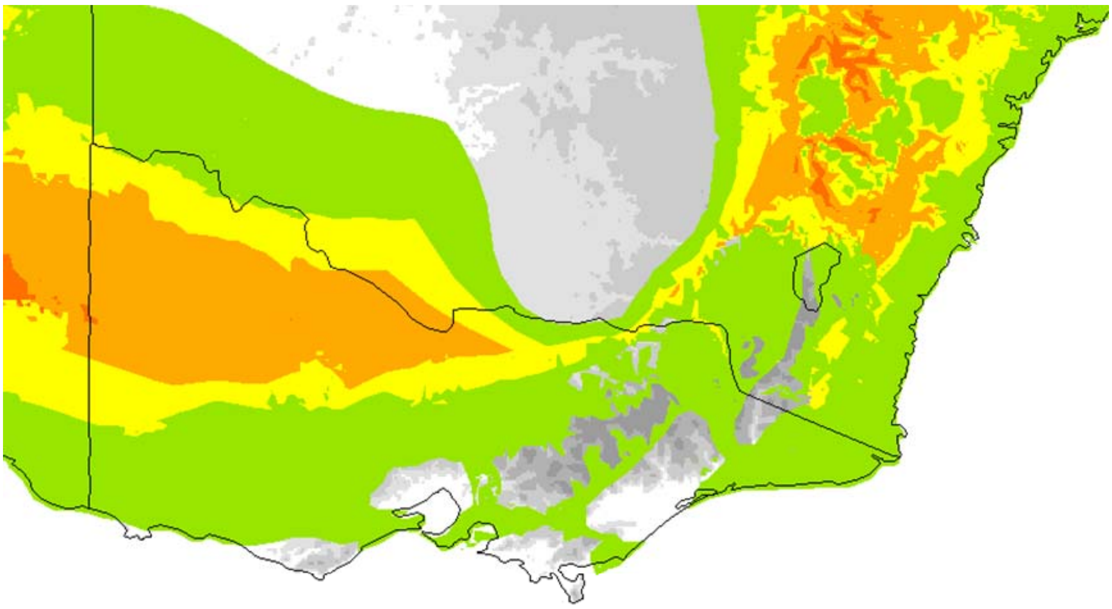
Figure 35c. *Hordeum glaucum* A1F scenario (high)



Baseline climate



2030



2070

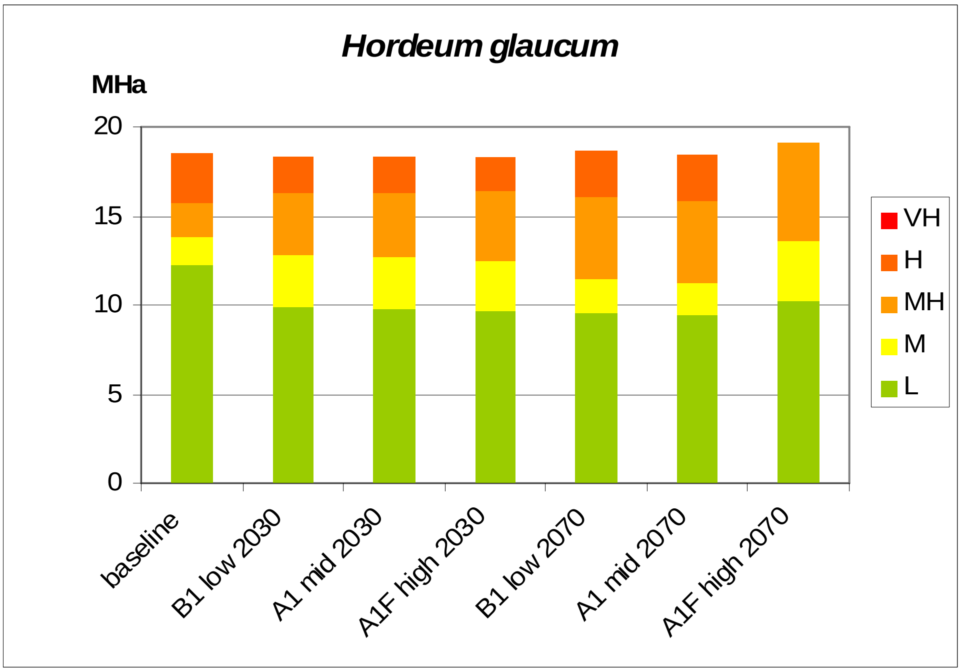


Figure 36. Area occupied by the climate envelope for *Hordeum glaucum* under a range of climate scenarios over time

Results summary for *Hordeum glaucum*

A large proportion of Victoria was occupied by the climate envelope at baseline conditions and this changed very little under climate change. Climatic suitability also changed little, but the pattern differed over time with a southern migration of the high climate match, leaving the northern part of the Mallee less climatically suited to this species, although still at a moderately high suitability. More southerly parts of the state appeared increasingly better suited climatically under all scenarios.

At A1F high, climatic conditions became less well suited in the north-west of the state as the high climate match almost disappeared. The climate envelope did expand slightly to the south, however, increasing the area of suitable climate for this species.

Lantana camara L. lantana

Originating from tropical and subtropical America (van Oosterhout, 2004), and now also present in warm temperate climates, lantana invades open and semi-open plant communities such as grasslands and woodlands (Swarbrick, Wilson and Hannan-Jones 1998). It forms dense clumps 2-4m tall and can smother vegetation to 15m high. In agricultural systems, lantana invades pasture and grazing land and is toxic to livestock. It "is now a major weed pest in over 60 countries, and is considered to be one of the 10 worst weeds worldwide" (van Oosterhout, 2004).

Lantana has naturalised in most states and territories in Australia, except Tasmania, with most populations occurring along the eastern seaboard, from southern NSW to northern Qld.

Lantana ceases to grow at temperatures below 5°C and shoots are sensitive to frost. It grows best in constant rainfall or in areas of high soil moisture, can survive prolonged dry periods, but will not tolerate waterlogging or lengthy droughts. Lantana seeds are dispersed by birds and mammals and require warm temperatures and sufficient moisture to germinate (van Oosterhout, 2004). The climatic variables likely to influence the distribution of lantana include minimum temperatures, rainfall and soil moisture.

The parameters used to model this species' distribution were: 2, 3, 4, 7, 8, 10, 12, 16, 17 & 18.

The climatic envelope for lantana's baseline climate (Fig. 37) enclosed almost all of the current distribution data. It showed a high potential distribution along the Eastern Seaboard, which is where lantana is mostly found.

Lantana camara

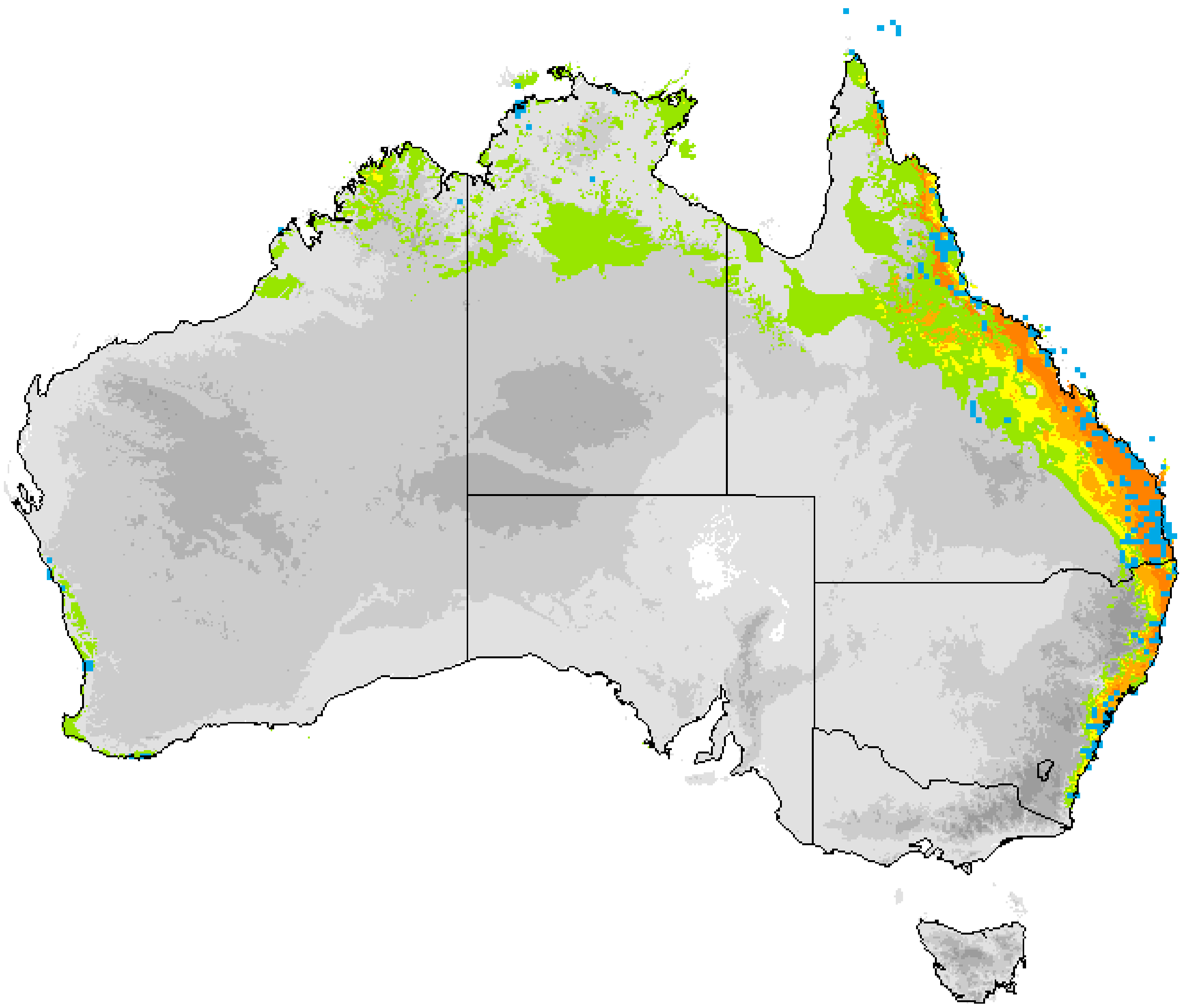
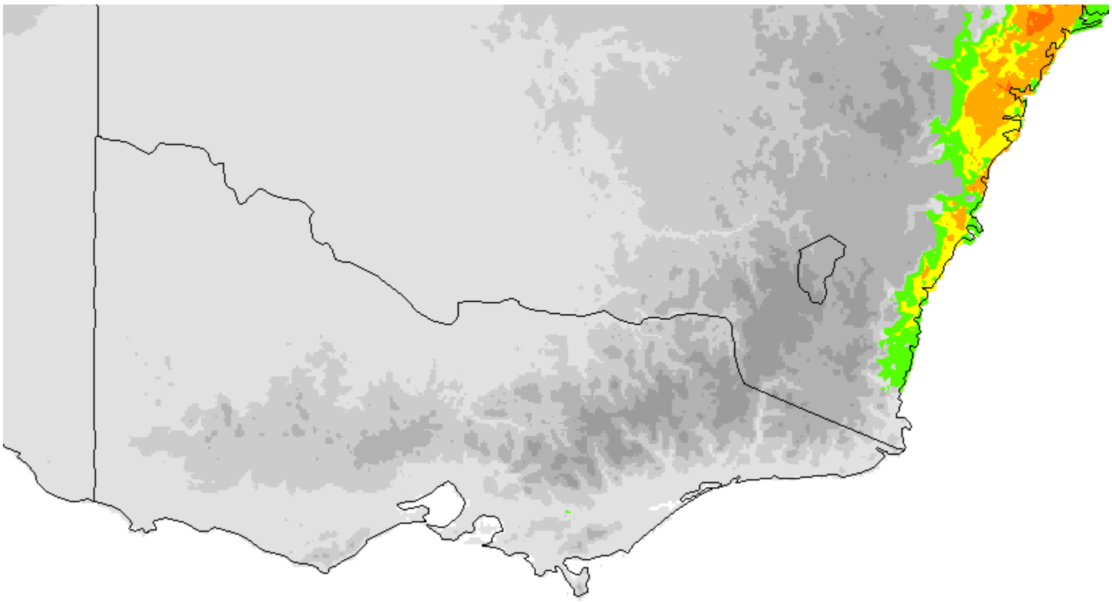


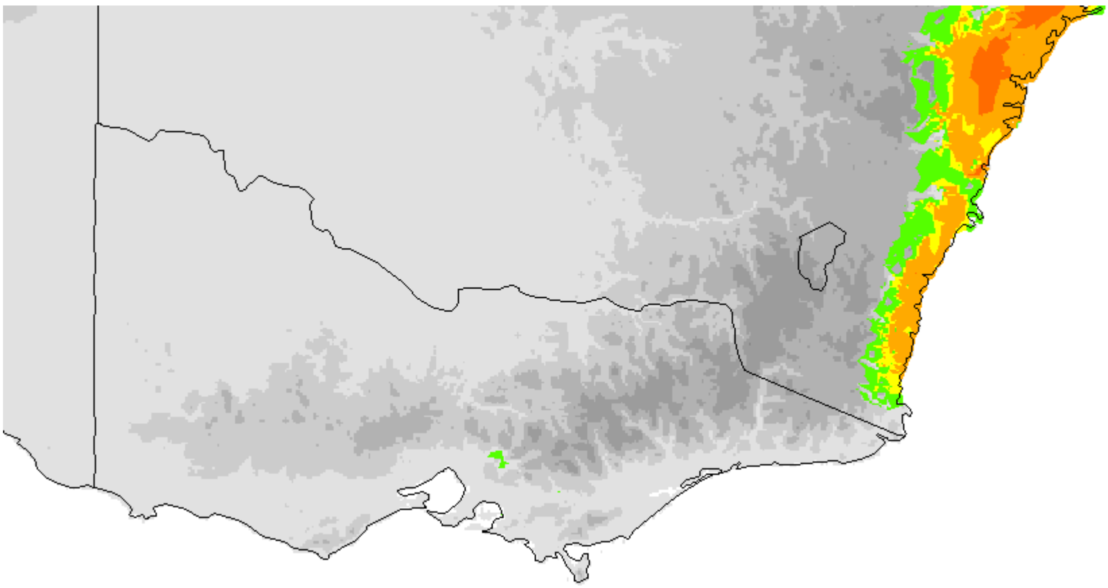
Figure 37. Comparison of current distribution with the baseline climate match

Figure 38a. ***Lantana camara*** B1 scenario (low)



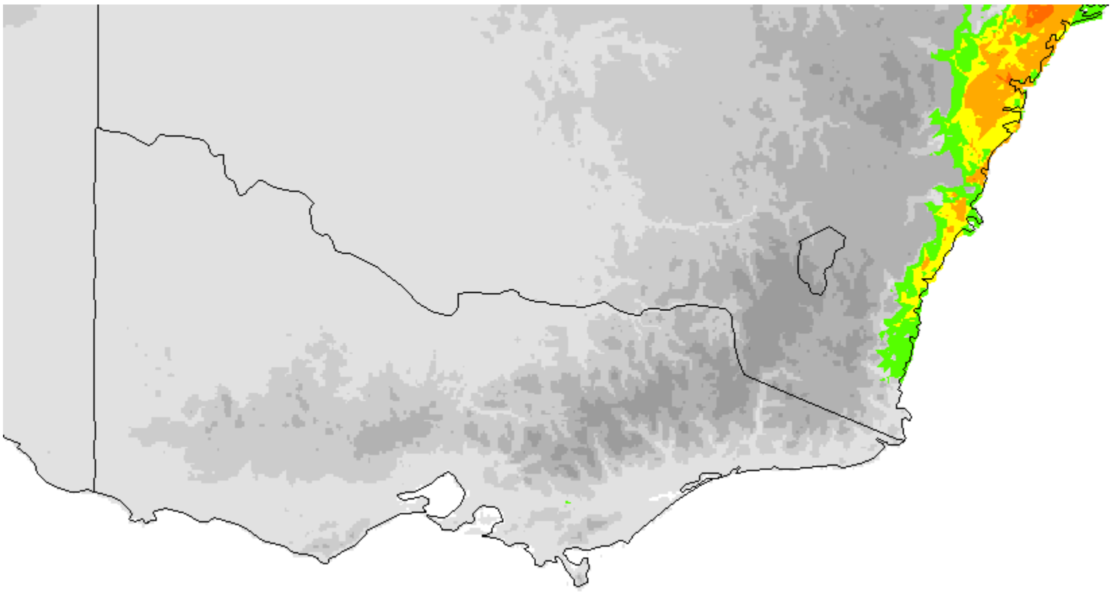
Baseline climate

2030

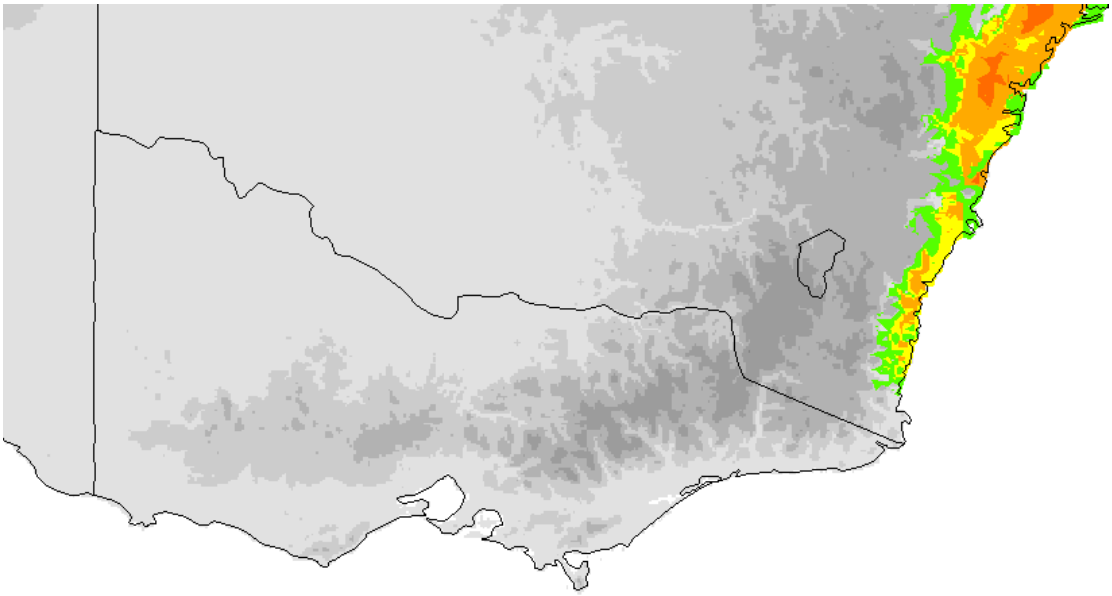


2070

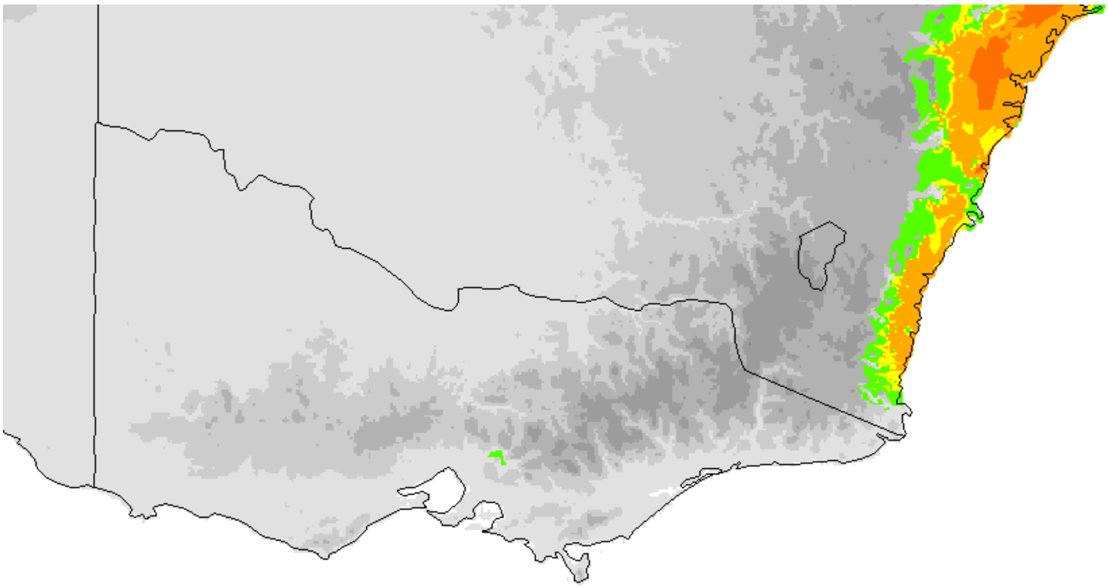
Figure 38b. *Lantana camara* A1 scenario (mid)



Baseline climate

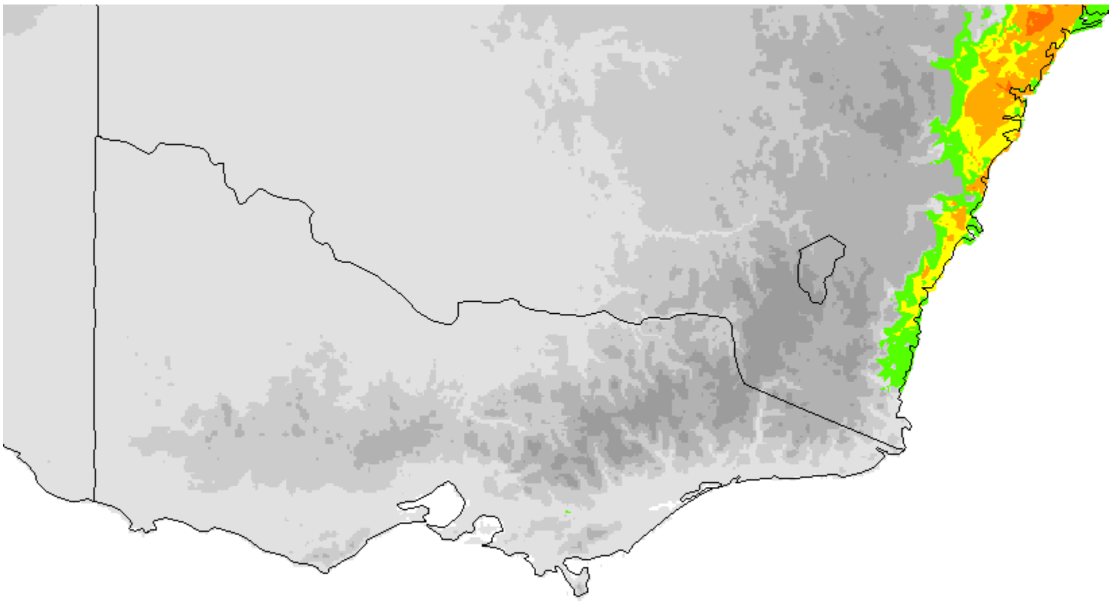


2030



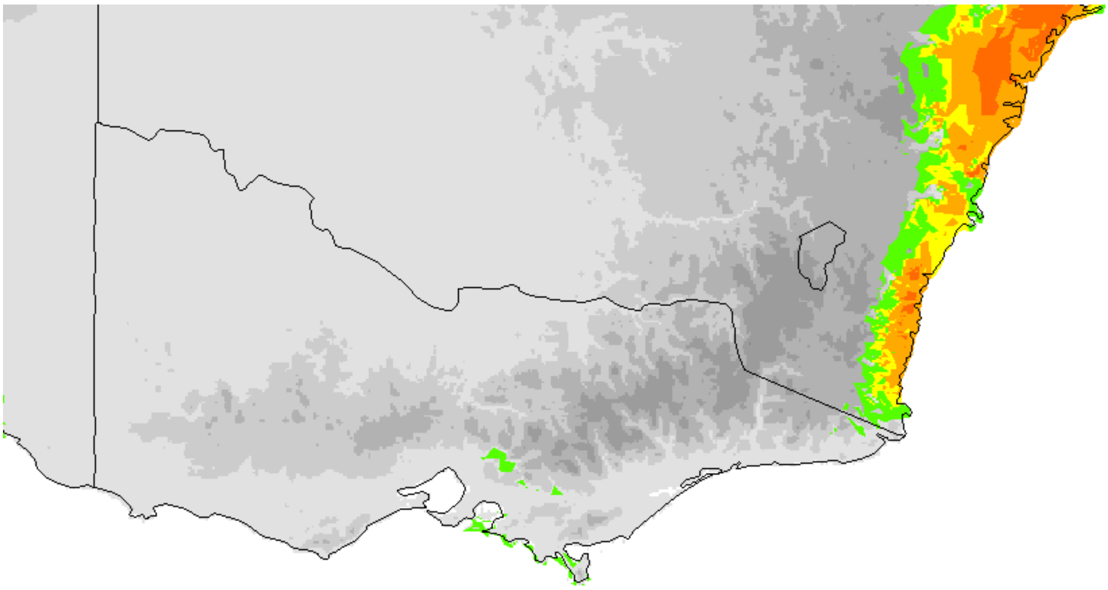
2070

Figure 38c. *Lantana camara* A1F scenario (high)

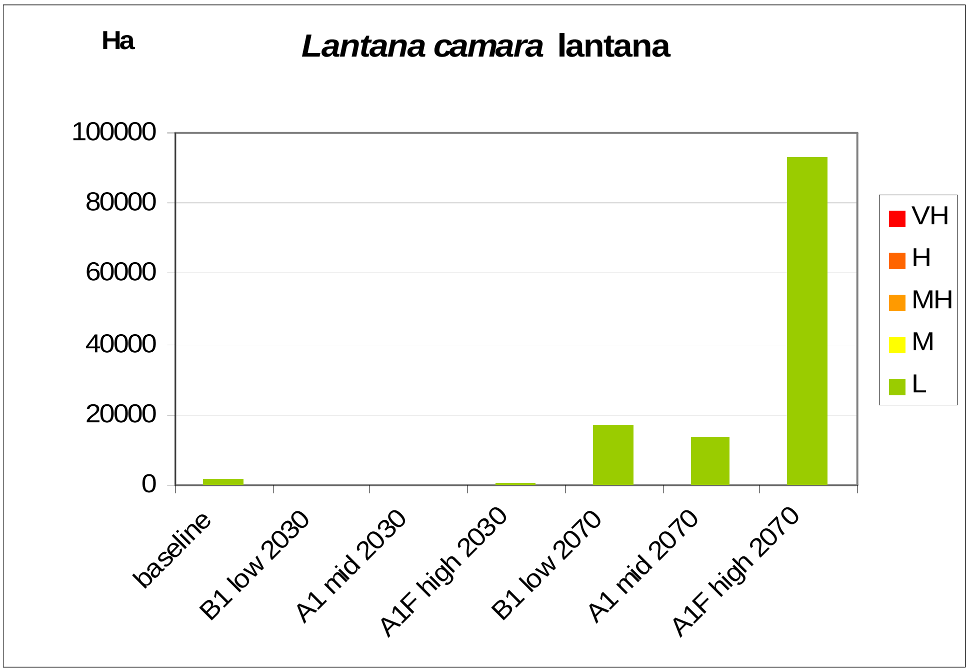


Baseline climate

2030



2070



Figue 39. Area occupied by the climate envelope for *Lantana camara* under a range of climate scenarios over time

Results summary for *Lantana camara*

Under baseline conditions there was a small patch of likely climate match around Morewell in Victoria. The rest of the climate envelope extended north from Merimbula, on the New South Wales coast.

B1 (low)

2030

The southern limit of the climatic envelope migrated south, but did not reach the Victorian border.

2070

The southern limit of the climatic envelope migrated south, but did not reach the Victorian border. A small patch of likely climate match appeared near Healesville.

A1 (mid)

2030 & 2070

As was observed under the B1 low scenario, the southern limit of the climatic envelope migrated toward Victoria, reaching a little further south in this scenario, but still did not reach the Victorian border. Again, there was a small patch of likely climate match near Healesville

A1F (high)

2030 & 2070

At 2030 the climatic envelope appears very similar for all three scenarios, but in 2070, for A1F high, the climate envelope along the NSW coast crossed the Victorian border and scattered patches of likely climate match appeared at the eastern tip of Gippsland. Further patches of likely climate match appeared along the southern coast from Western Port Bay to Wilson's Promontory, and there were scattered patches from Healesville to around Moe.

Leycesteria formosa Wallich. in Roxb.

Himalayan honeysuckle

Himalayan honeysuckle is native to the Himalayas and West China (Harden, 1992).

It is not a weed of agriculture, but competes strongly with trees establishing in forestry plantations (Webb *et al*. 1988) and can also establish in scrublands, riverbanks, lakesides, forest margins, especially common in cut-over forest (Webb *et al*. 1988). Himalayan Honeysuckle invades damp sclerophyll forest, wet sclerophyll forest and riparian vegetation (Carr *et al.* 1992). It has also become a weed in UK (Clapham, 1952).

It occurs in cool, high rainfall regions, mainly in gullies and protected hillsides with partial shade and moist to wet fertile soils. It is frost resistant but drought tender (Blood 1998, Bodkin 1990).

Parameters used to model species distribution: 1 & 12.

The baseline climate match for Himalayan honeysuckle (Fig. 40) was fairly successful, with more than 99% of the current distribution points enclosed in the climate envelope.

Lecesteria formosa

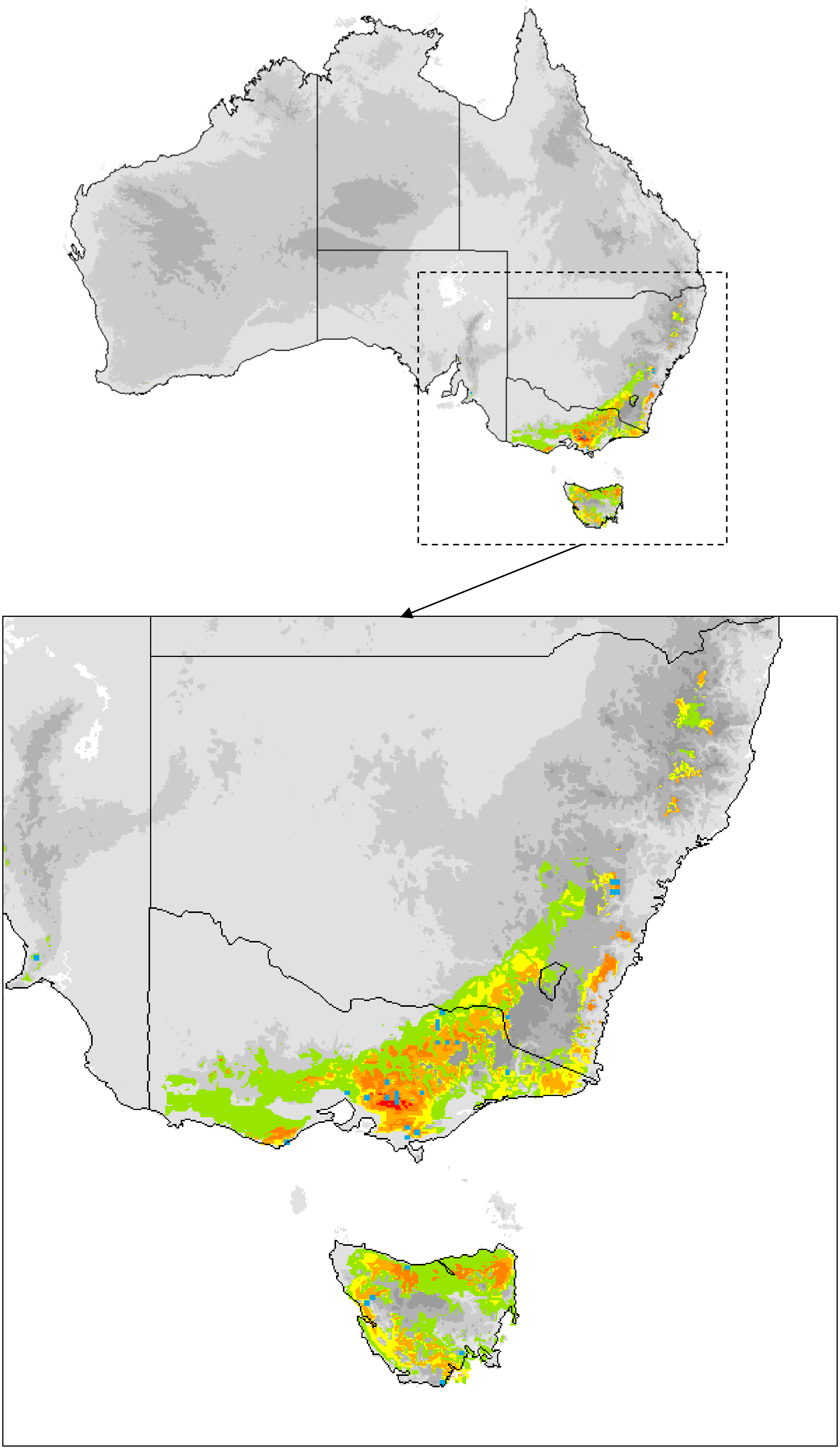
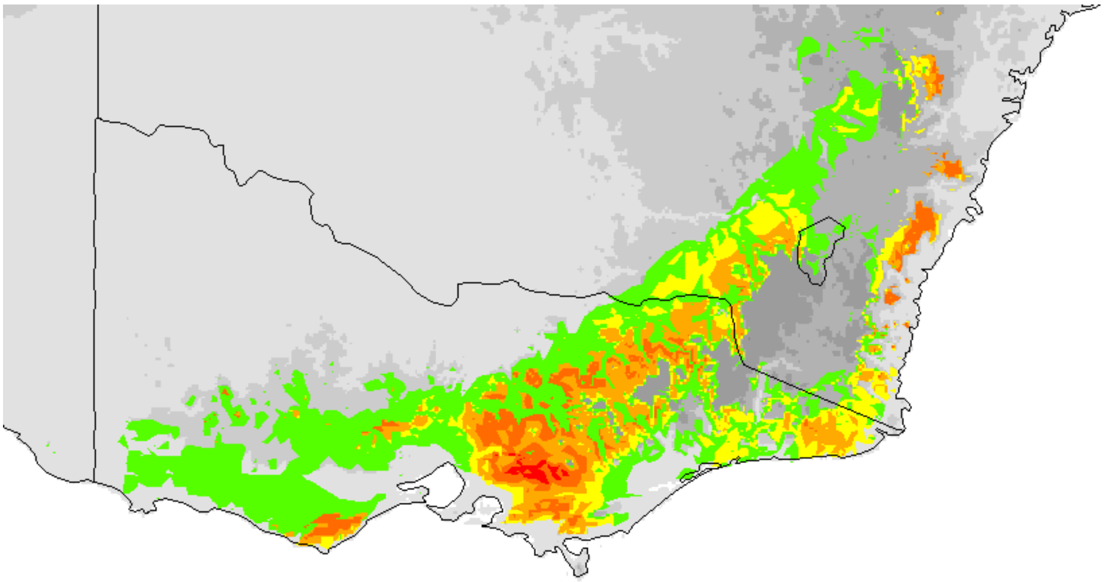
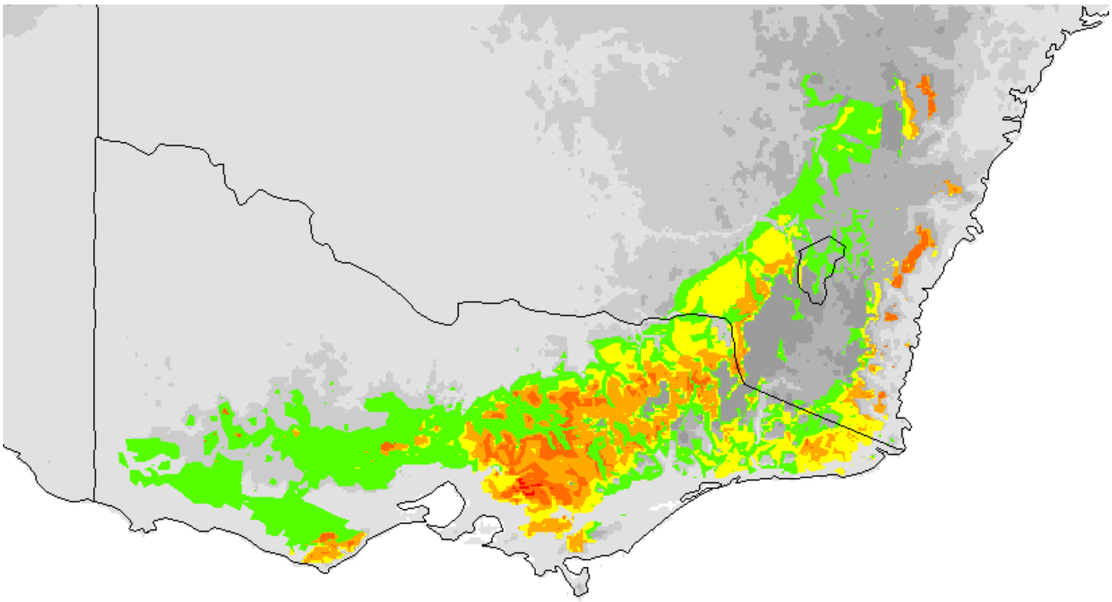


Figure 40. Comparison of current distribution with the baseline climate match

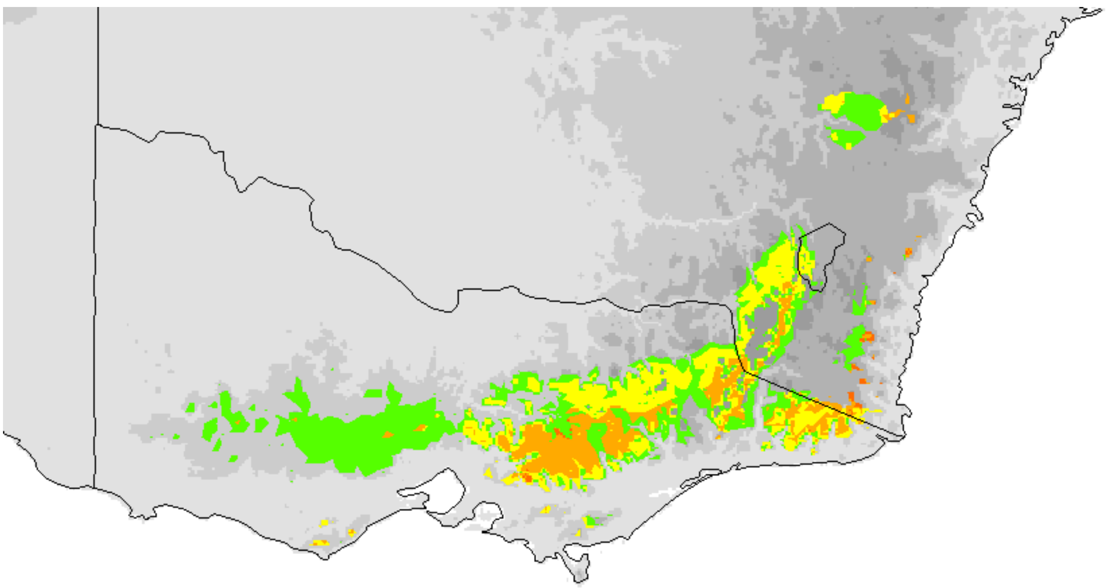
Figure 41a. *Leycesteria formosa* B1 scenario (low)



Baseline climate

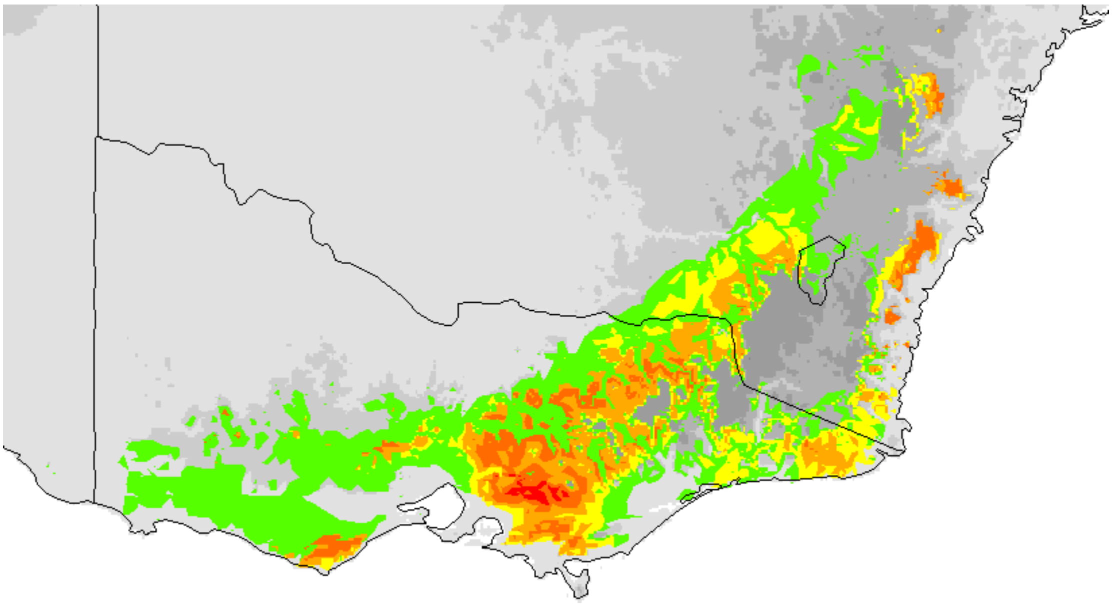


2030

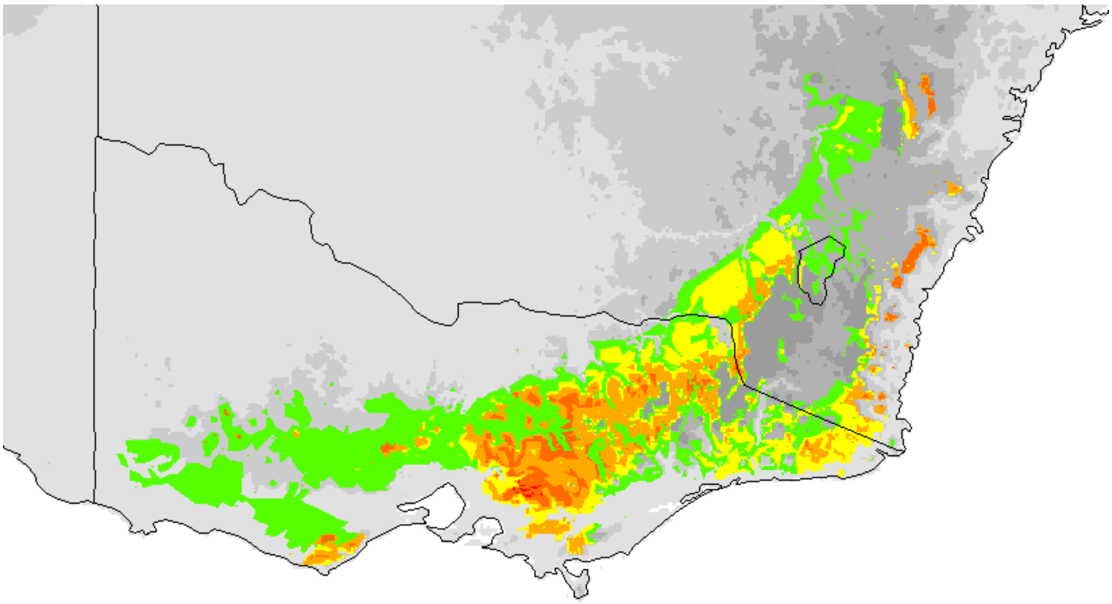


2070

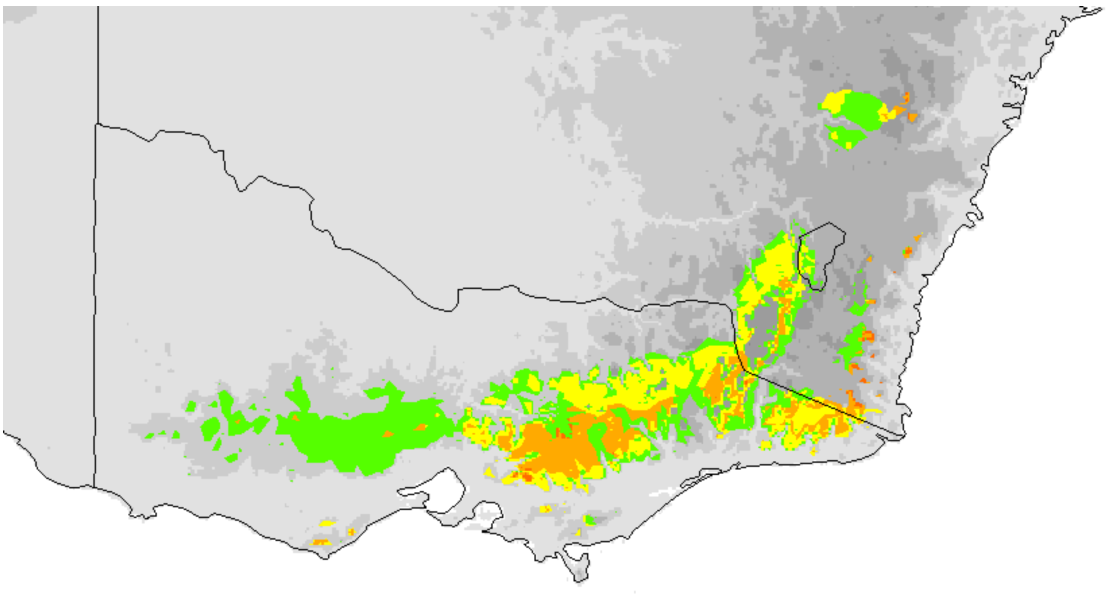
Figure 41b. *Leycesteria formosa* A1 scenario (mid)



Baseline climate

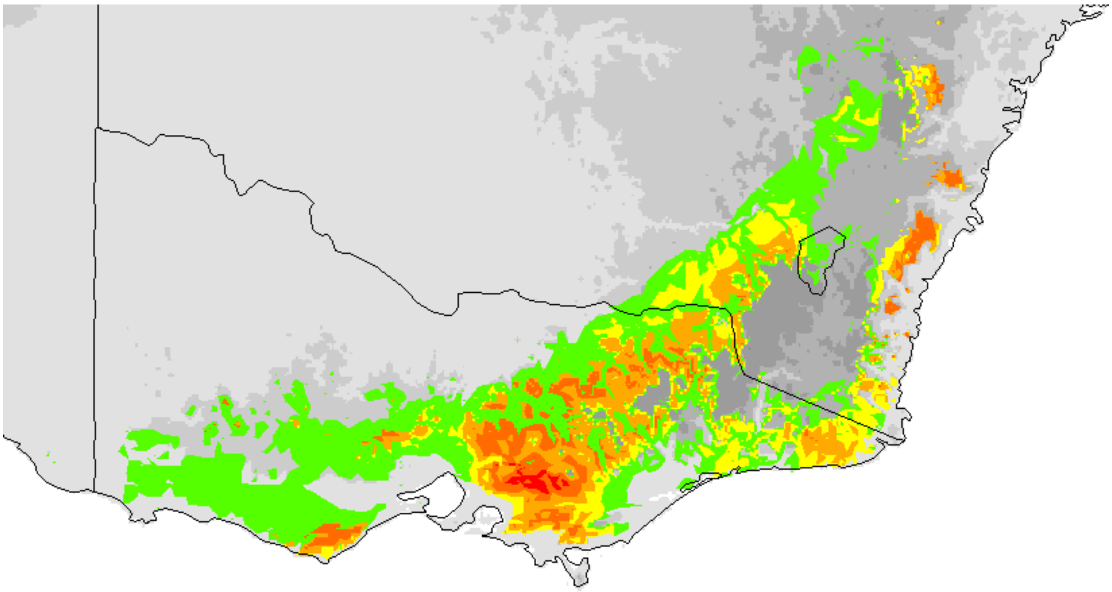


2030

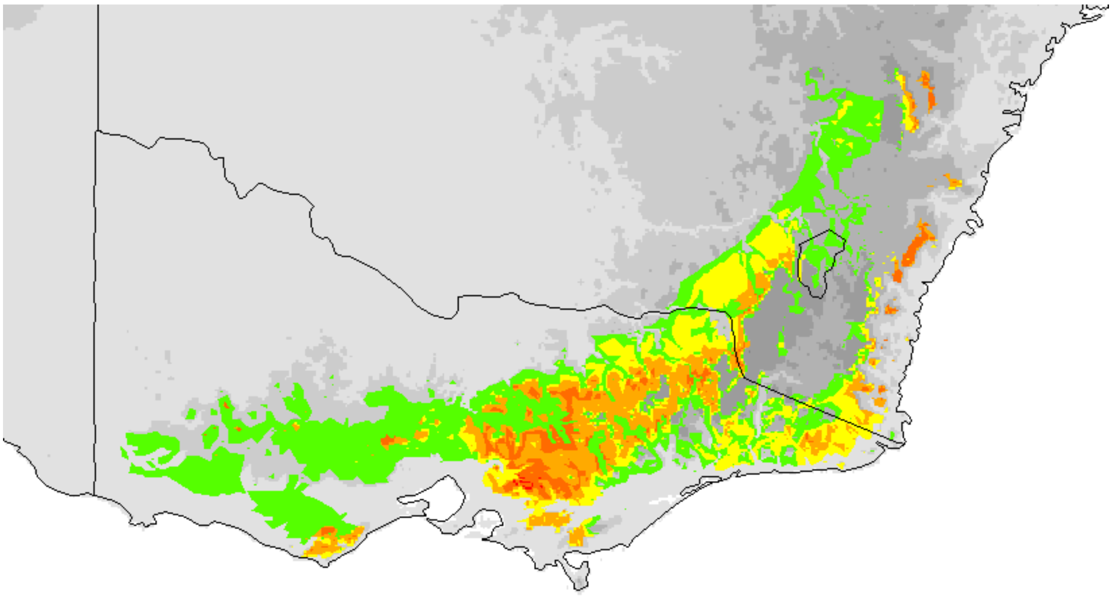


2070

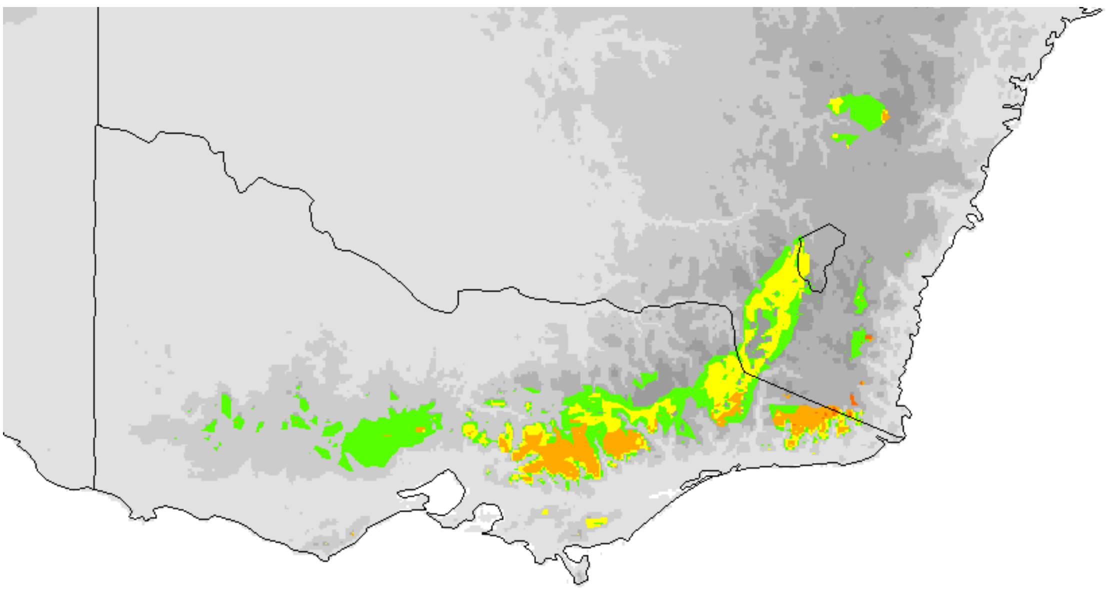
Figure 41c. *Leycesteria formosa* A1F scenario (high)



Baseline climate



2030



2070

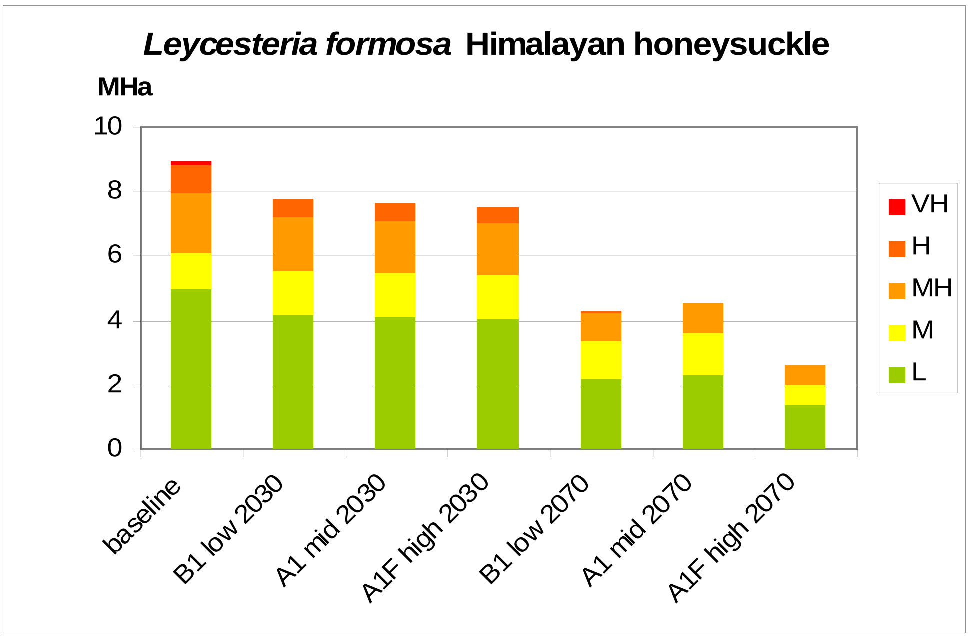


Figure 42. Area occupied by the climate envelope for *Leycesteria formosa* under a range of climate scenarios over time

Results summary for *Leycesteria formosa*

The size and quality of the climate envelope for this species in Victoria generally declined, with the areas of very high climate match disappearing under all scenarios at 2070. Suitable climatic conditions generally only remained at the highest altitudes.

B1 (low)

2030

The climate envelope contracted from the coast and occupied higher elevations.

2070

The climatic envelope was further constrained to higher elevations, contracting from the south almost entirely.

A1 (mid)

2030

A fairly similar pattern to B1 low 2030 emerged.

2070

As in B1 low 2070, the climatic envelope was practically constrained to higher elevations, but it appeared to have a slightly larger distribution in this A1 mid scenario than in the B1 low scenario.

A1F (high)

2030

As with A1 mid, a fairly similar pattern to B1 low 2030 emerged again.

2070

The climate envelope contracted drastically, confined only to the higher altitude parts of the state.

Ligustrum sinense Lour.

privet

This species was introduced from Asia (Weiss & McLaren 1999) and has become a weed in USA, and in Vic, NSW and Qld (Richardson & Richardson 2007; Weiss & McLaren 1999), where it competes with native shrubs and trees "and is a major cause of…remnant vegetation change" (Weiss & McLaren 1999).

L. sinense prefers warm, humid and moist habitats, but can establish in drier locations (Muyt 2001). Seed germinates after ripening in late Autumn/Winter in temperatures from 15-25 ^{o}C. The seedlings are able to tolerate long periods of water shortage (Weiss & McLaren 1999).

The parameters chosen to model this species were 1, 28 & 31.

The baseline climate match (Fig. 43) was very good, and encompassed more than 99% of the distribution points, with only 3 locations appearing further inland than the western boundary of the climate envelope.

Ligustrum sinense

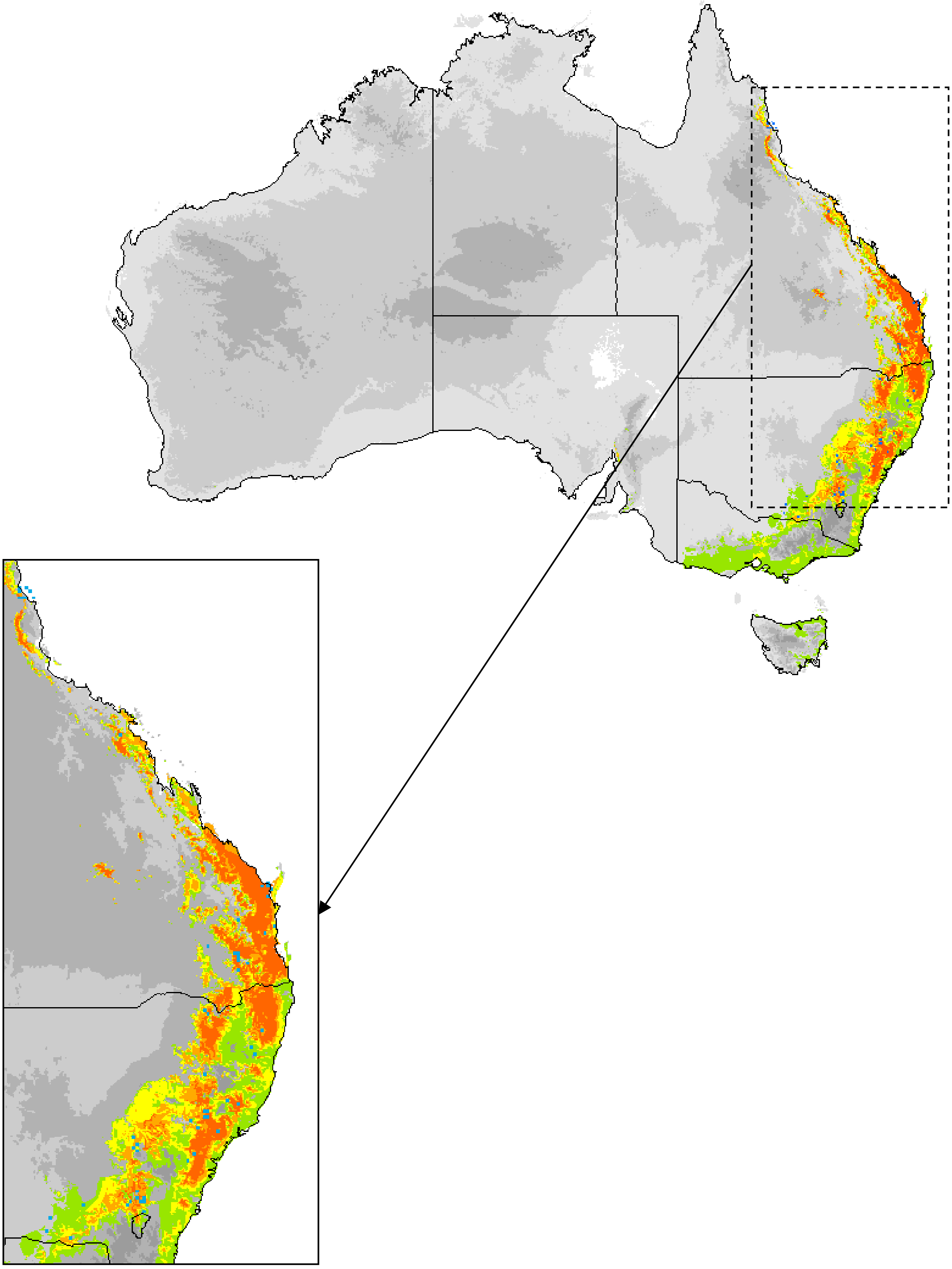
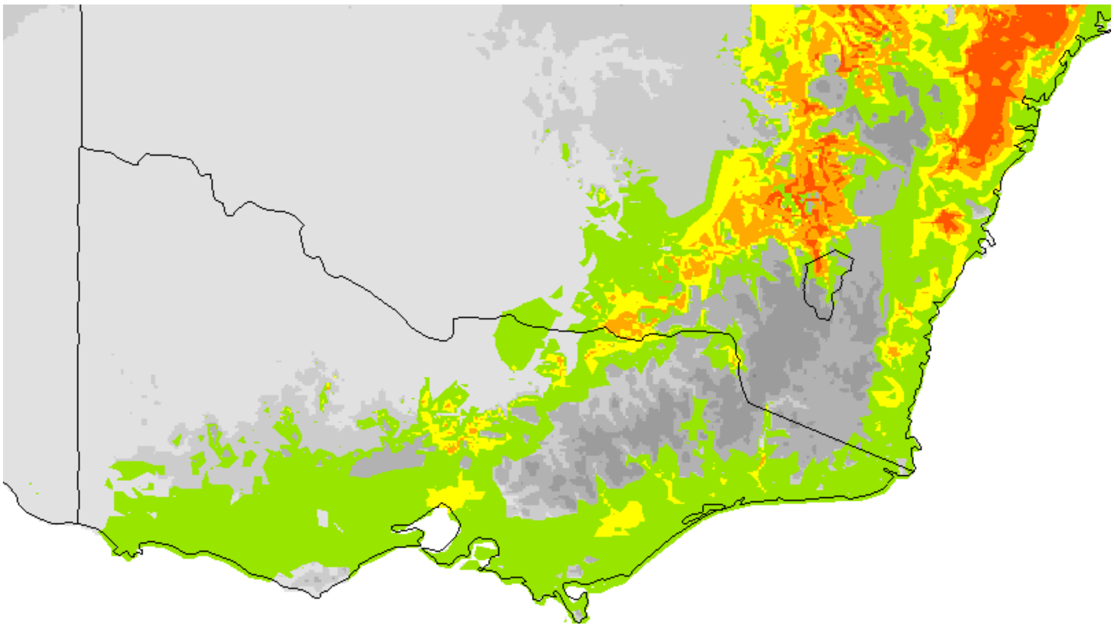
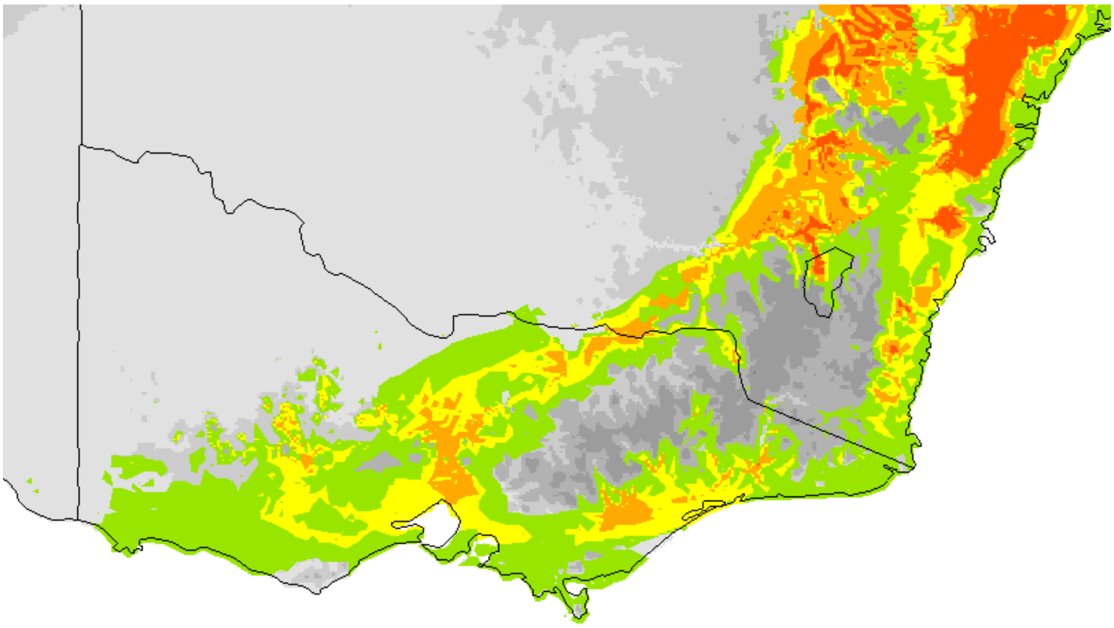


Figure 43. Comparison of current distribution with the baseline climate match

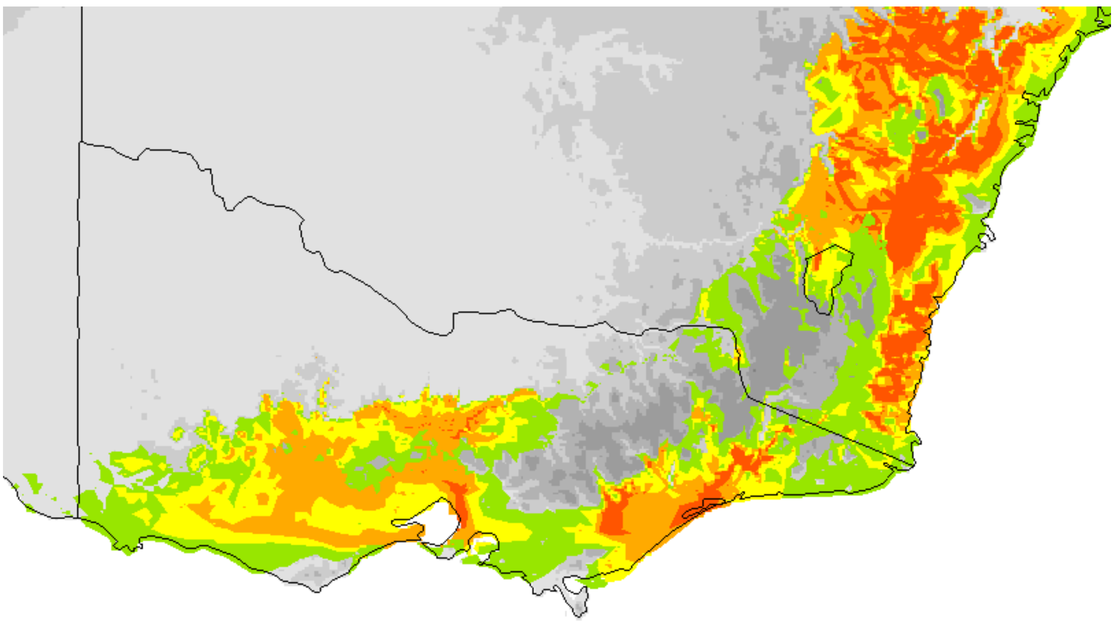
Figure 44a. ***Ligustrum sinense*** B1 scenario (low)



Baseline climate

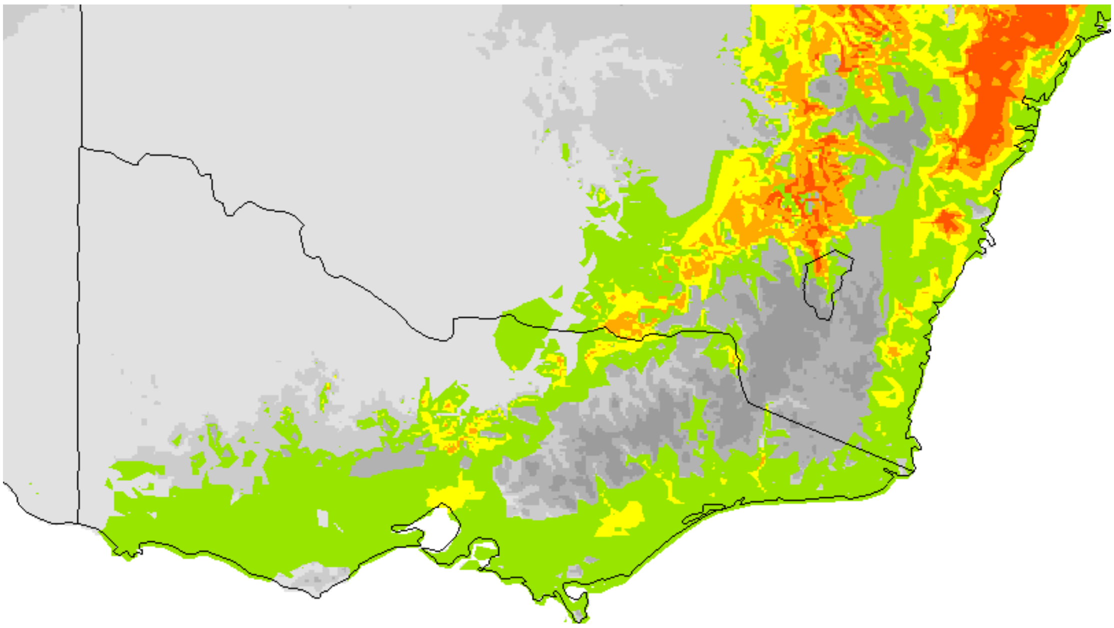


2030

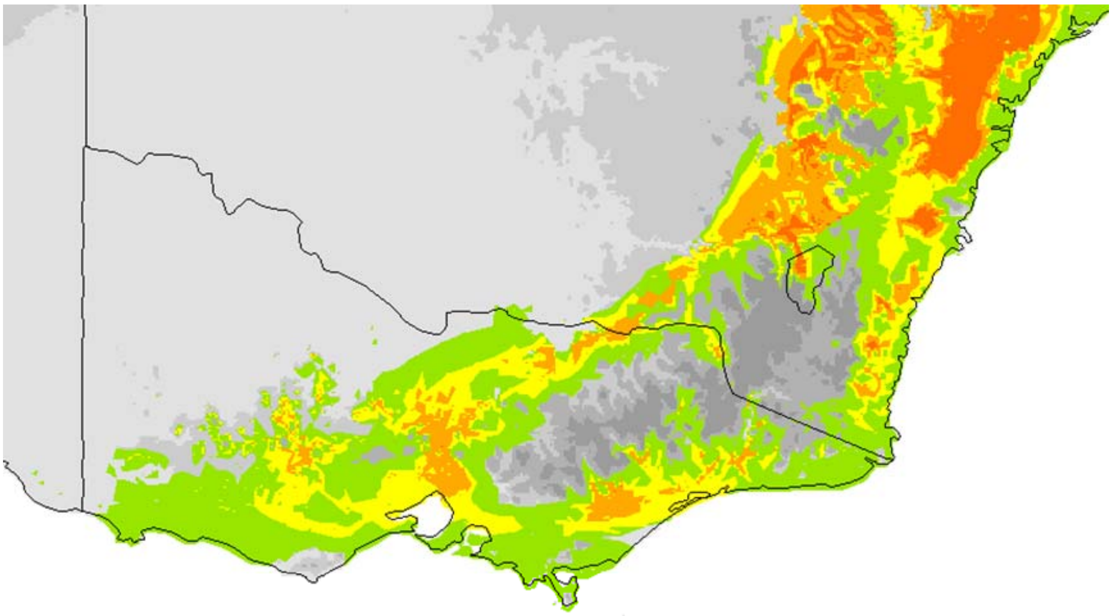


2070

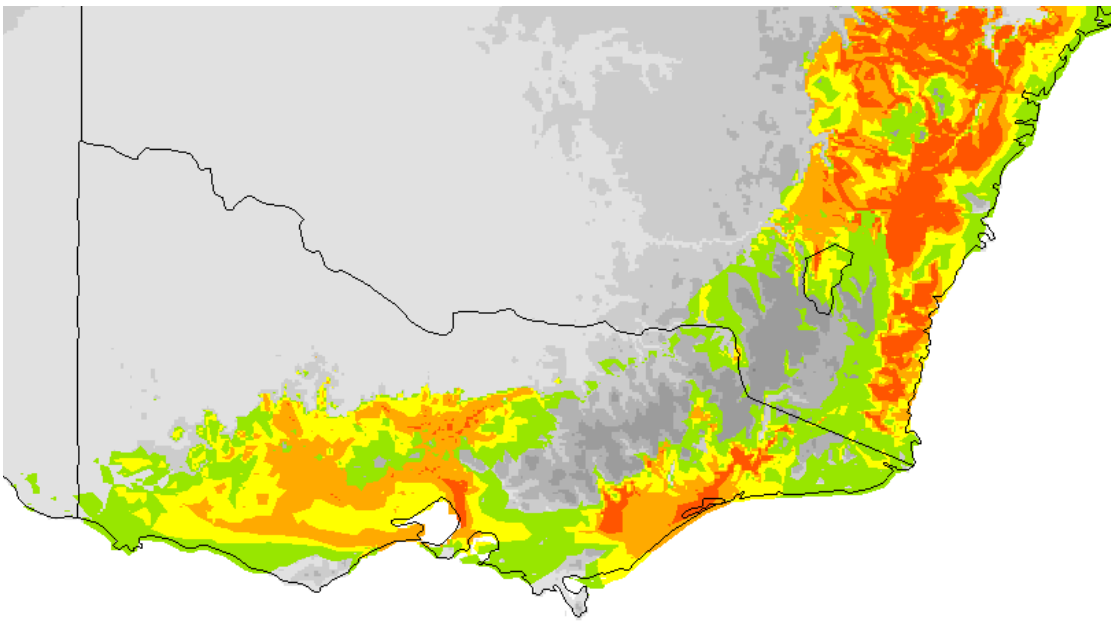
Figure 44b. *Ligustrum sinense* A1 scenario (mid)



Baseline climate

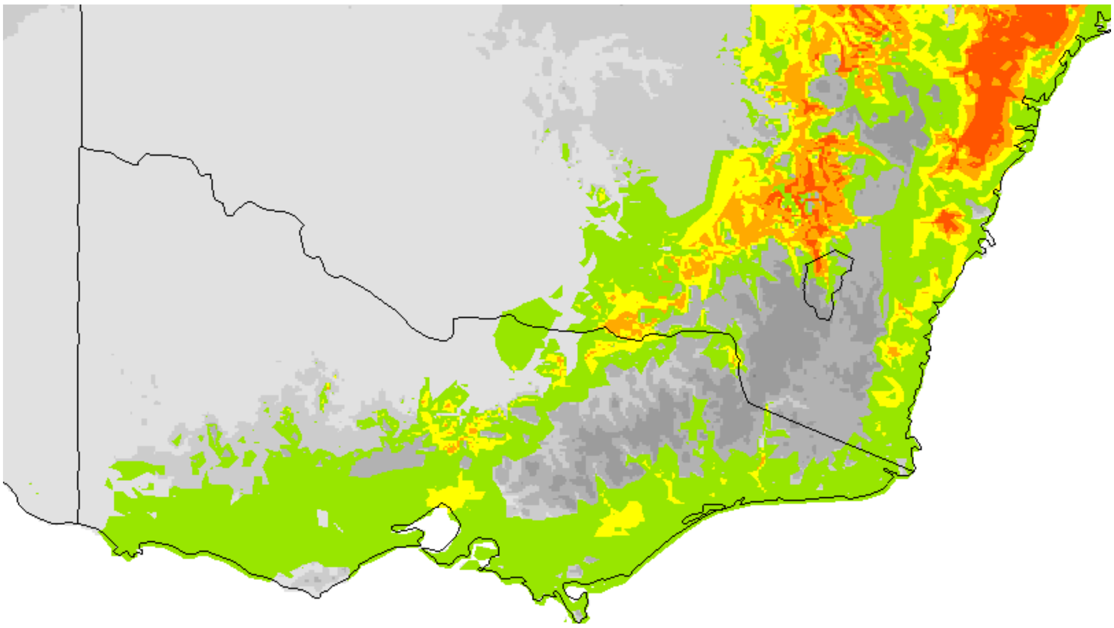


2030

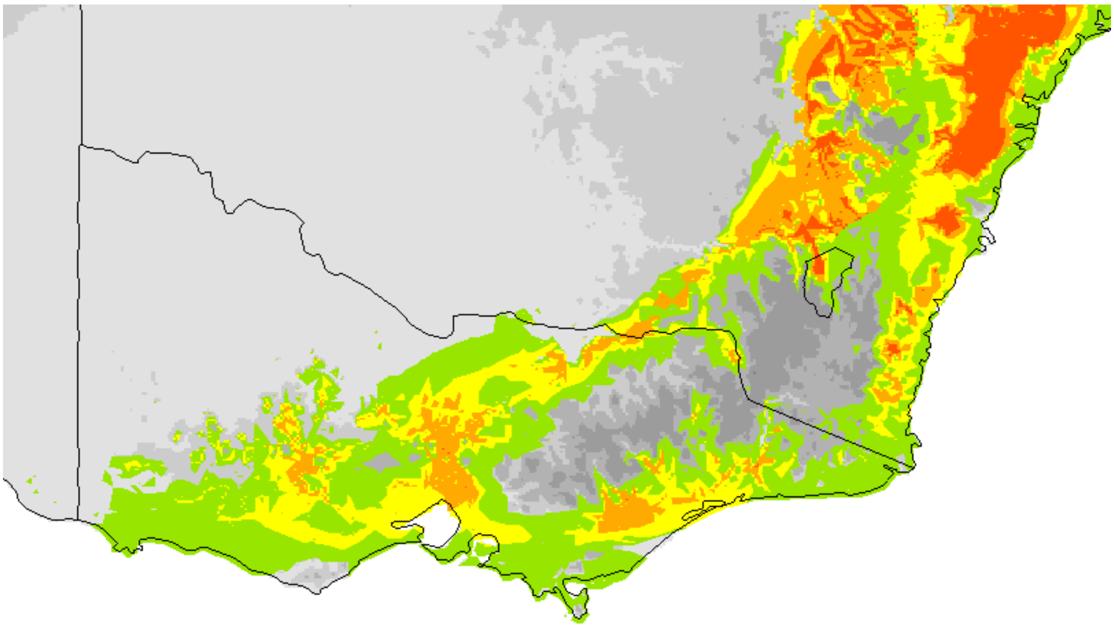


2070

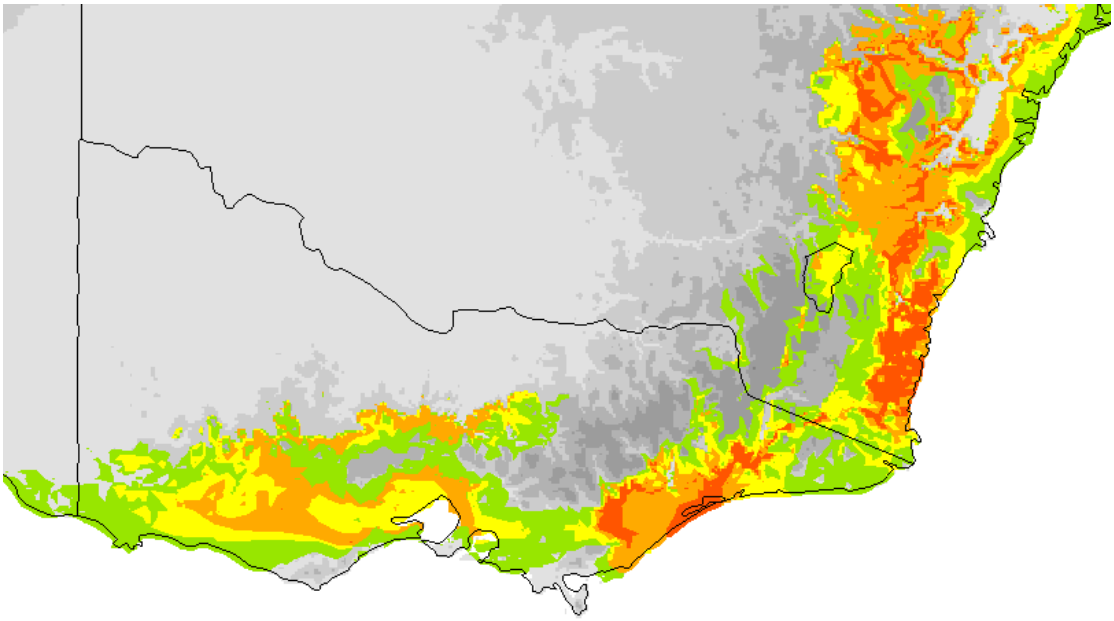
Figure 44c. *Ligustrum sinense* A1F scenario (high)



Baseline climate



2030



2070

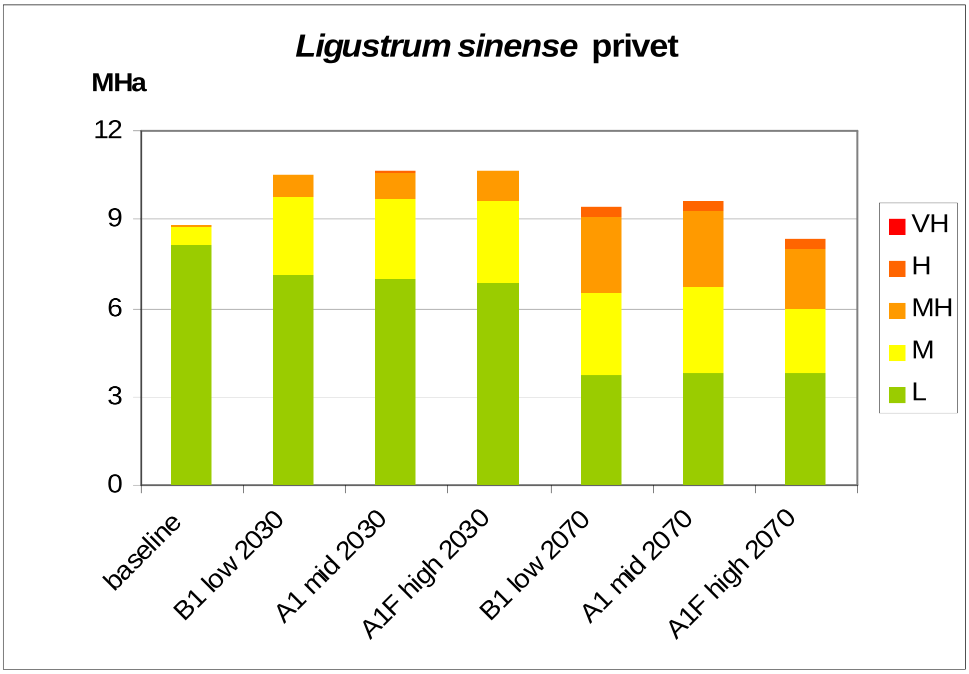


Figure 45. Area occupied by the climate envelope for *Ligustrum sinense* under a range of climate scenarios over time

Results summary for *Ligustrum sinense*

The climate envelope for this species showed a mixed response to climate change. There was a general increase in the area of the climate envelope as well as an increase in the quality of the climate match at 2030. At 2070 the quality of the climate match continued to improve, but the area occupied by the climate envelope was not as large as at 2030, and under A1F was smaller than that at baseline climate. Conditions under climate change appeared more favourable for the establishment and growth of *L. sinense*, and there were larger areas of climate match under all scenarios, except for A1F high at 2070.

B1 (low)

2030

The climate envelope expanded to the north, especially in central Victoria. Generally the quality of the climate match increased, with a smaller area of likely (L) climate match, larger moderate (M) and moderately high (MH) areas, and and area of high (H) climate match appeared in Gippsland.

2070

The climate envelope contracted south, however it was still larger than that at baseline conditions, and greater proportions of the area were occupied by moderate, moderately-high and high climate matches, with less area occupied by the likely climate match.

A1 scenario (mid)

2030

There was little difference in the climate envelope under this scenario than under B1 low at 2030, but the climate envelope was slightly larger, with a stronger shift to an increased climate match.

2070

There was little difference in the climate envelope under this scenario than under B1 low at 2070, but the climate envelope was slightly larger, with a stronger shift to an increased climate match.

A1F scenario (high)

2030

There was little difference in the climate envelope under this scenario than under B1 low at 2030, but the climate envelope was slightly larger, with a stronger shift to an increased climate match.

2070

The climate envelope contracted to occupy an area smaller than that under baseline conditions. However, the climate match remained at a greater intensity, with moderate, moderately high and high areas being larger than baseline and the likely climate match occupying a smaller area.

Medicago laciniata (L. Mill.)

cut-leaf medic

Medicago laciniata is native to north Africa, Middle East, western Asia and Mediterranean. It has naturalised in crops and grassland in WA, SA & Vic (Spooner *et al*. 2007b).

This species appears to be favoured by minimum temperatures between 3^{O}C and 7^{O}C and maximum temperature > 35^{O}C in low rainfall zones of less than 300 mm (Bounejmate, Dobson & Beal 1992).

The parameters chosen to model this species were 1, 5, 10, 11, 17 & 21.

The baseline climate match for this species (Fig. 46) was very good with more that 95% of current distribution points encompassed by the climate envelope, and the highest concentration of infestations in NSW concurring with the high climate match.

Medicago laciniata

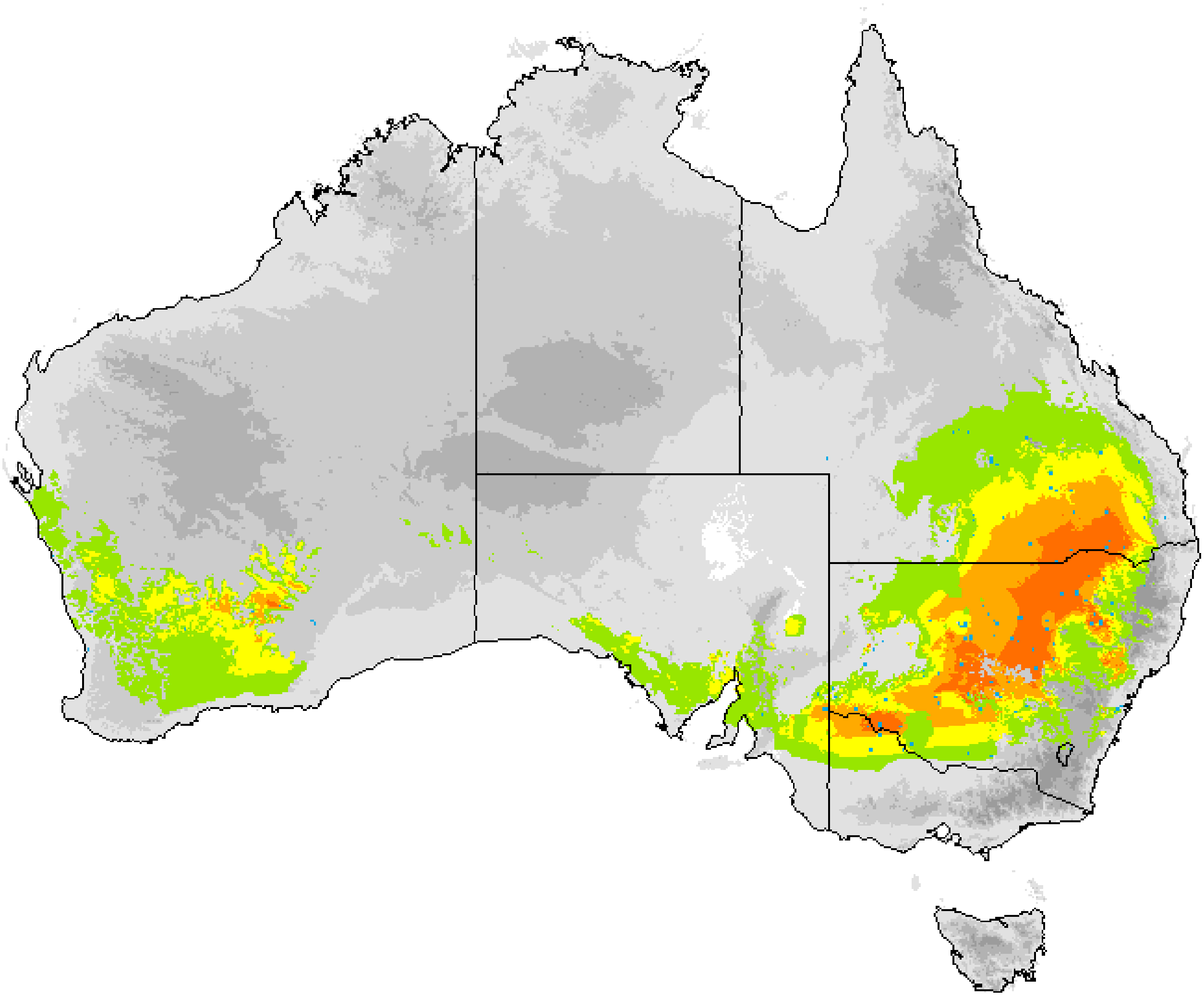
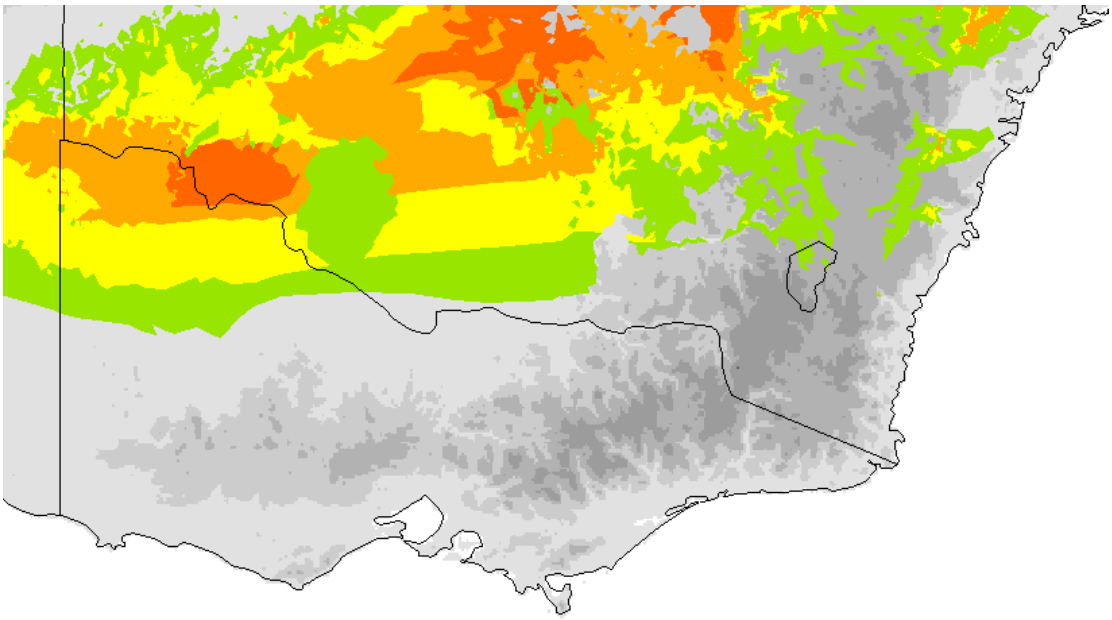
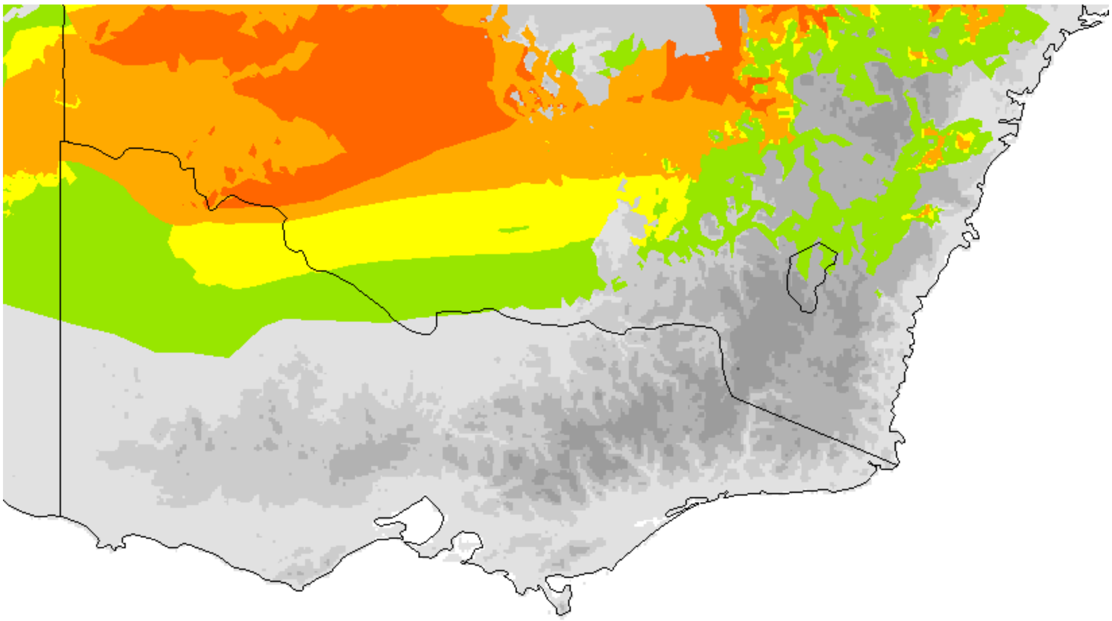


Figure 46. Comparison of current distribution with the baseline climate match

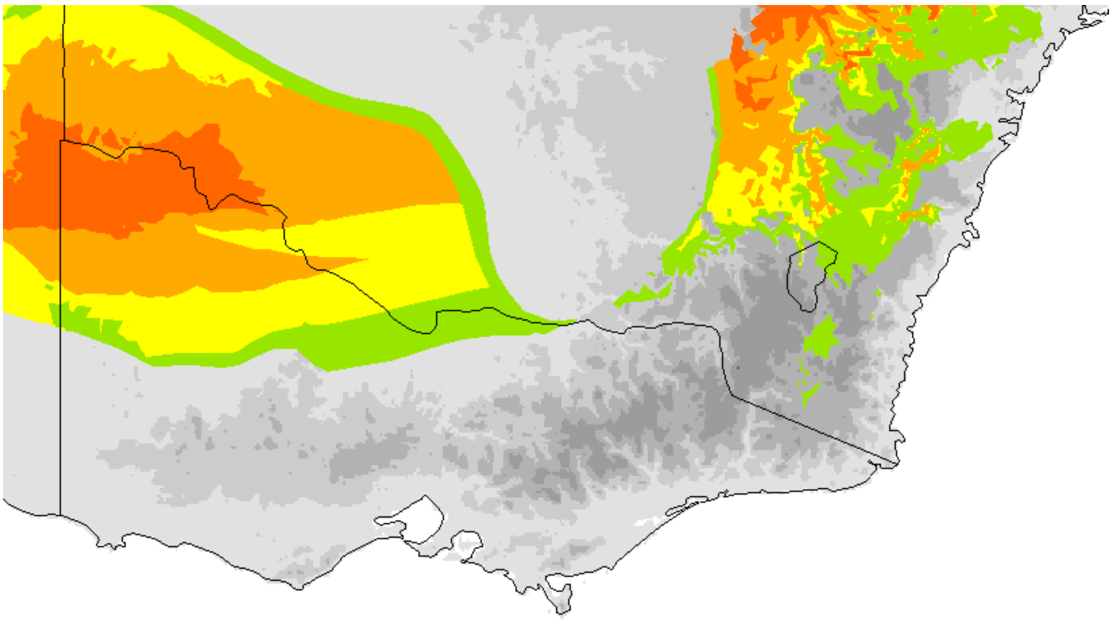
Figure 47a. *Medicago laciniata* B1 scenario (low)



Baseline climate

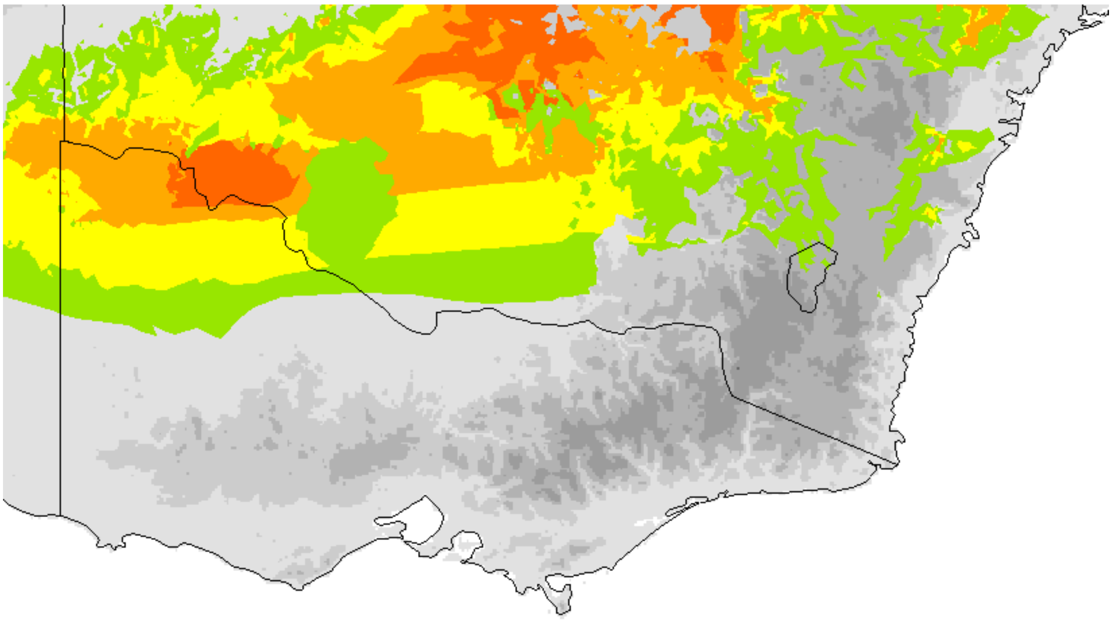


2030

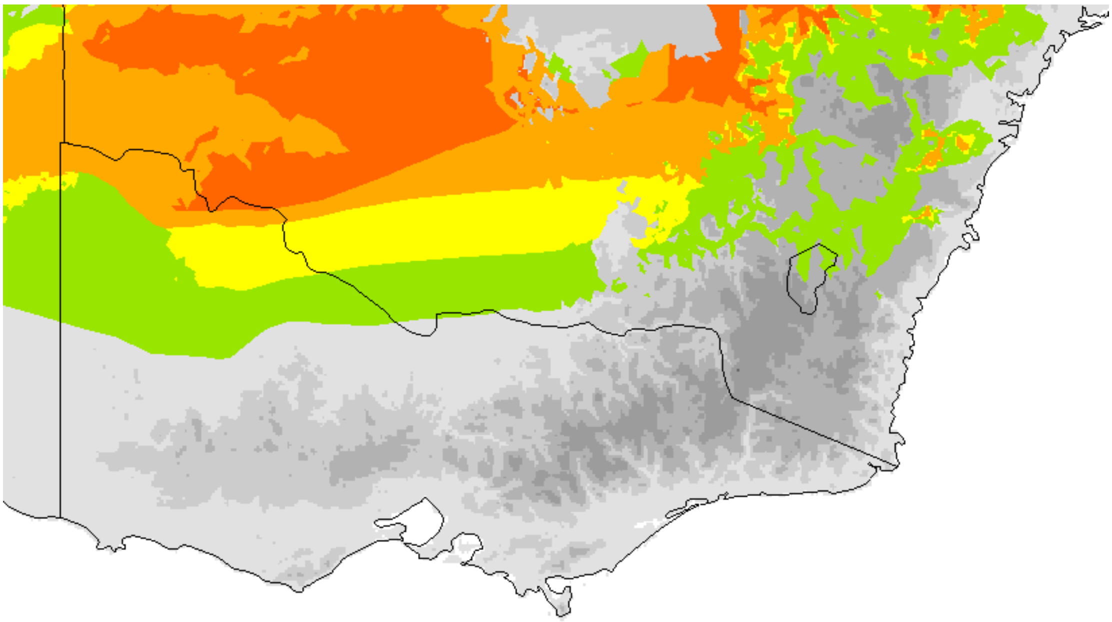


2070

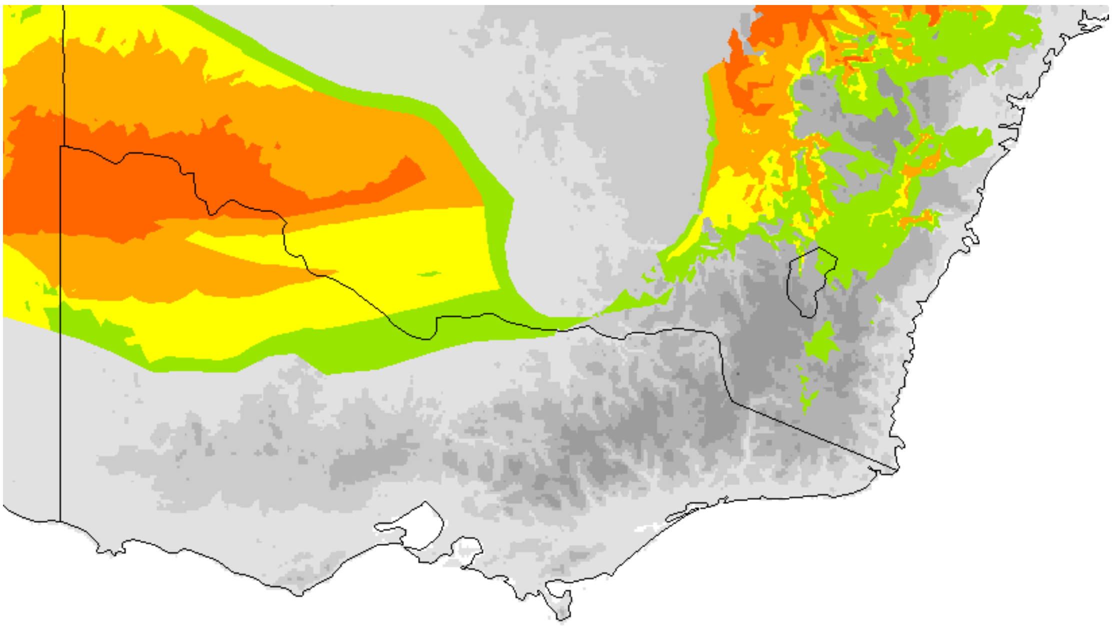
Figure 47b. *Medicago laciniata* A1 scenario (mid)



Baseline climate

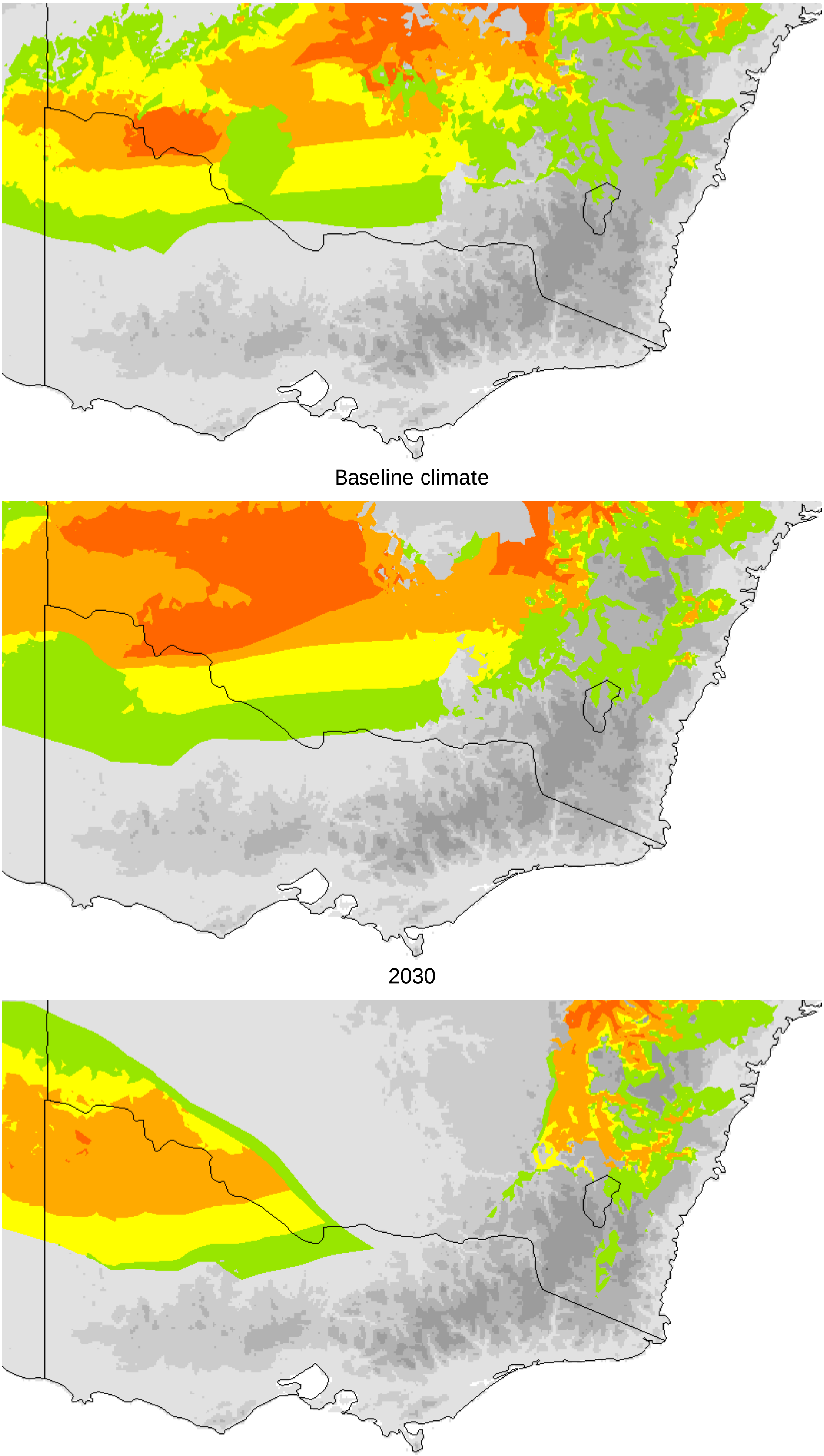


2030



2070

Figure 47c. *Medicago laciniata* A1F scenario (high)



Baseline climate

2030

2070

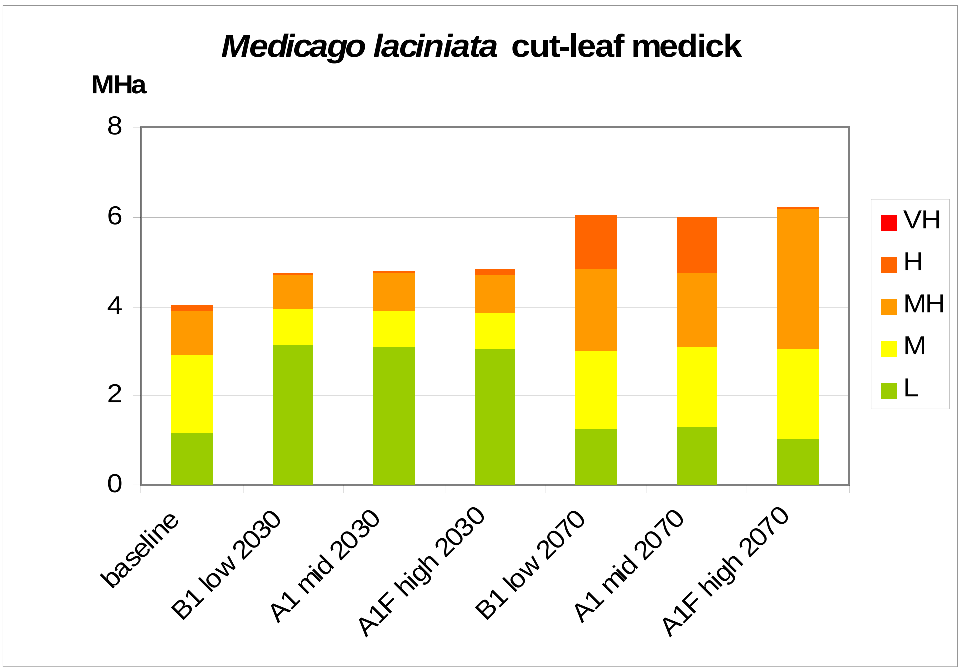


Figure 48. Area occupied by the climate envelope for *Medicago laciniata* under a range of climate scenarios over time

Results summary for *Medicago laciniata*

There was a general southern expansion of the climate envelope with greater degree of climatic suitability, except under A1F high at 2070, when the high climate match almost vanished.

B1 (low)

2030

There was an expansion of the climate envelope to the south but a large part of the moderate climate match in the south of the Mallee became less climatically suited to the establishment and growth of this species.

2070

There was a further expansion of the climate envelope and increased climate suitability across all of the area that was occupied by climate match at baseline conditions. A noticeable large area of high climate match occupied the north-west corner of the state.

A1 (mid)

2030

There was very little difference in the climate envelope under this scenario when compared with B1 low.

2070

There was very little difference in the climate envelope under this scenario when compared with B1 low.

A1F (high)

2030

There was very little difference in the climate envelope under this scenario when compared with B1 low.

2070

The climate envelope under A1F high was slightly larger than that under B1 low or A1 mid, but the climate match was lower with the high suitability almost gone.

Nassella neesiana (Trin. & Rupr.)

Chilean needle grass

syn. *Stipa neesiana*

N. neesiana is a tufted perennial grass from Argentina, Bolivia, Chile, Ecuador, Southern Brazil and Uruguay that is becoming a serious pasture and environmental weed in south-eastern Australia (McLaren, unpub.), capable of invading lowland grassland, grassy woodland and rocky outcrop vegetation (Carr *et al.* 1992) and can withstand temporary flooding as well as seasonally dry environments (McLaren, unpub.). It flowers during warmer months (McLaren, unpub.).

The parameters chosen to model this species were 1, 8, 11 & 29.

The climate match (Fig. 48) was very good with few points outside the envelope and the best climate matches concurring with the largest number of infestations.

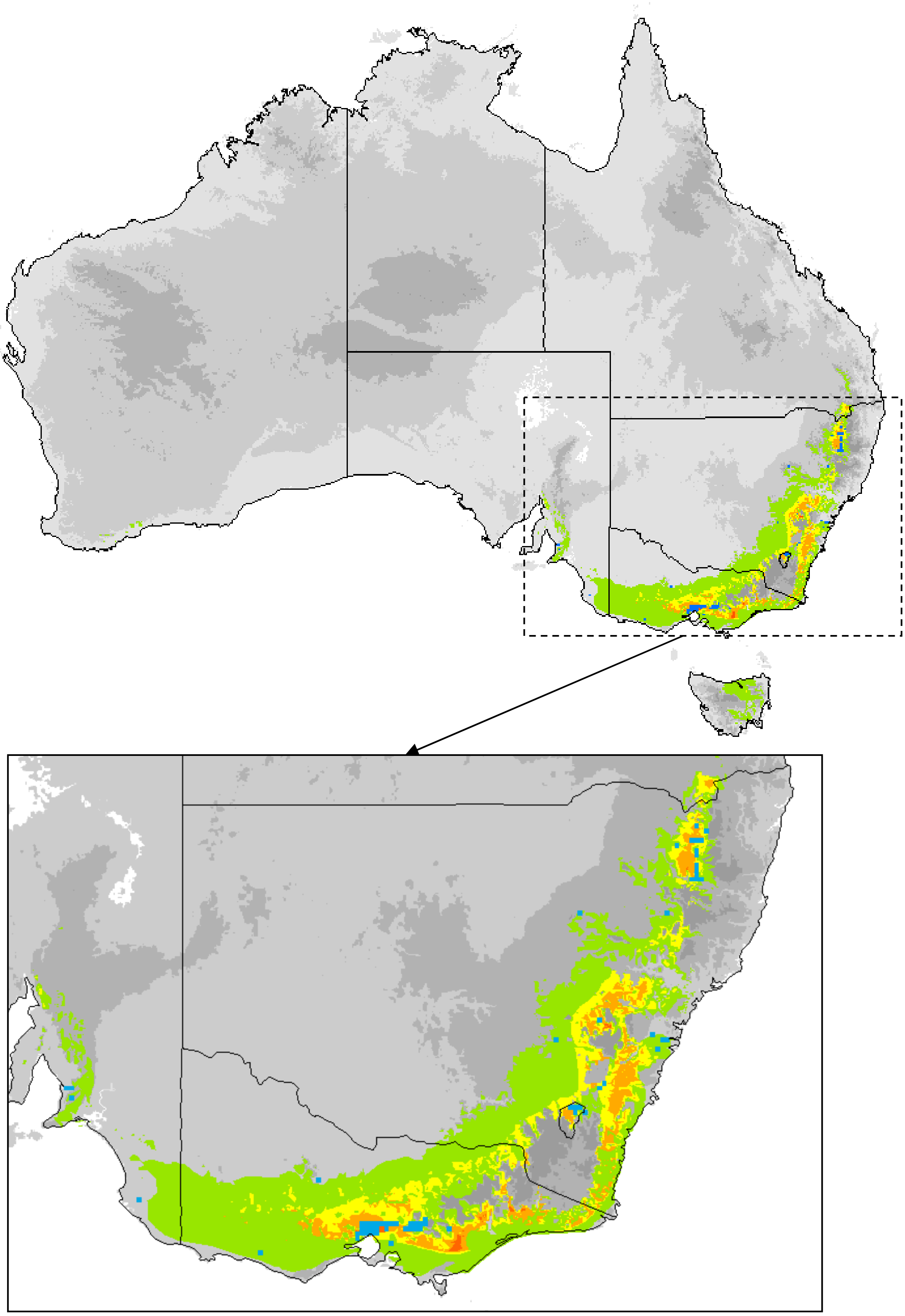
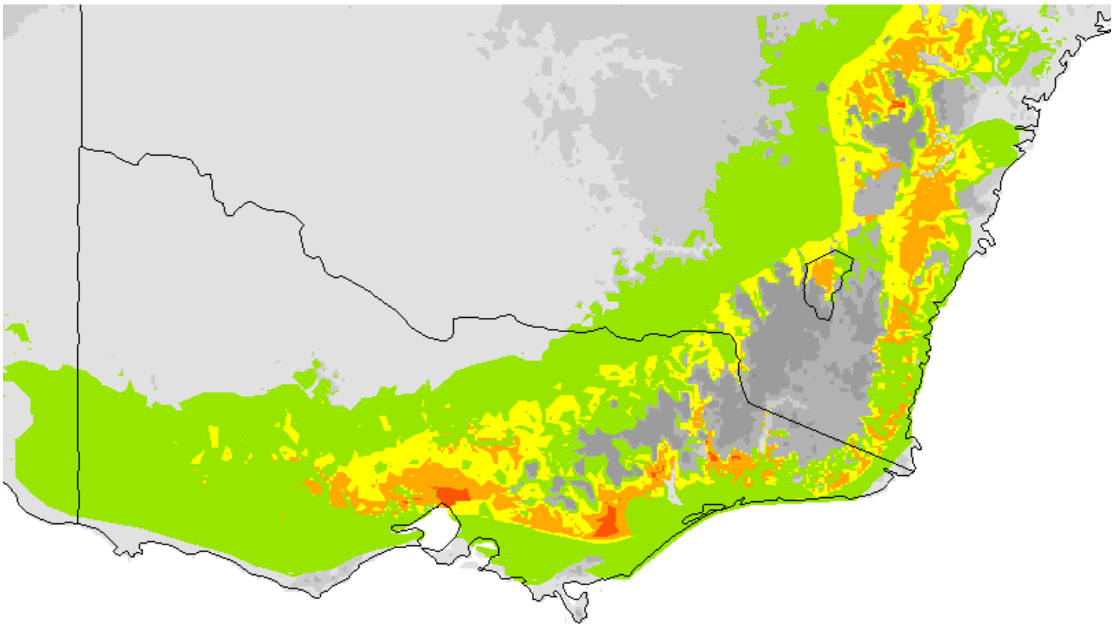
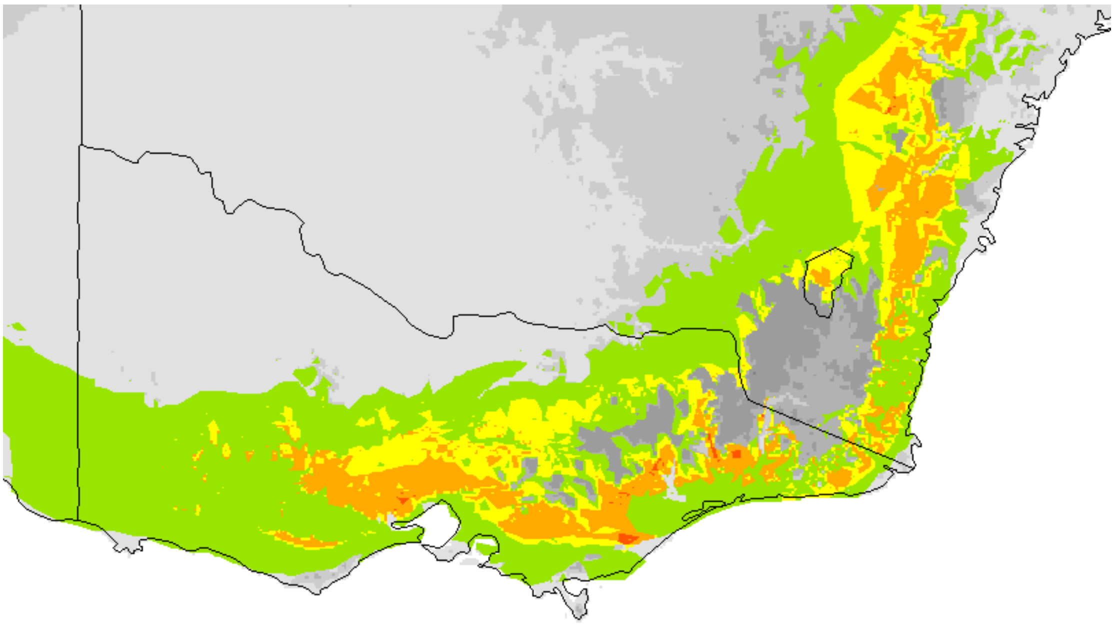


Figure 48. Comparison of current distribution with the baseline climate match

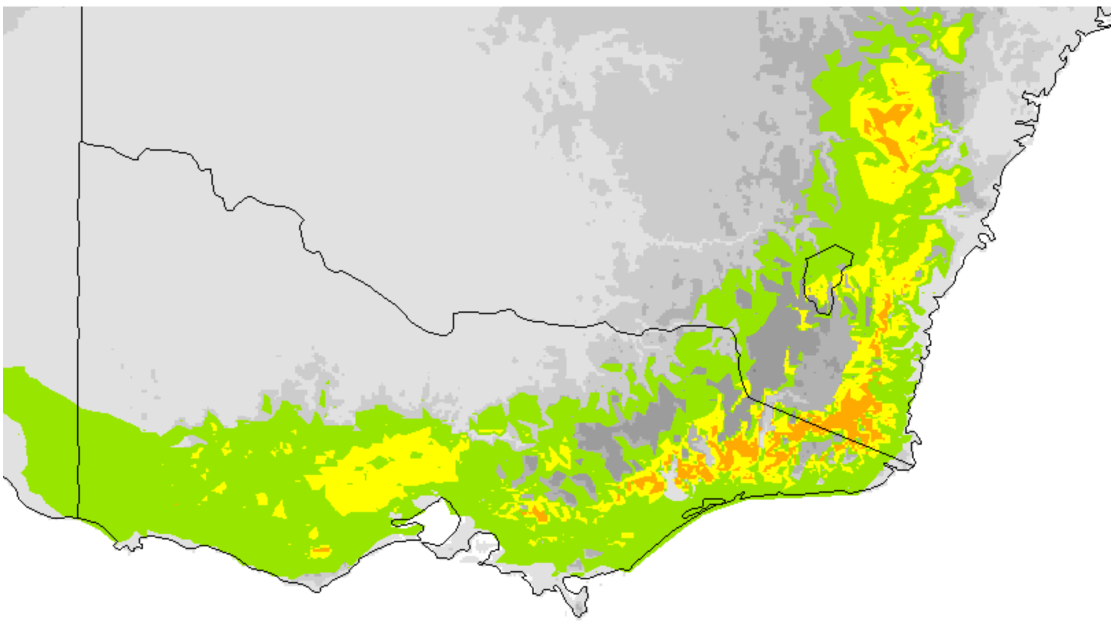
Figure 49a. ***Nassella neesiana*** B1 scenario (low)



Baseline climate

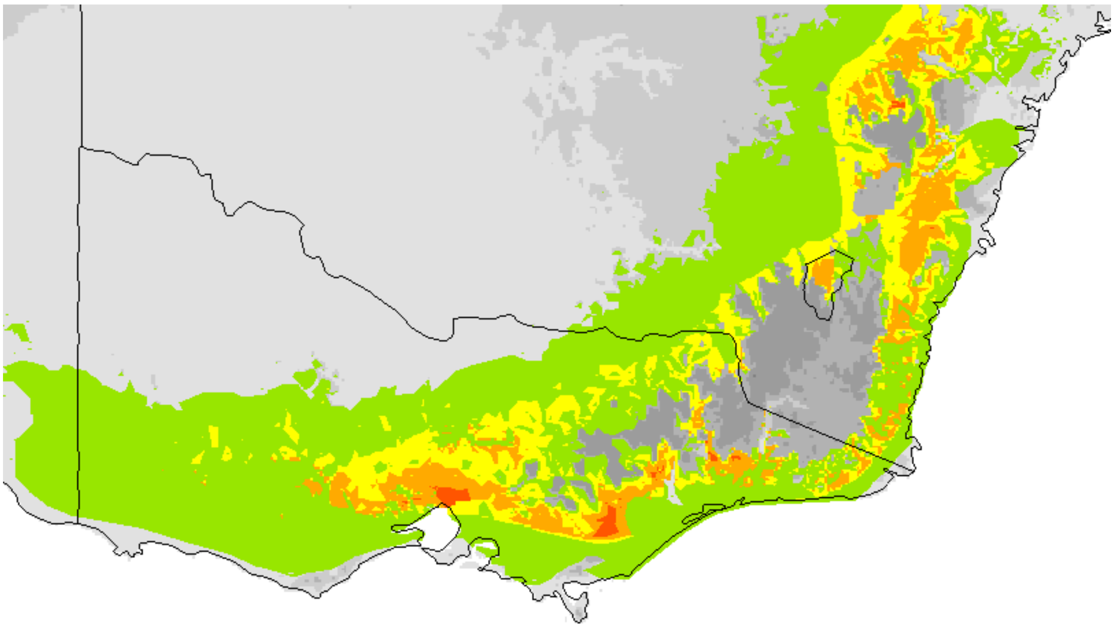


2030

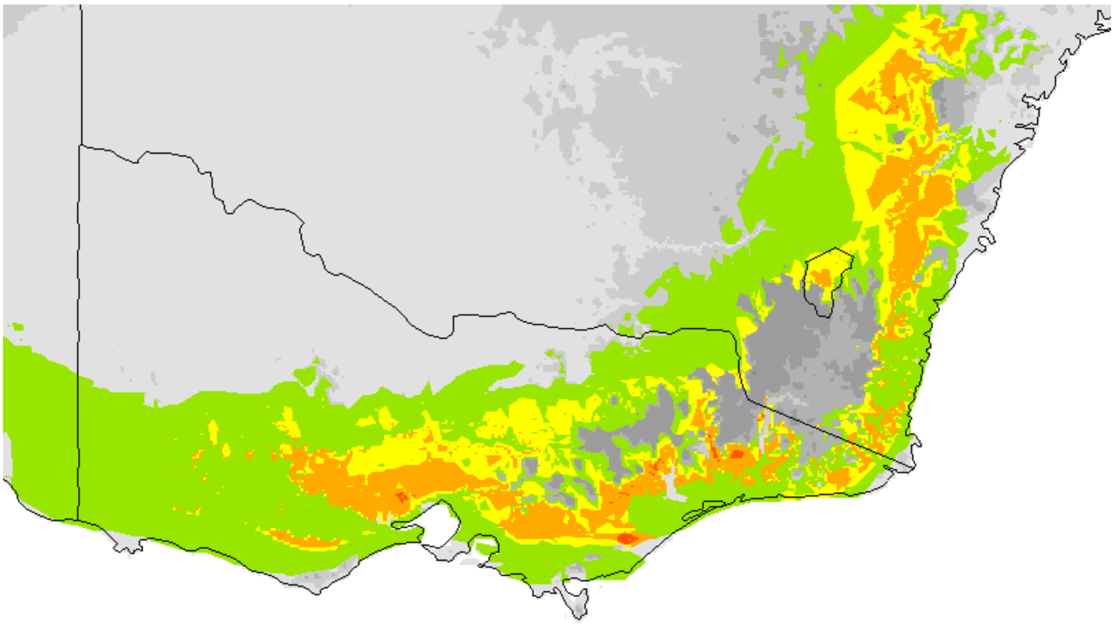


2070

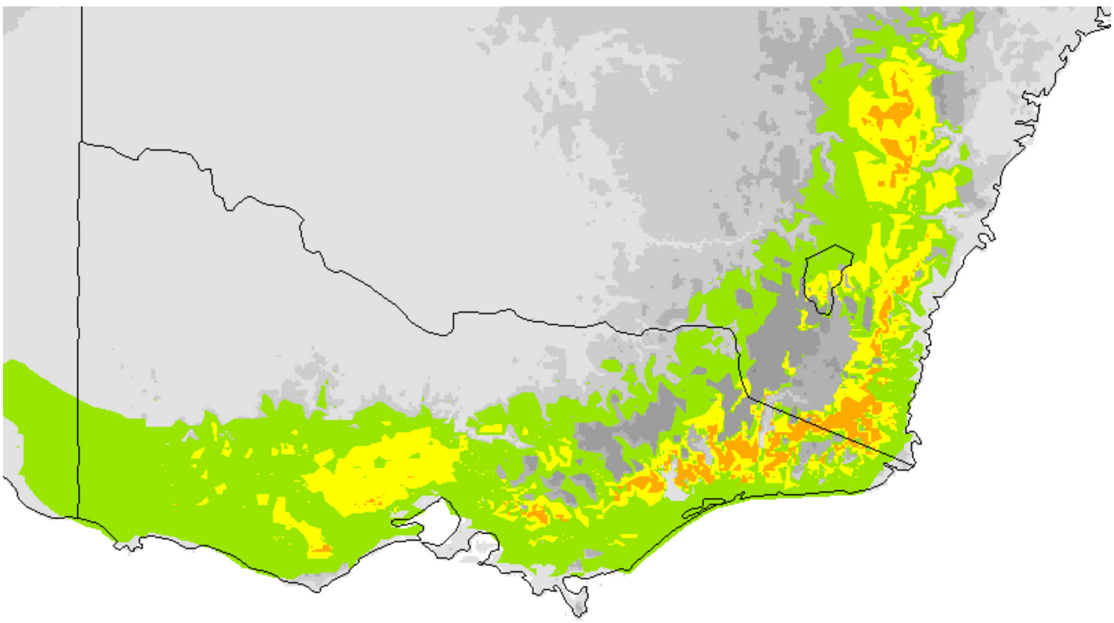
Figure 49b. *Nassella neesiana* A1 scenario (mid)



Baseline climate

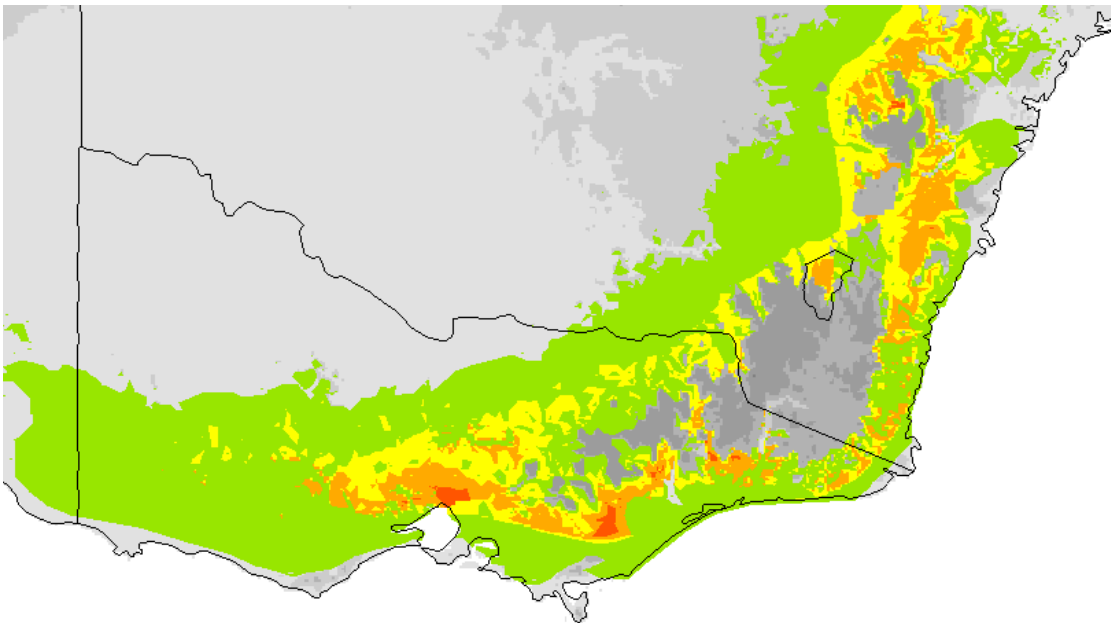


2030

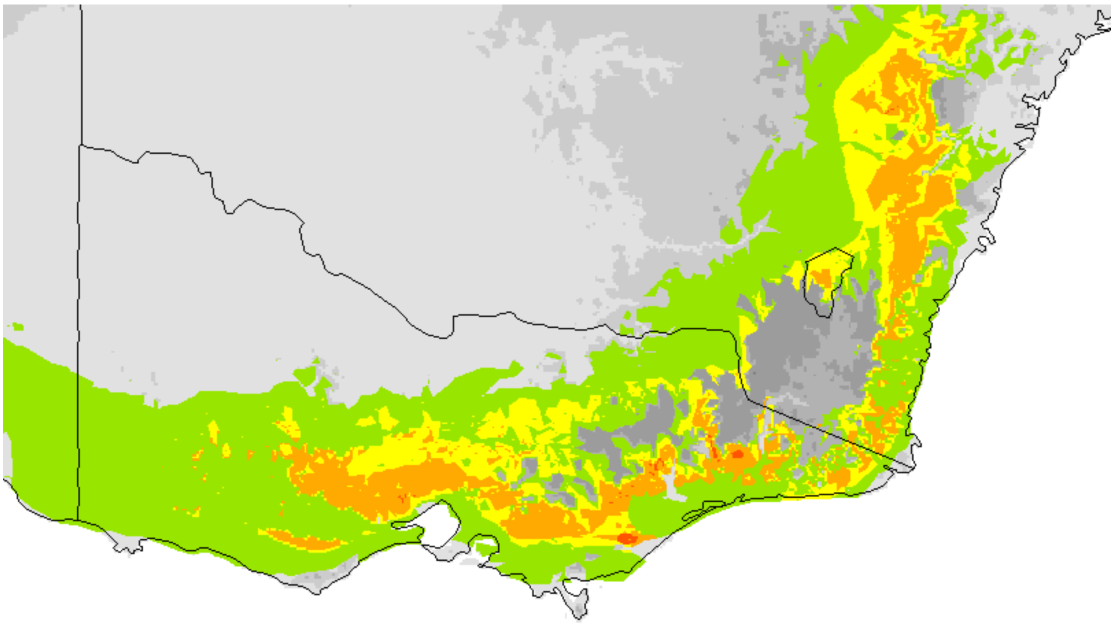


2070

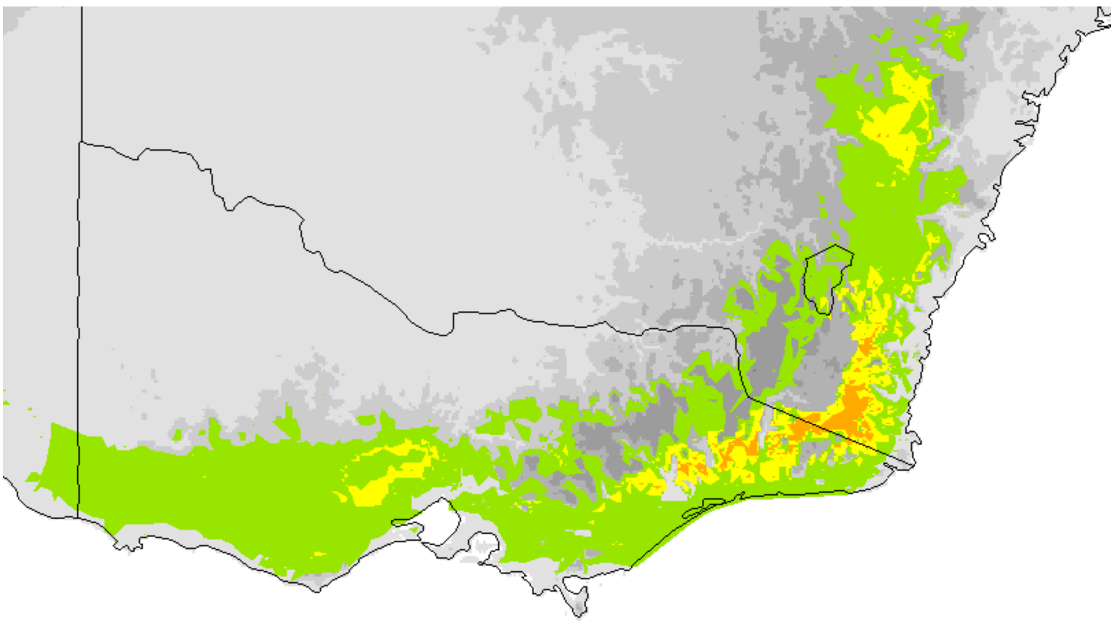
Figure 49c. *Nassella neesiana* A1F (high)



Baseline climate



2030



2070

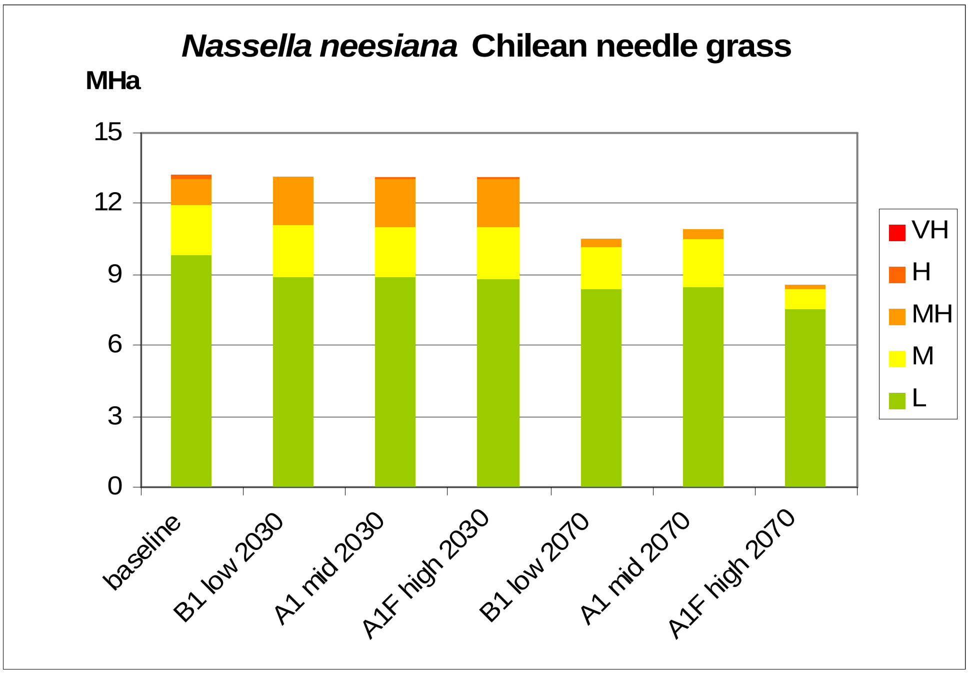


Figure 50 Area occupied by the climate envelope for *Nassella neesiana* under a range of climate scenarios over time

Results summary for *Nassella neesiana*

Generally there was little change in the climate envelope of this species at 2030 under any scenario. At 2070, however, the envelope was noticeable smaller and lacked the high climate match that was present at 2030. Over the longer term the climatic conditions suited to the establishment and growth of this species in Victoria are likely to decline in area and quality.

B1 (low)

2030

The climate envelope changed very little, although it was slightly reduced, with less area in both the likely and high climate matches, but more moderate and moderately high area.

2070

There was a contraction to the south and the climate match became less intense, with no high climate match and much less moderately high match too.

A1 scenario (mid)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

There was little difference between this scenario at 2070 and the changes observed under the B1 low scenario.

A1F scenario (high)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

The climate envelope was noticeable smaller than that under any other climate, having contracted both from the north, and also away from the coast.

Nassella trichotoma (Nees) Hack. ex Arechav

Serrated tussock

syn. *Stipa trichotoma*

N. trichotoma is a perennial, drought resistant grass that is native to Argentina, Uruguay, Chile and Peru (McLaren, unpub.). It is a proclaimed noxious weed in the Australian Capital Territory, New South Wales, Victoria, South Australia and Tasmania and has been described as potentially causing greater reductions in carrying capacity than any other plant in Australia (Parsons and Cuthbertson 1992).

The parameters chosen to model this species were 1, 2, 4, 5, 8, 26 & 27.

The baseline climate match (Fig. 51) was very good with only three location outside the climate envelope and the areas of highest climate match concurring with the areas with the largest number of recorded infestations.

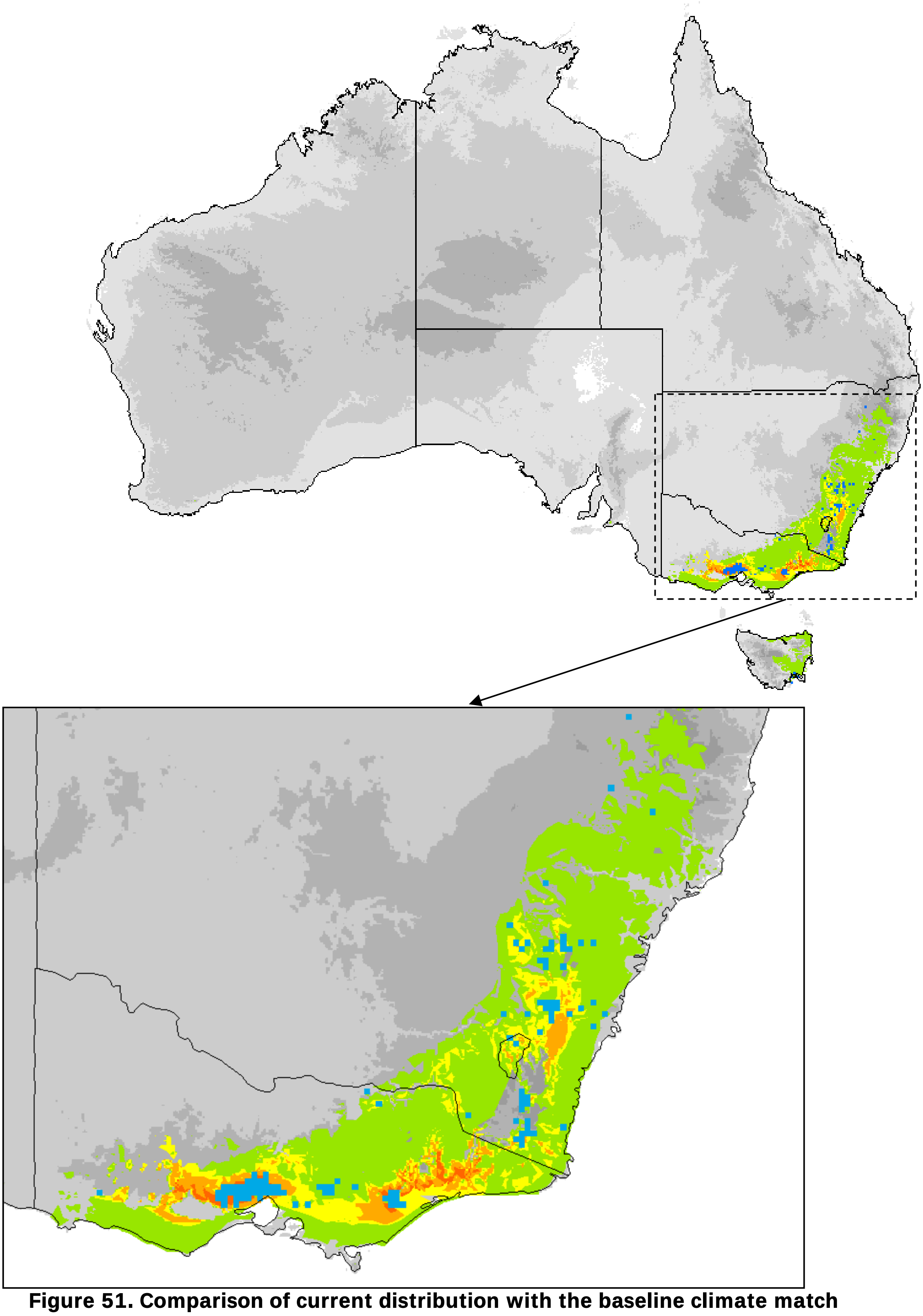
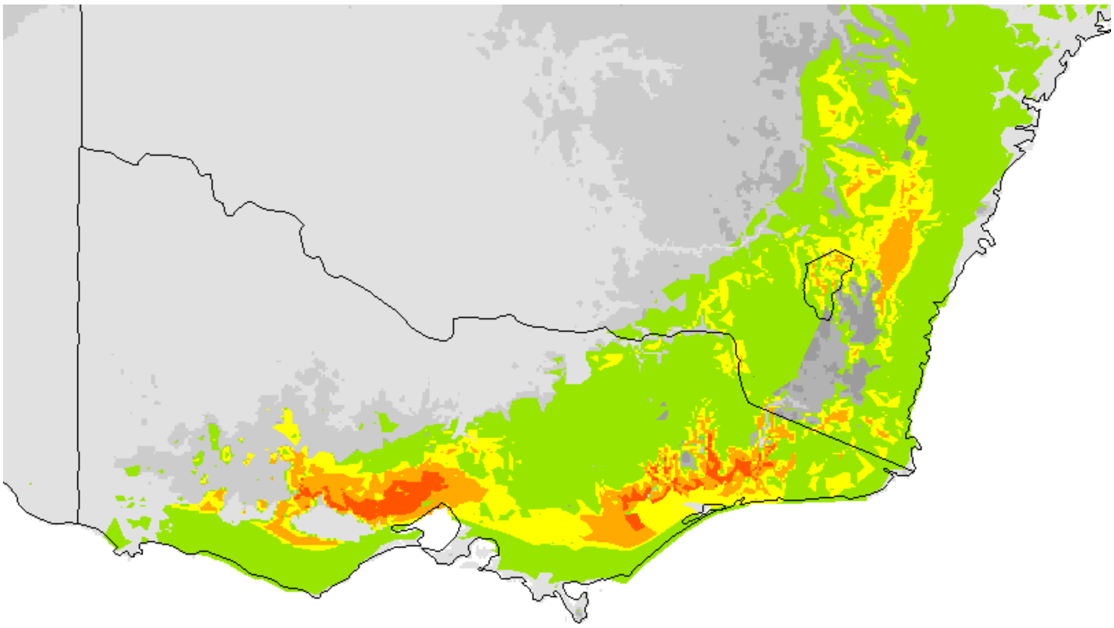
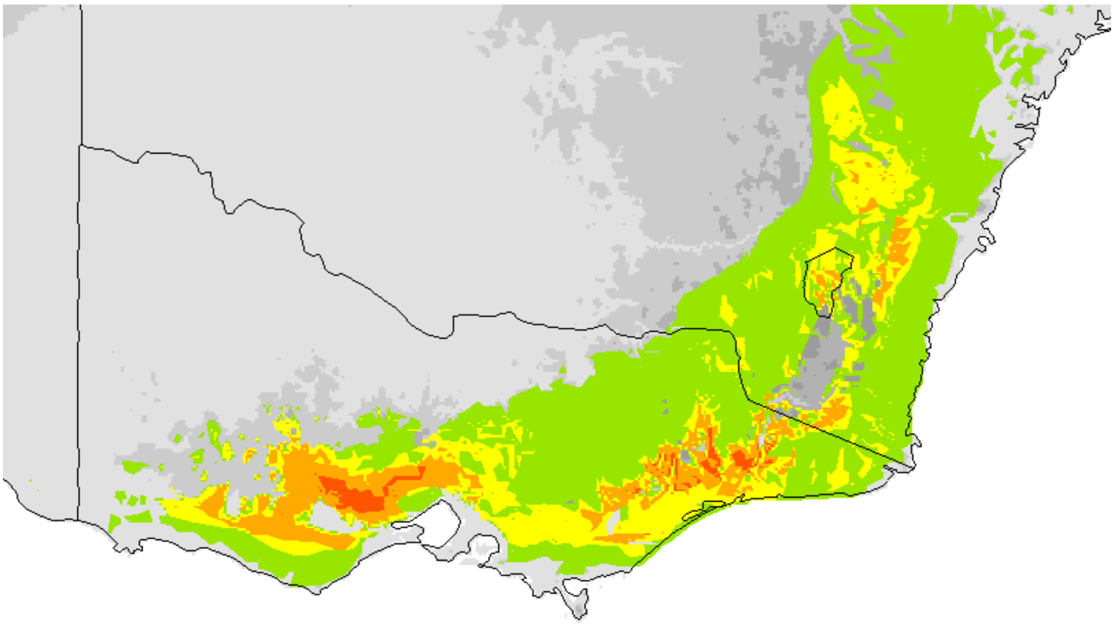


Figure 51. Comparison of current distribution with the baseline climate match

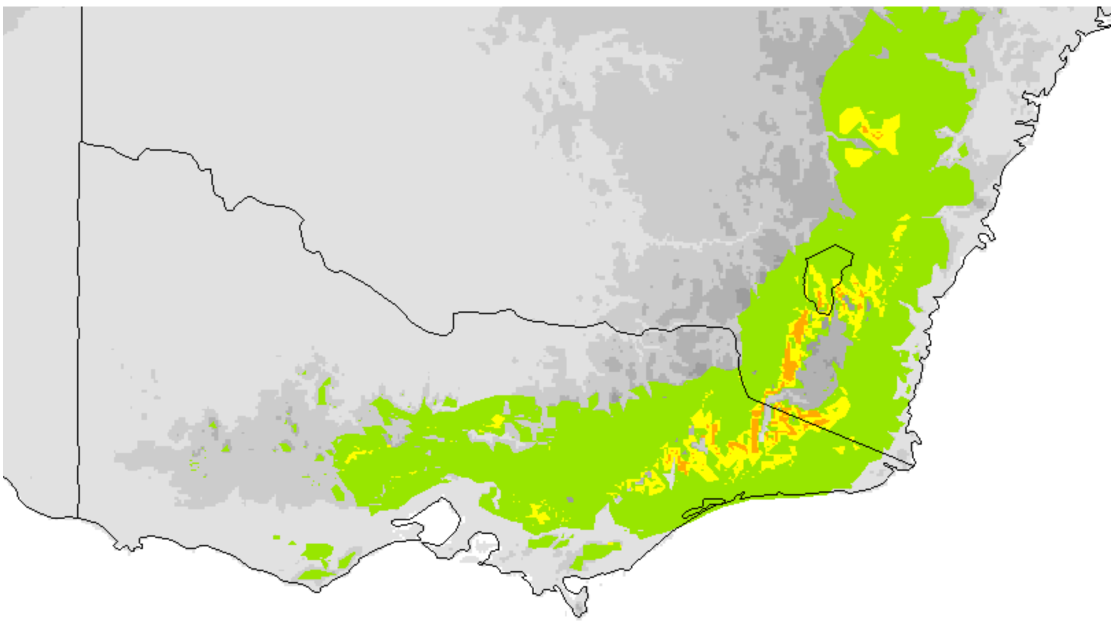
Figure 52a. ***Nassella trichotoma*** B1 scenario (low)



Baseline climate

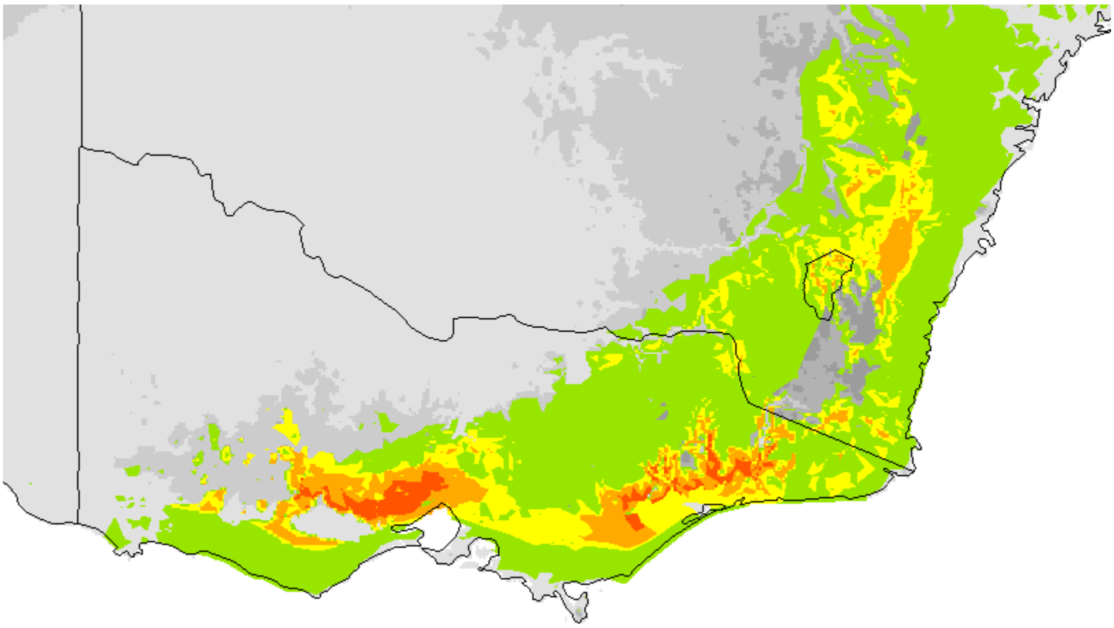


2030

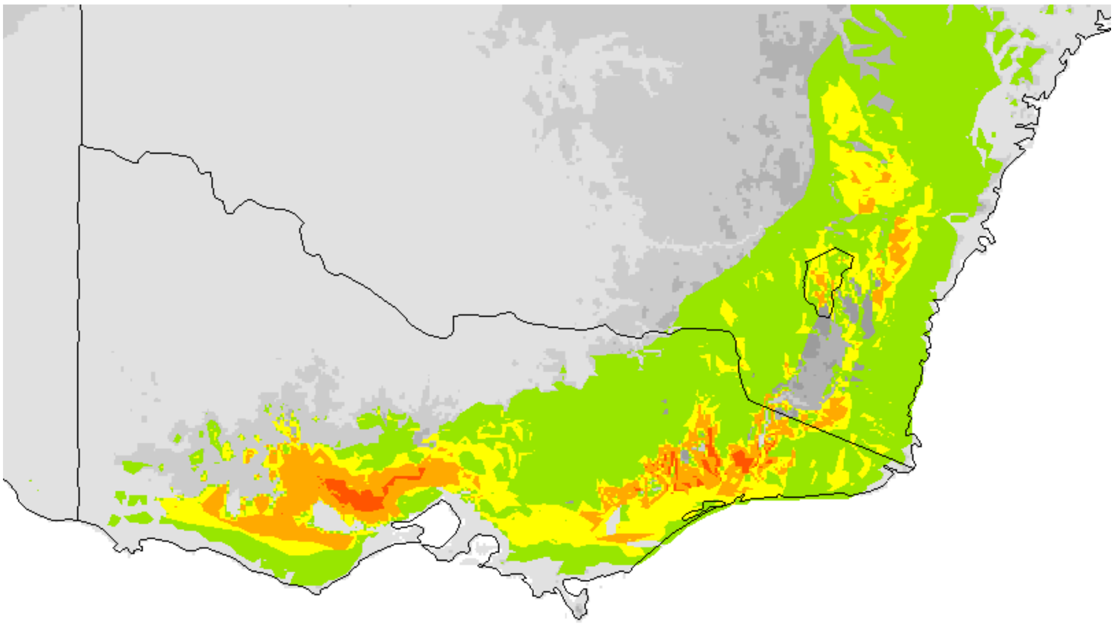


2070

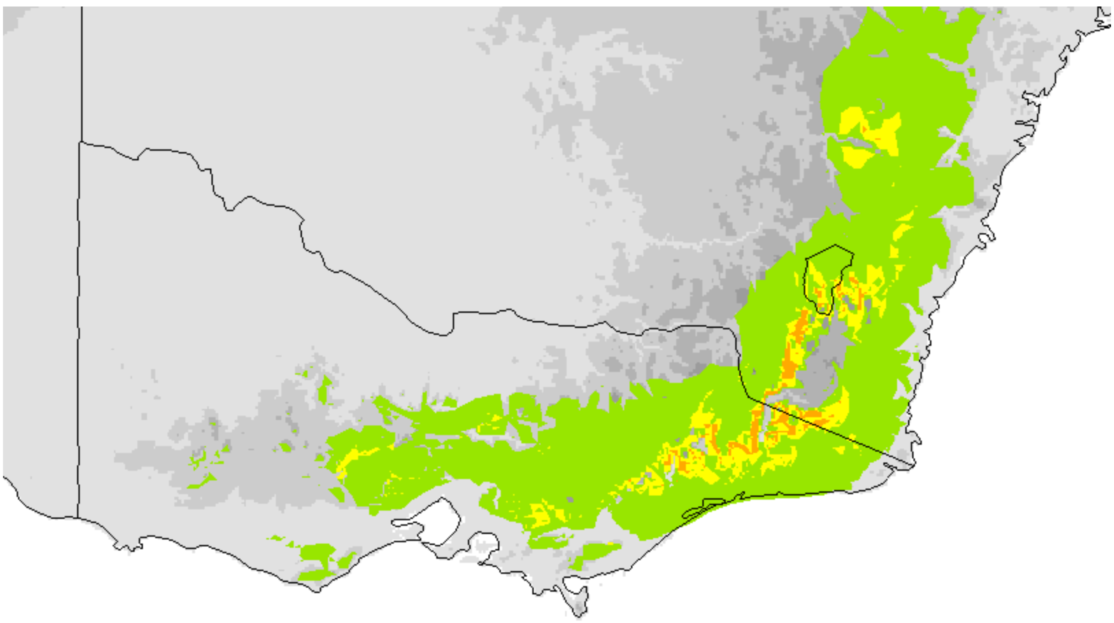
Figure 52b. *Nassella trichotoma* A1 scenario (mid)



Baseline climate

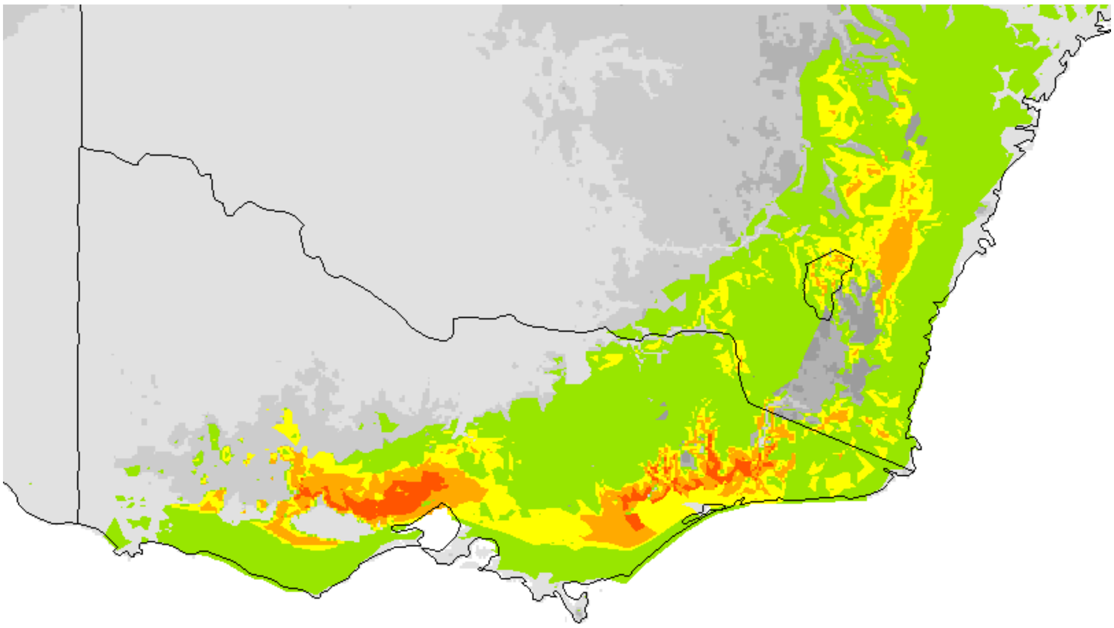


2030

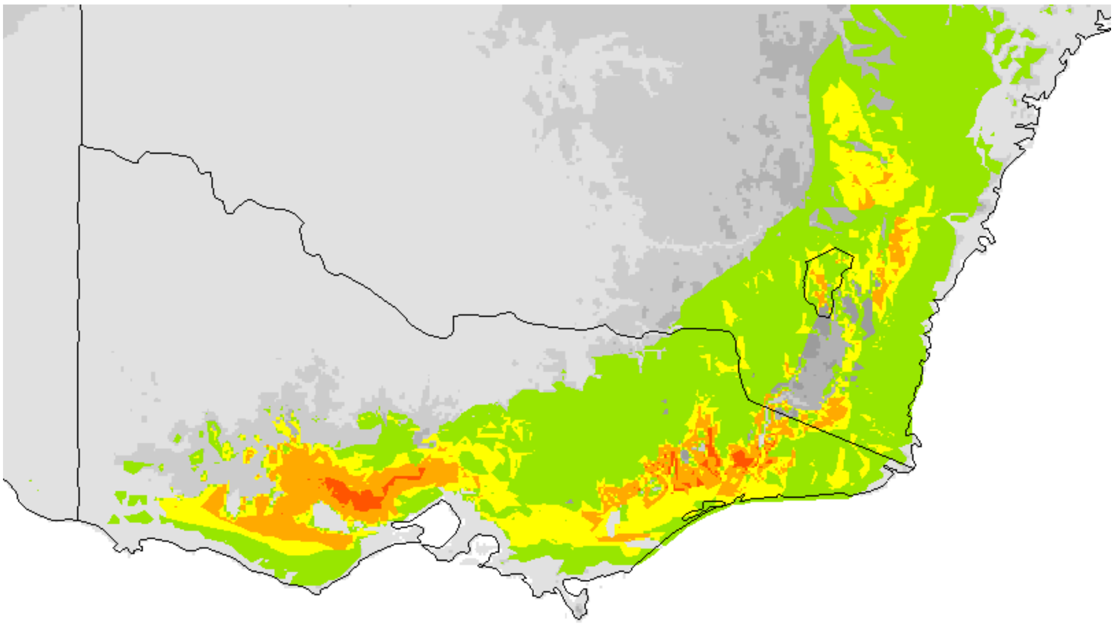


2070

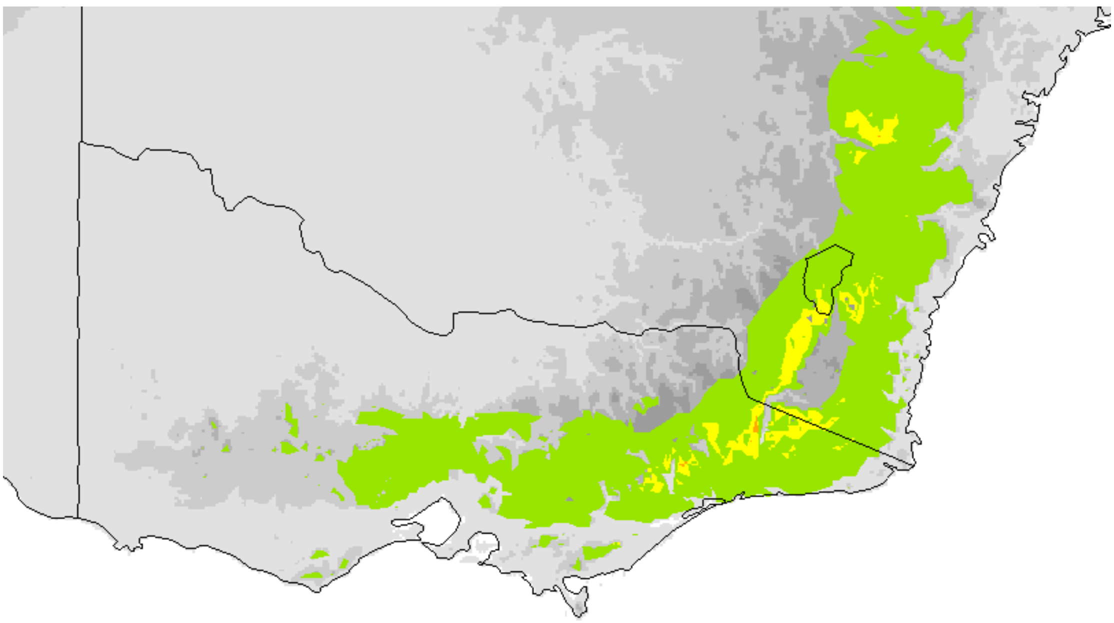
Figure 52c. *Nassella trichotoma* A1F scenario (high)



Baseline climate



2030



2070

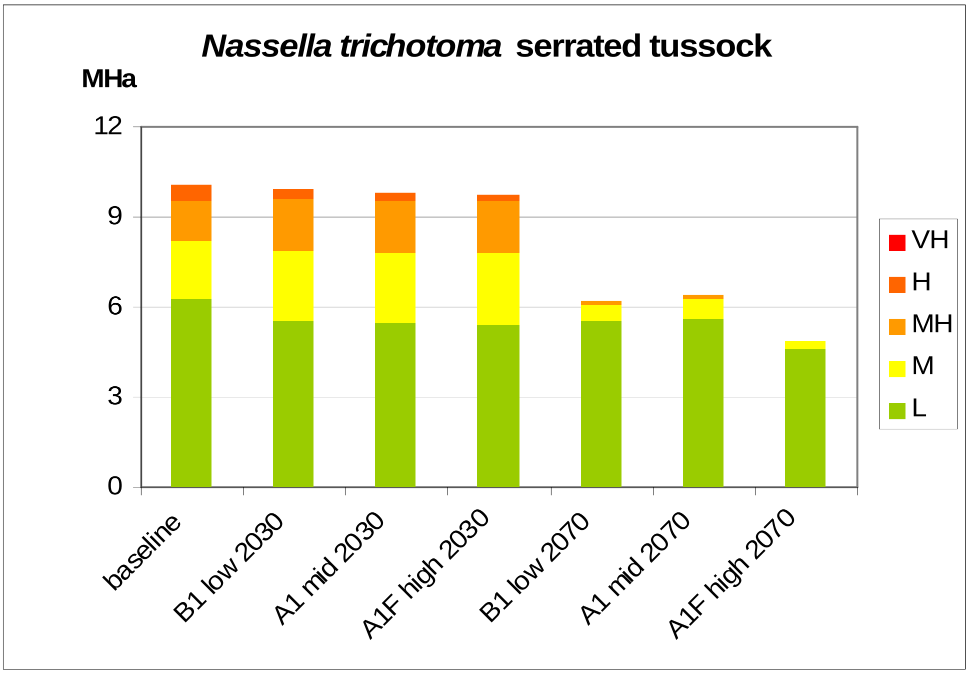


Figure 53. Area occupied by the climate envelope for *Nassella trichotoma* under a range of climate scenarios over time

Results summary for *Nassella trichotoma*

There was generally little change in the climate envelope under all climate change scenarios until 2070, when there was a decrease in both the area and the quality of the climate match. Over the longer term the climatic conditions suited to the establishment and growth of this species in Victoria are likely to decline in area and quality.

B1 (low)

2030

There was a slight contraction of the climate envelope from coastal areas, with less of both the high and likely climate matches, but more area of moderate and moderately high.

2070

The climate envelope occupied a much reduced area, largely confined to the east and centre of the state. There was no high climate match.

A1 scenario (mid)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

The response of the climate envelope was similar to that observed under B1 low conditions, however there was less contraction, but it was still a much smaller area than under baseline or 2030 conditions.

A1F scenario (high)

2030

There was little difference between this scenario at 2030 and the changes observed under the B1 low scenario.

2070

The climate envelope occupied the smallest area of the state A1F high at 2070. It was less than half the area at baseline conditions due to contraction from both the north and the coast. Very little of the moderately high climate match remained.

Passiflora suberosa L.

P. suberosa is a vine that is native to South America and has become a weed in moist coastal and subcoastal areas of southern to northern Queensland and the Gulf area of the Northern Territory (Swarbrick 1981) and NSW (Andresen 2005). It has also invaded sugar and *Eucalyptus* plantations (Seeruttum, Barbe & Guamgoo 2005).

The parameters chosen to model this species were 1, 2, 3, 4 & 12.

The baseline climate match (Fig. 54) was very good with more than 99% of the data points concurring with the area encompassed by the climate envelope.

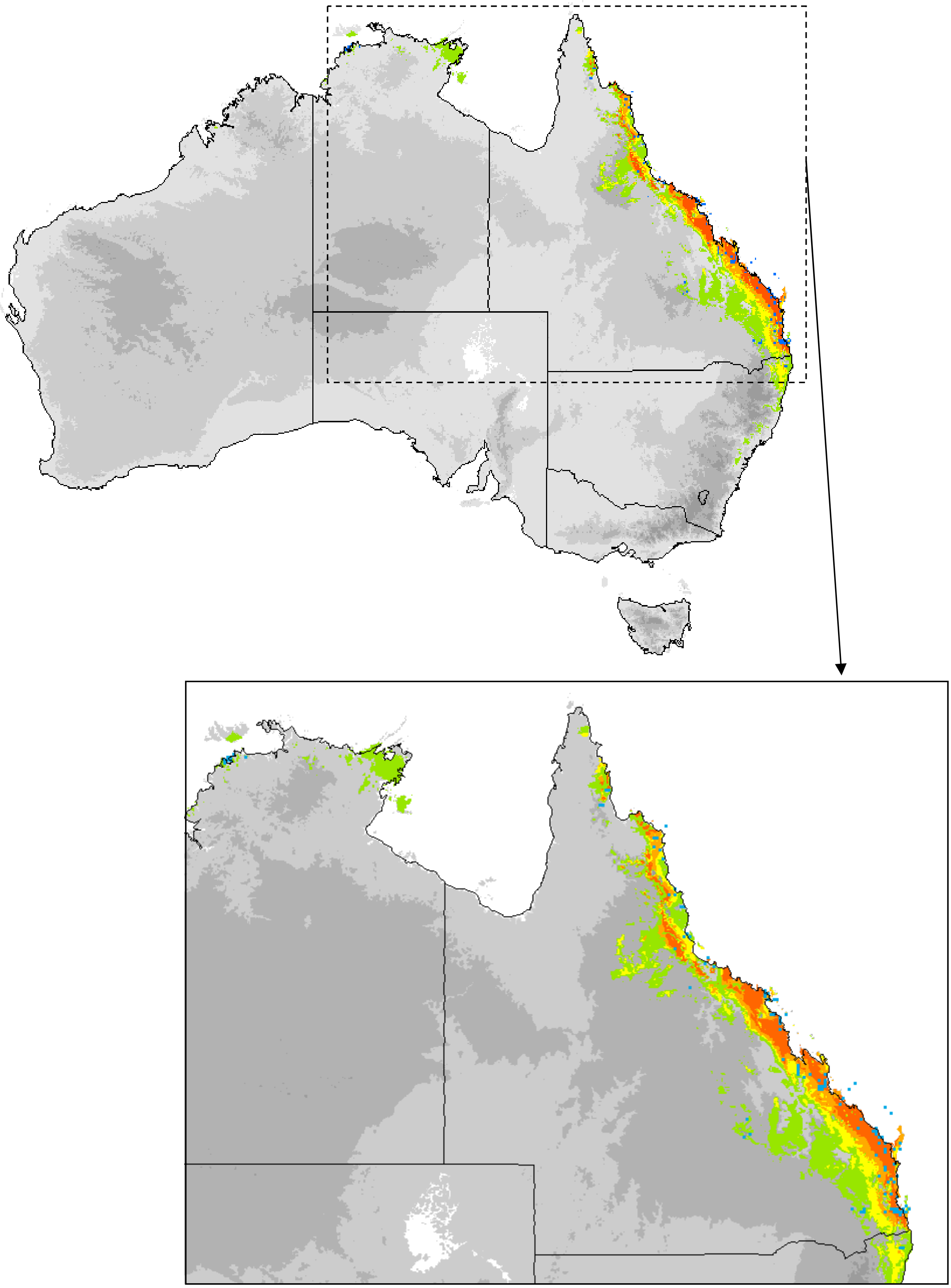
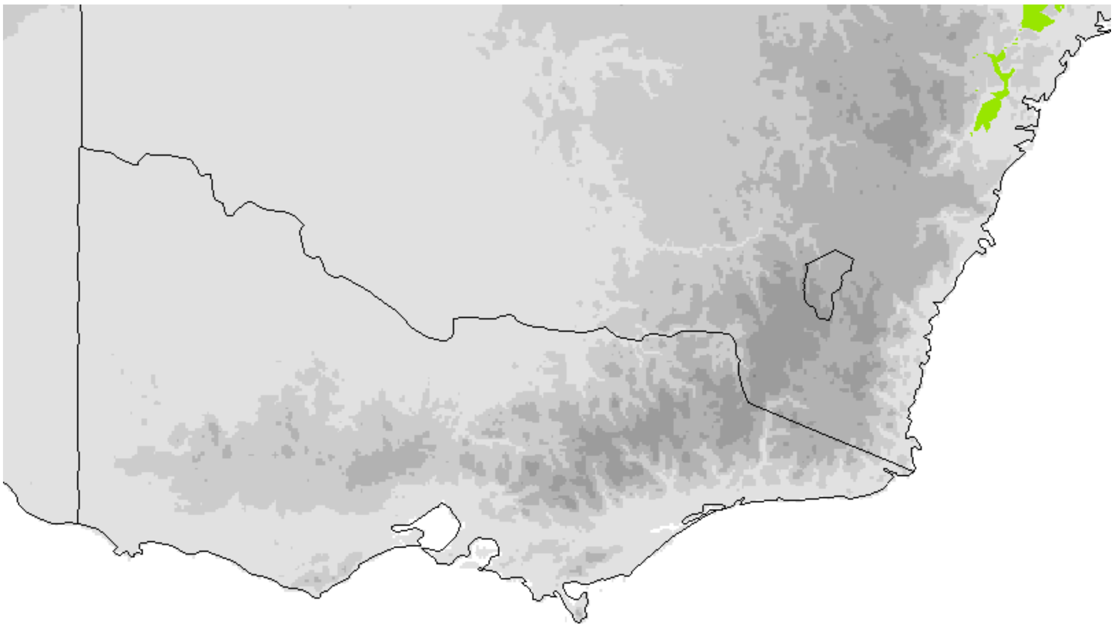


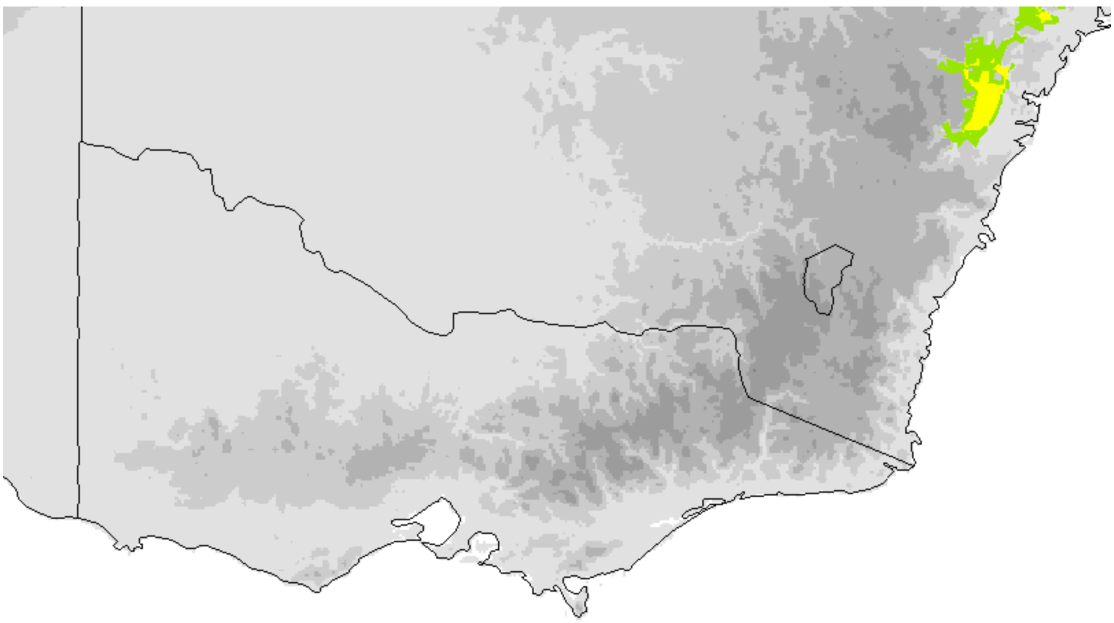
Figure 54. Comparison of current distribution with the baseline climate match

Figure 55a. ***Passiflora suberosa*** B1 scenario (low)



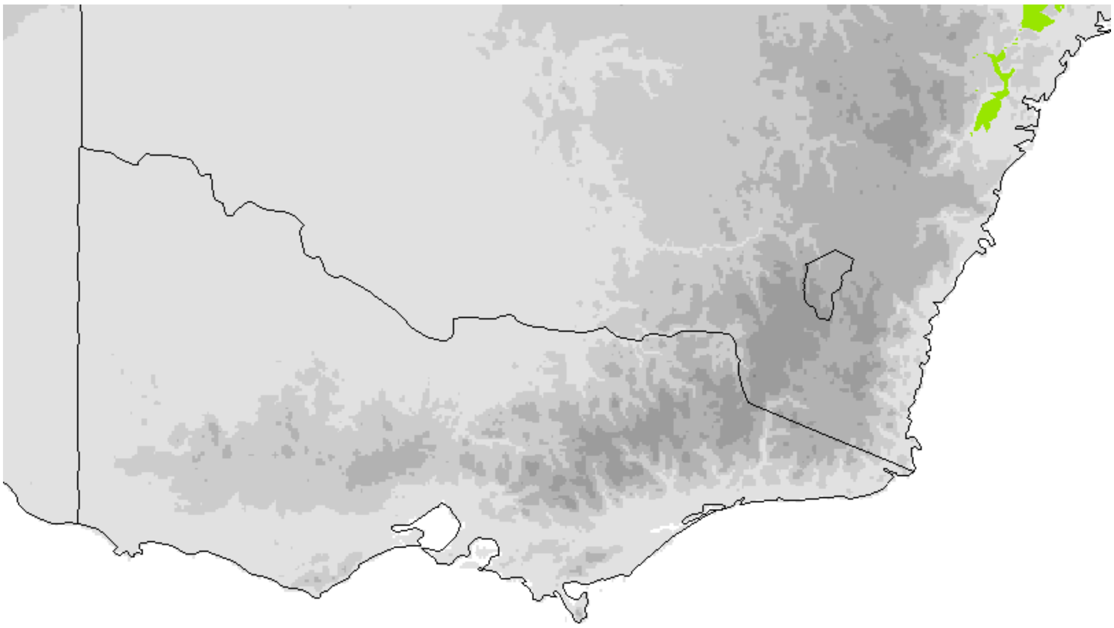
Baseline climate

2030



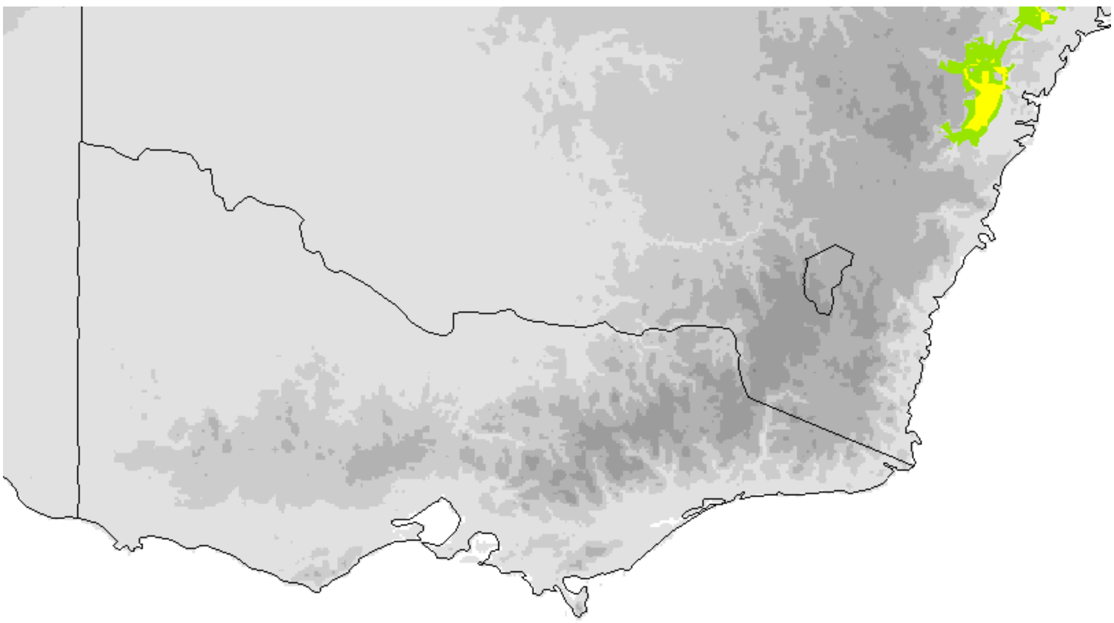
2070

Figure 55b. *Passiflora suberosa* A1 scenario (mid)



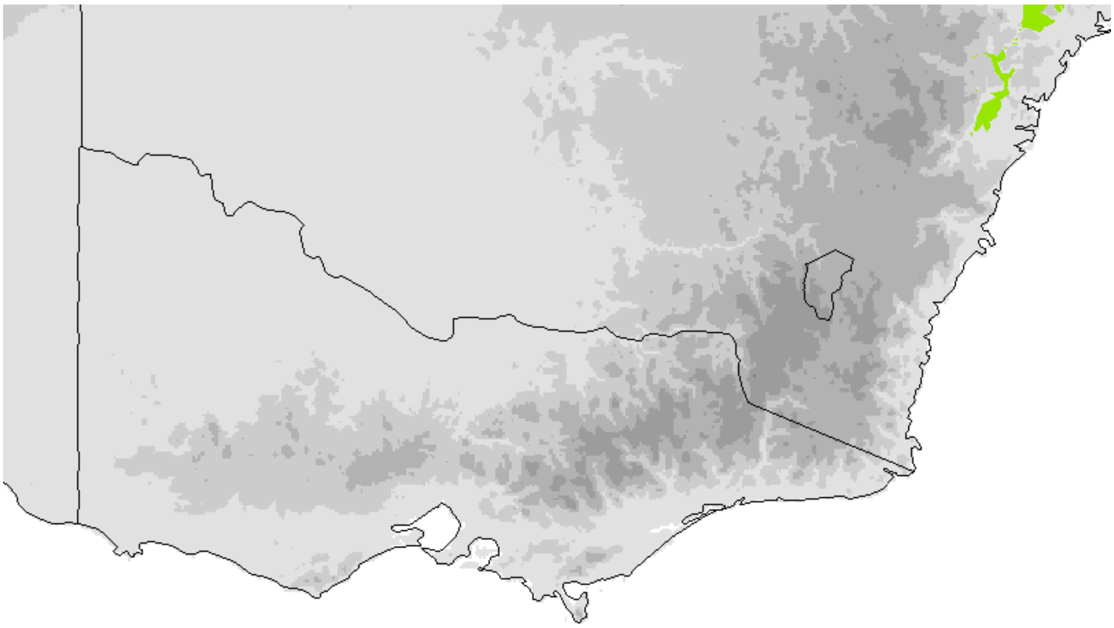
Baseline climate

2030



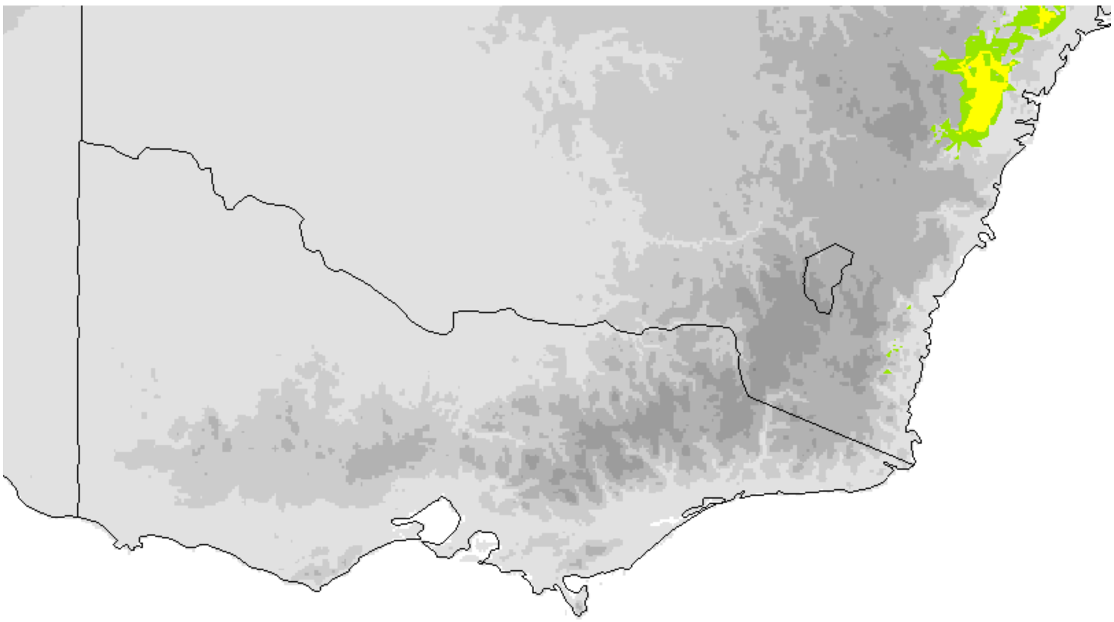
2070

Figure 55c. *Passiflora suberosa* A1F scenario (high)



Baseline climate

2030



2070

Results summary for *Passiflora suberosa*

Whilst all climate change scenarios saw a southward shift and increase in area and quality of the climate match envelope for this species, at no stage did it encroach into Victoria. The leading edge of the climate envelope never reached as far south as Wollongong. Climatic conditions in Victoria do not appear to ever become suitable for the establishment and growth of this species.

Prosopis pallida

mesquite

Prosopis are native to southern USA, Central America and northern South America and have now become weeds of grasslands and grazing areas in their native countries, as well as in Jamaica, India, Pakistan, South Africa and mainland Australia (Parsons & Cuthbertson 2001).

In Hawaii, kiawe is most common in leeward coastal areas that have an annual rainfall of 250 to 760 mm and a mean annual temperature of 24° C with a range of 13° to 35° It rarely extends above 150 m in elevation because higher rainfall and lower temperature give other species competitive advantage, however it can grow in rainfall zones of up to 1240mm. It can tolerate temperatures down to -6.1° C (Skolmen 2005).

The parameters chosen to model this species were 9, 6 & 23.

The baseline climate match for this species (Fig. 56) was excellent, encompassing all but one of the current distribution data points, the most easterly point.

Prosopis pallida

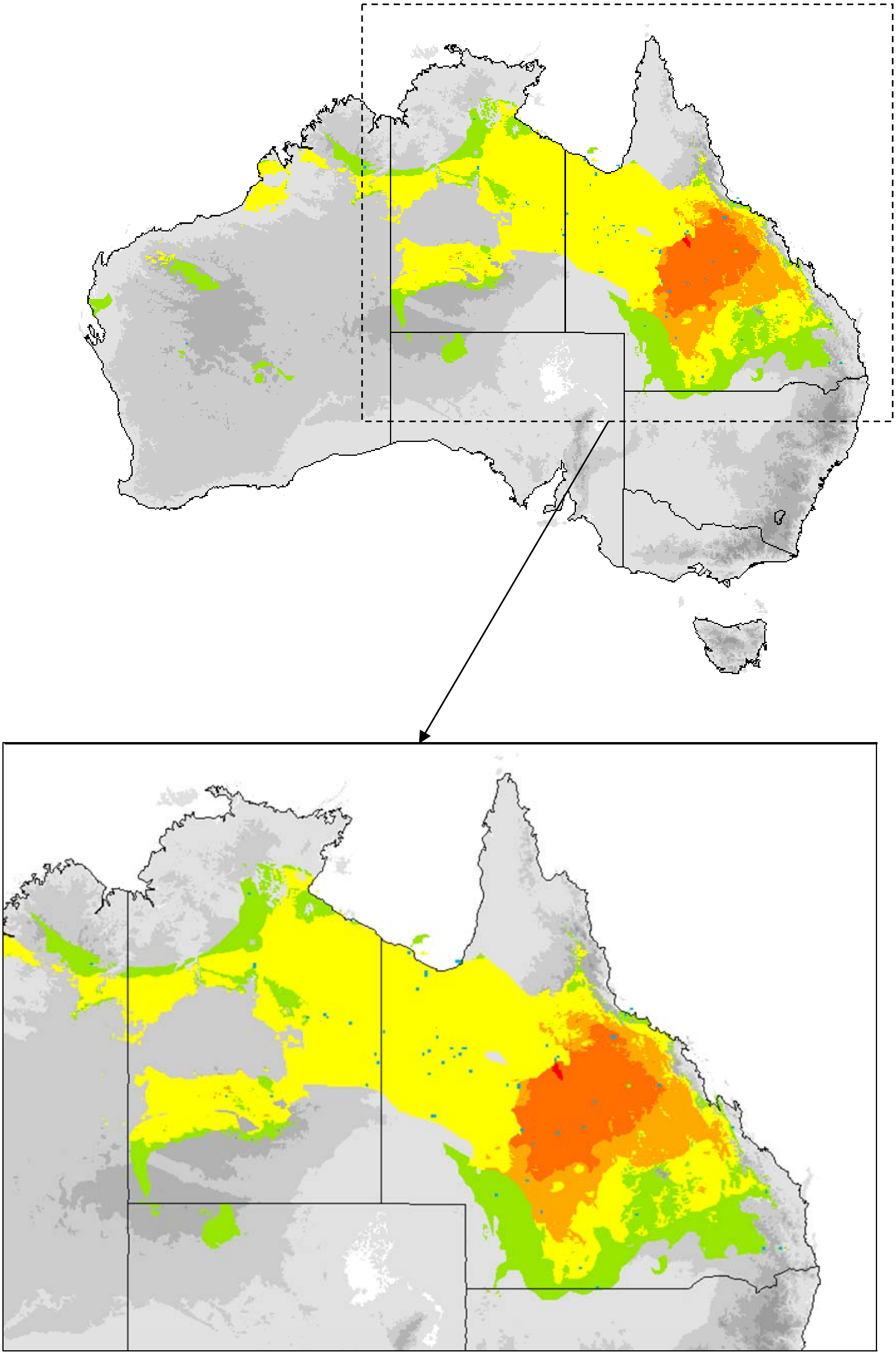
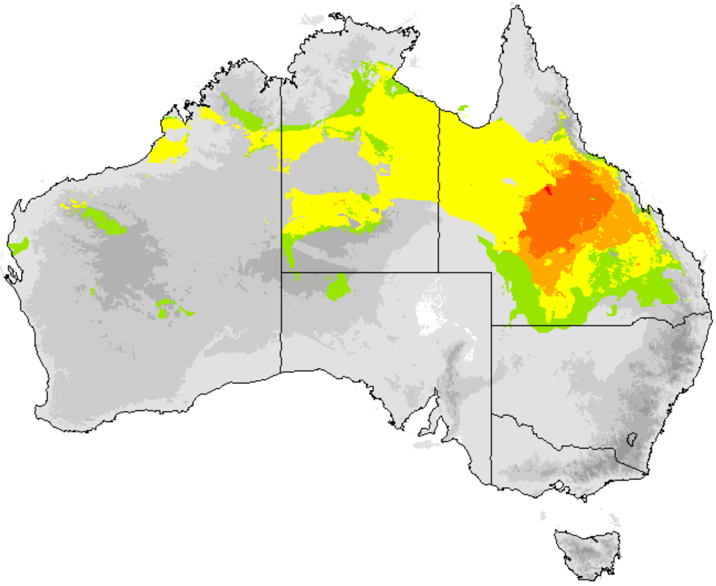
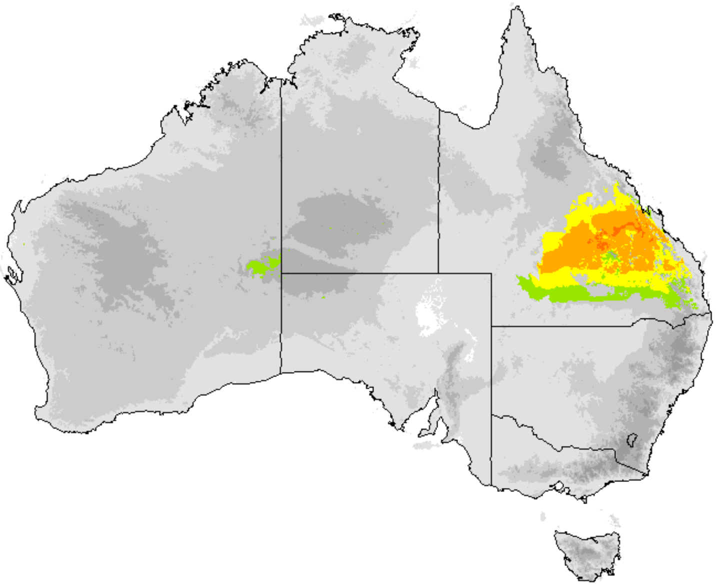


Figure 56. Comparison of current distribution with the baseline climate match

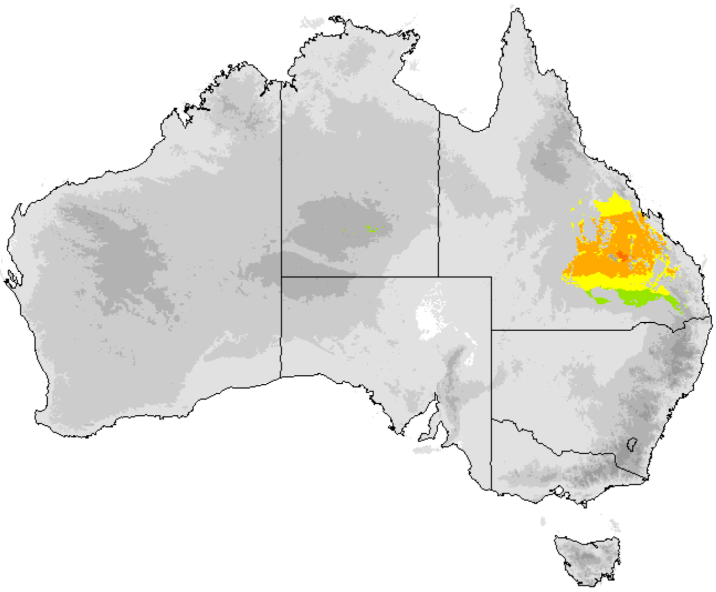
Figure 57a. *Prosopis pallida* B1 scenario (low)



Baseline climate

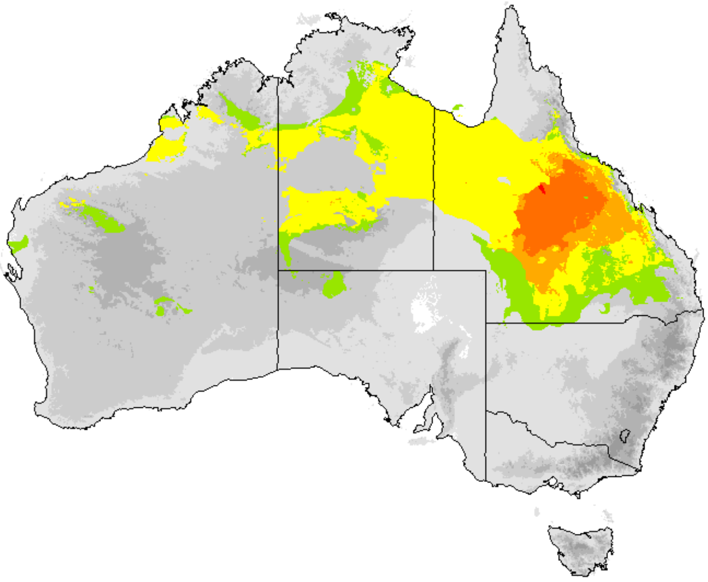


2030

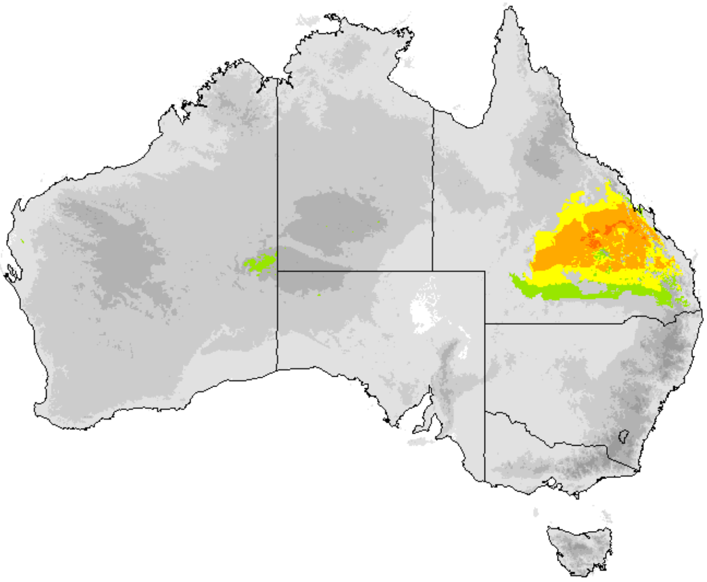


2070

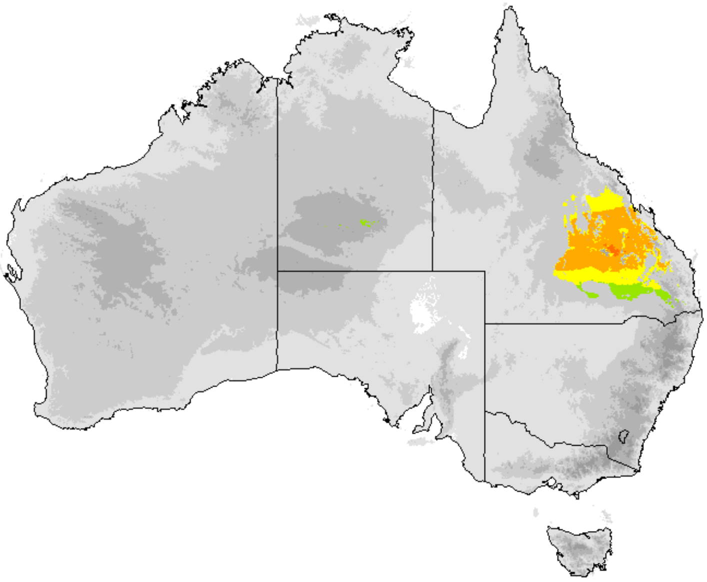
Figure 57b. ***Prosopis pallida*** A1 scenario (mid)



Baseline climate

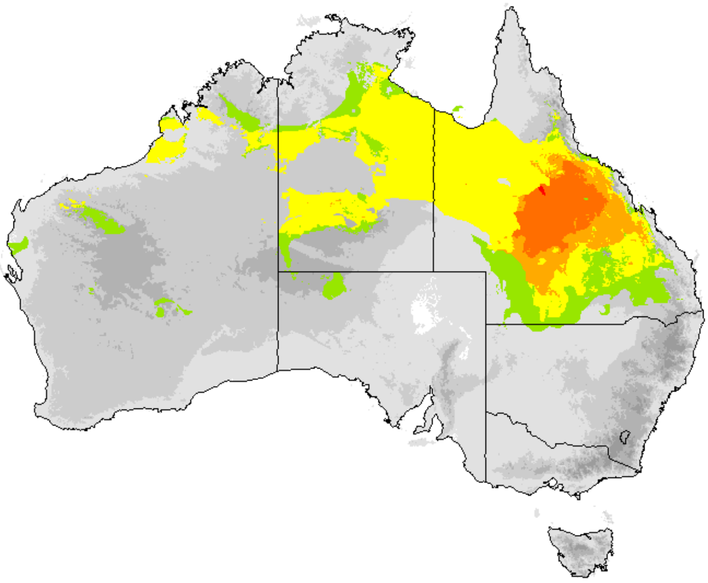


2030

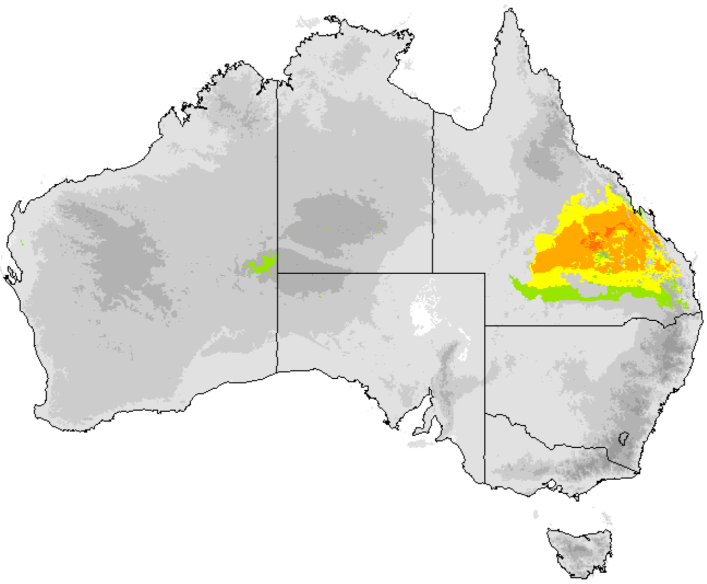


2070

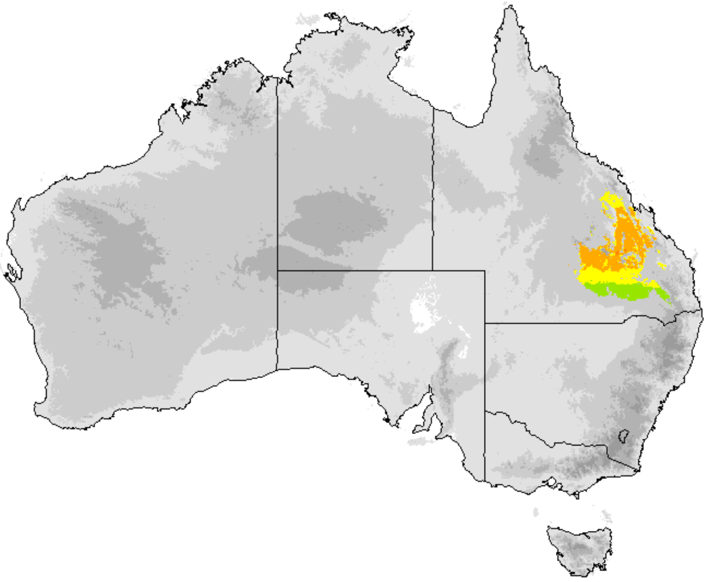
Figure 57c. *Prosopis pallida* A1F scenario (high)



Baseline climate



2030



2070

Results summary for *Prosopis pallida*

The climate envelope for this species was not observed to expand to the south and it never occupied Victoria. The climate envelope contracted under all scenarios reaching its smallest size at 2070, mainly contracting from the west. The degree of climatic suitability also decreased over time.

Rubus fruticosus **L. agg.**

blackberry

(*R. selmeri, R. laciniatus, R. polyanthemus, R. cissburiensis, R. ulmifolius, r. procerus, R. vestitus* & *R. rosaceus*)

The European blackberry has become weedy in North and South America and parts of Africa and Asia, and all Australian states and territories, except NT (Parsons & Cuthbertson 2001).

It is a weed of roadsides, streambanks, neglected areas and farmlands, including pastures, orchards, forest plantations and bushland (Parsons and Cuthbertson 2001). Blackberry also invades lowland grassland & grassy woodland, dry sclerophyll forest, damp sclerophyll forest, wet sclerophyll forest, riparian vegetation, freshwater wetland, warm temperate rainforest and cool temperate rainforest (Carr *et al* 1992).

Blackberry occurs in humid and subhumid temperate regions mainly in areas with fertile soils and an annual rainfall greater than 750mm. High temperatures limit its distribution in Qld and SA (Parsons and Cuthbertson 2001).

Parameters used to model species distribution: 1, 5, 6, 7, 9, 10, 11, 12, 13 & 17.

The baseline climate match for this species (Fig. 58) worked extremely well, especially in south-east Australia, where all of the current distribution was encompassed in the climate envelope. And the best climate matches occurred where some of the densest infestations appeared to be.

Rubus fruticosus agg.

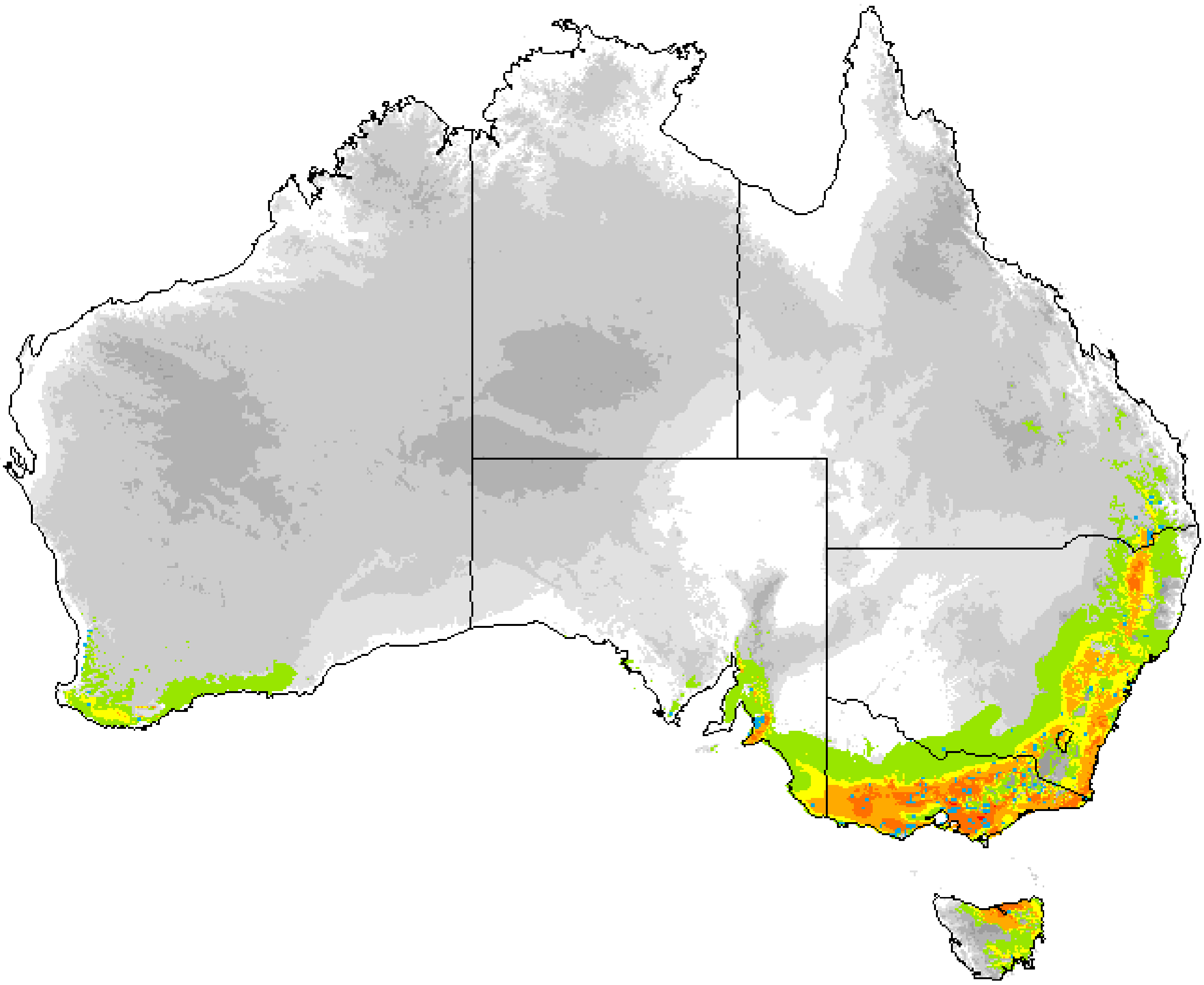
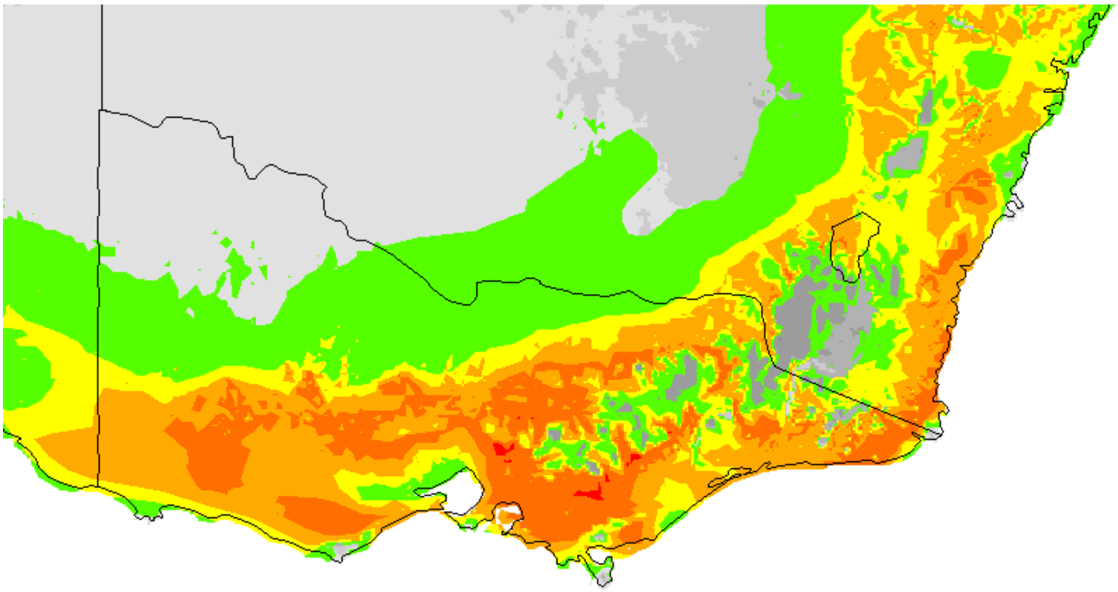
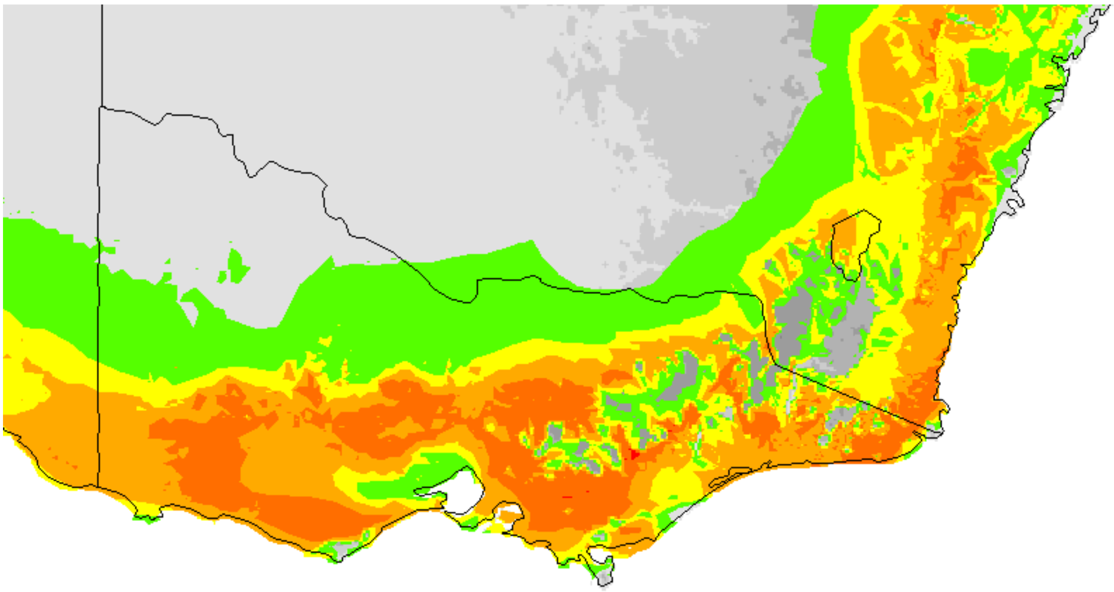


Figure 58. Comparison of current distribution with the baseline climate match

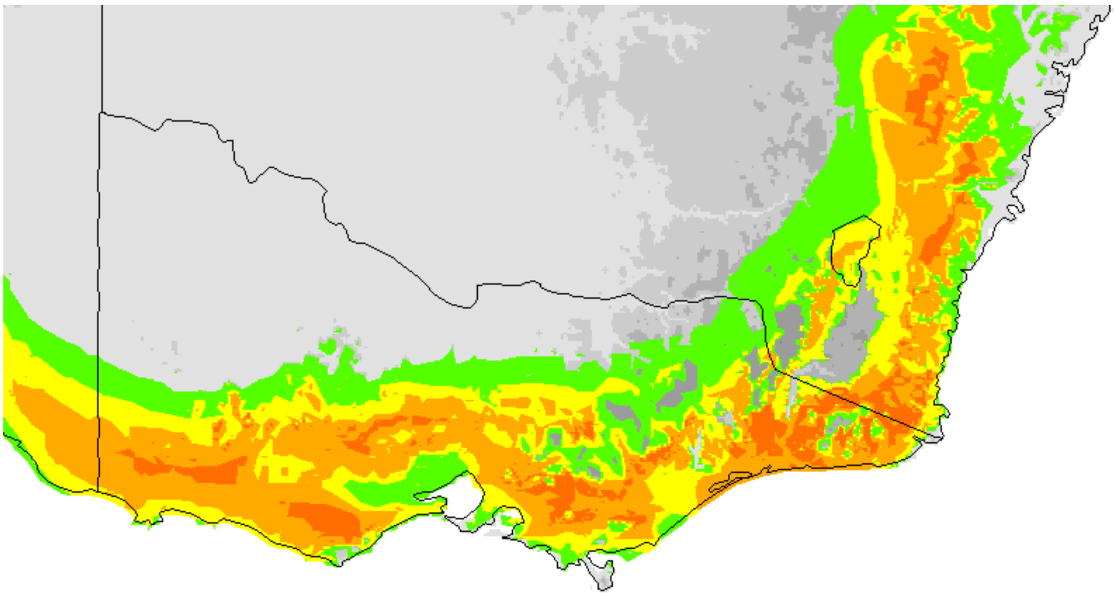
Figure 59a. *Rubus fruticosus* agg. B1 scenario (low)



Baseline climate

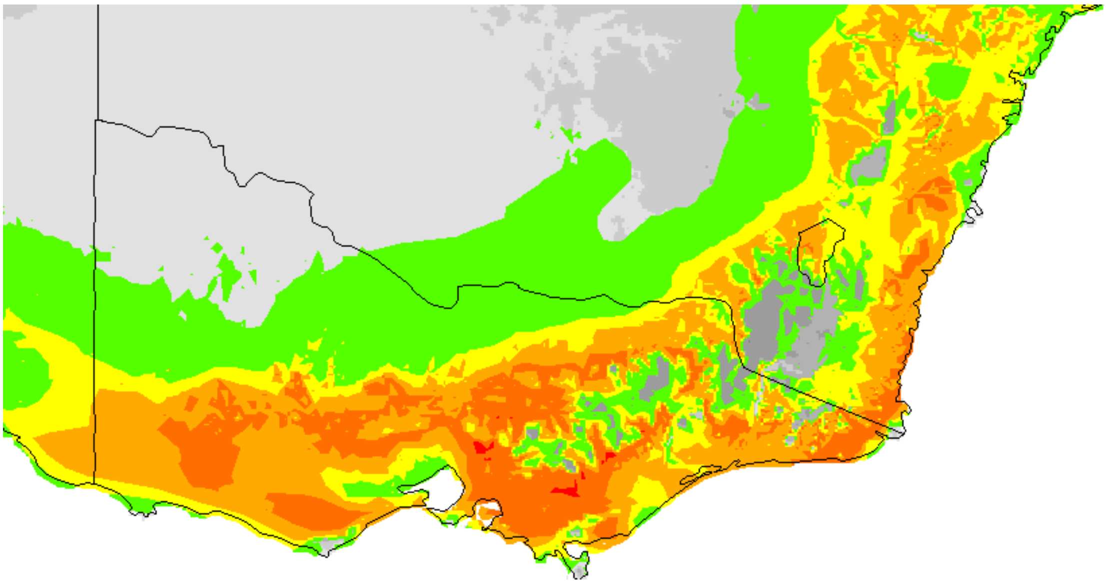


2030

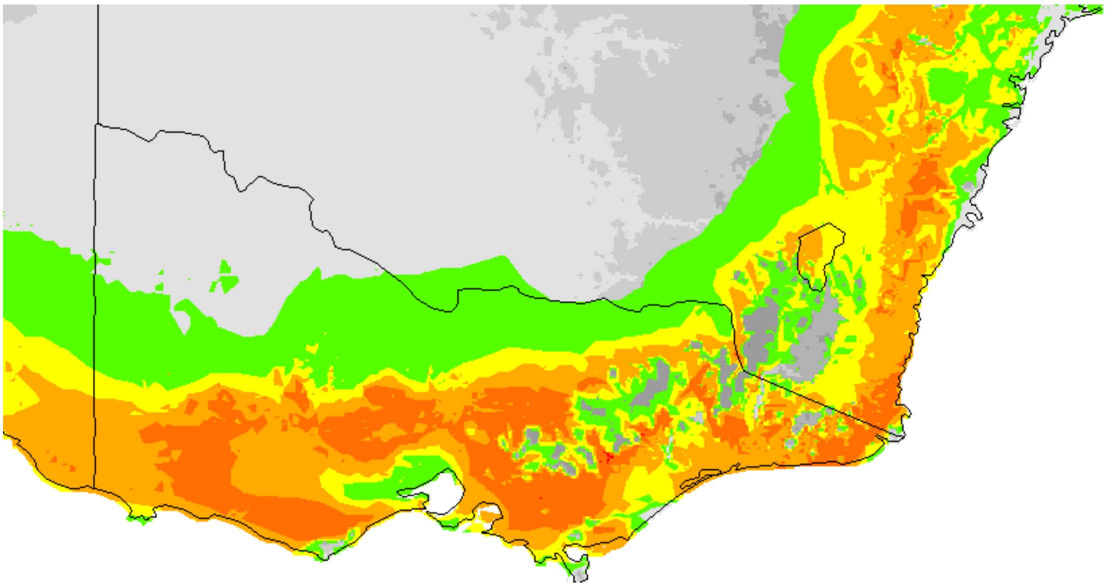


2070

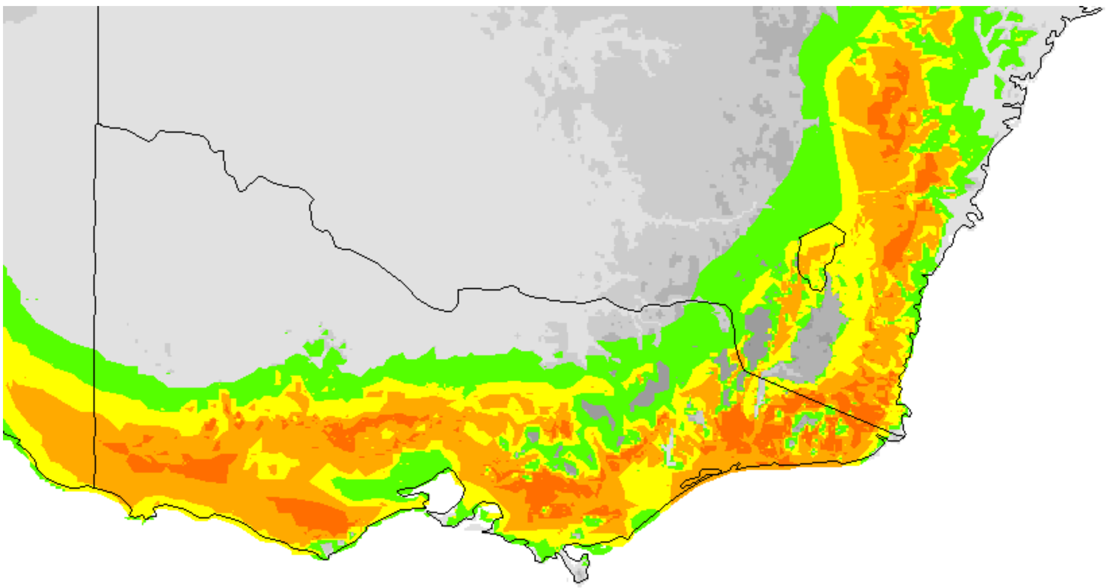
Figure 59b. *Rubus fruticosus* agg. A1 scenario (mid)



Baseline climate

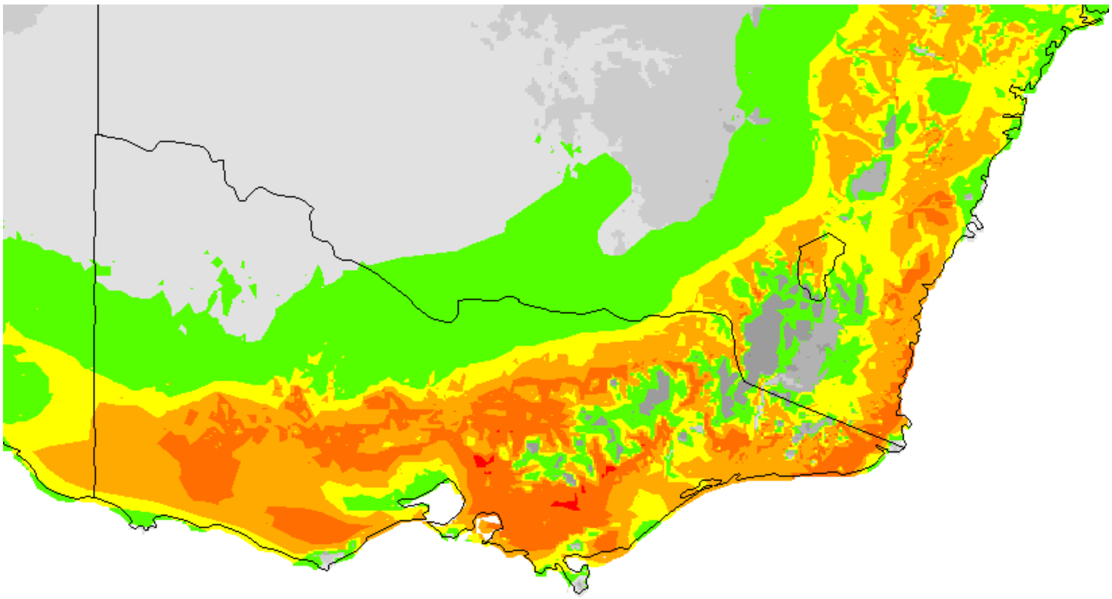


2030

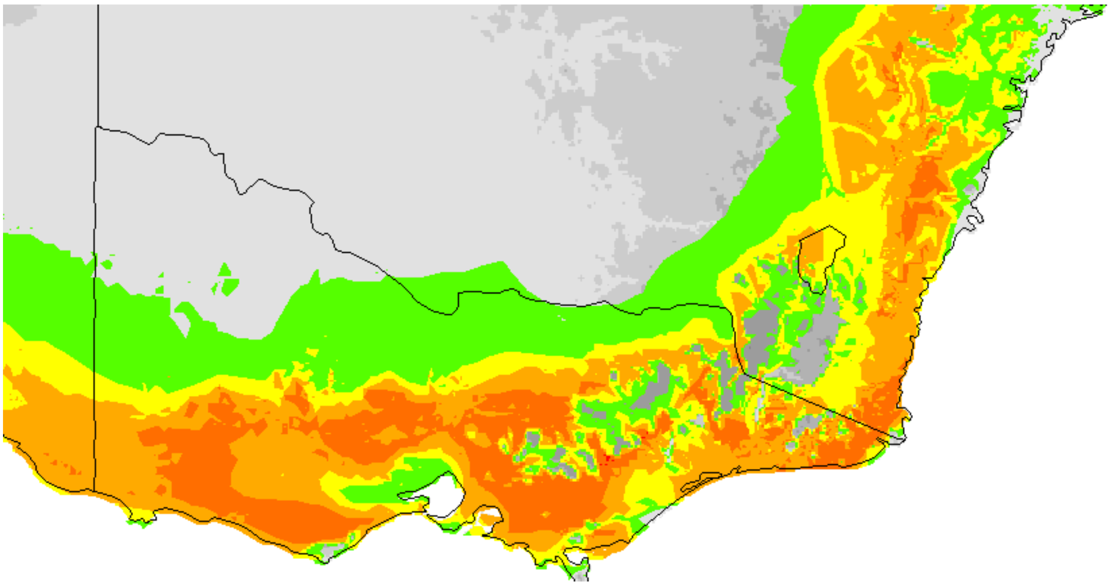


2070

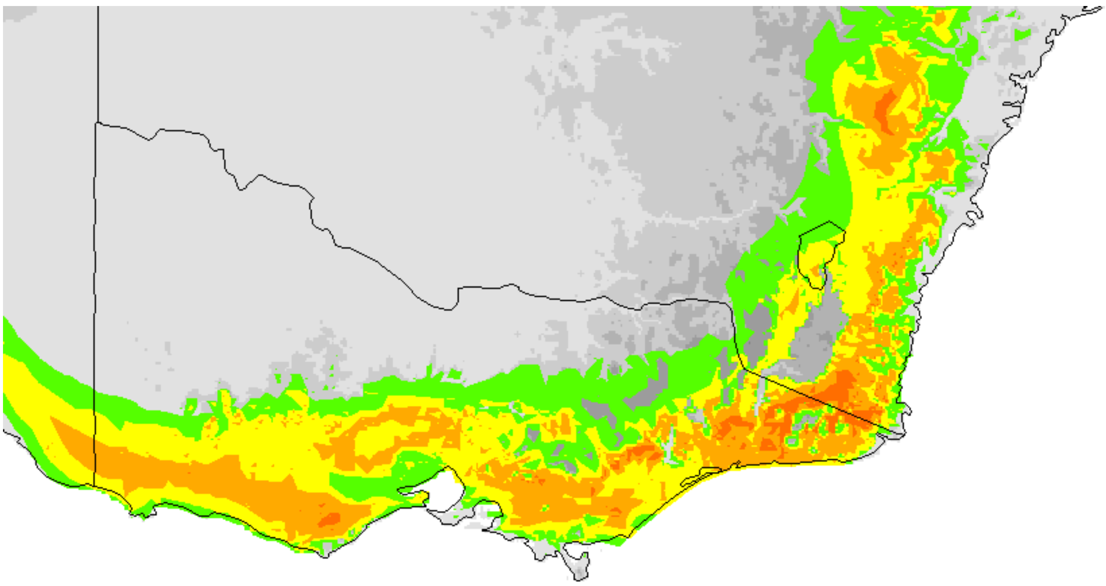
Figure 59c. *Rubus fruticosus* A1F scenario (high)



Baseline climate



2030



2070

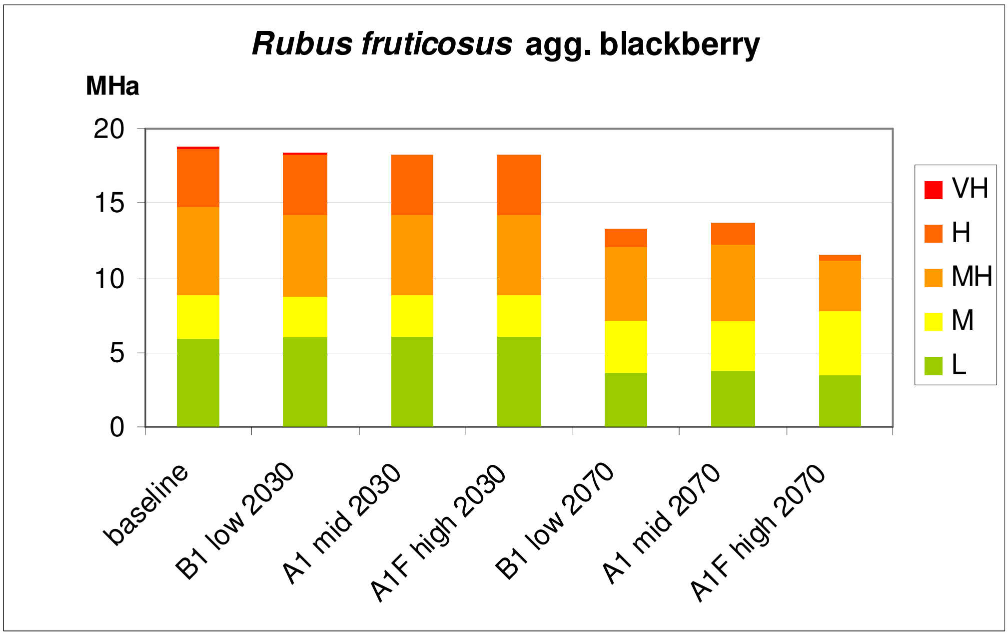


Figure 60. Area occupied by the climate envelope for *Rubus fruticosus* agg. **under a range of climate scenarios over time**

Results summary for *Rubus fruticosus* agg.

There was very little change in the climate envelope for blackberry under all climate change scenarios at 2030; however the area of the climate envelope declined under all scenarios at 2070, with the smallest area occurring under A1F high scenario. Over the longer term the climatic conditions suited to the establishment and growth of this species in Victoria are likely to decline in area and quality.

B1 (low)

2030

The outer boundary of the climate envelope reduced slightly within Victoria; however, the very high climate match was substantially reduced. The high climate match became less fragmented, occupying a greater area, especially in the central and south-western parts of the state. The climate match appeared to retreat to slightly lower altitudes around the Great Dividing Range.

2070

The northern boundary of the climate envelope retracted south and, where the climate match remained, it was largely at a lower intensity. Suitable climates became apparent at higher altitudes in the Great Dividing Range but the coastal climate became less well-matched.

A1 (mid)

2030

This scenario had a similar result to the 2030 B1 low scenario.

2070

This potential distribution appeared to be very similar to that of 2070 B1 low, with perhaps some slightly larger areas of moderately high and high climate matches occurring, especially in the south-west of the state.

A1F (high)

2030

This potential distribution appeared to be very similar to that of 2070 B1 low.

2070

As in B1 low 2070, the northern boundary of the climate envelope retracted south, but the remaining climate matches were of a much lower intensity and became more fragmented.

Senecio jacobaea L.

ragwort

This species originate in Europe and has become a weed both in its native range and in Canada, USA, New Zealand, South Africa and South America. In Australia it has become a weed of poorly managed, degraded pasture in Victoria and Tasmania (Parsons & Cuthbertson 2001).

Senecio jacobaea grows in humid temperate regions with an annual rainfall greater than 750mm (Parsons & Cuthbertson, 2001). It is a major agricultural weed in cooler, high rainfall districts (Muyt, 2001).

The parameters used to model this species were: 1, 5 & 12.

The baseline climate envelope (Fig. 61) encompassed more than 99% of the current distribution data points, with the highest climate matches concurring with the largest number of infestations.

Senecio jacobaea

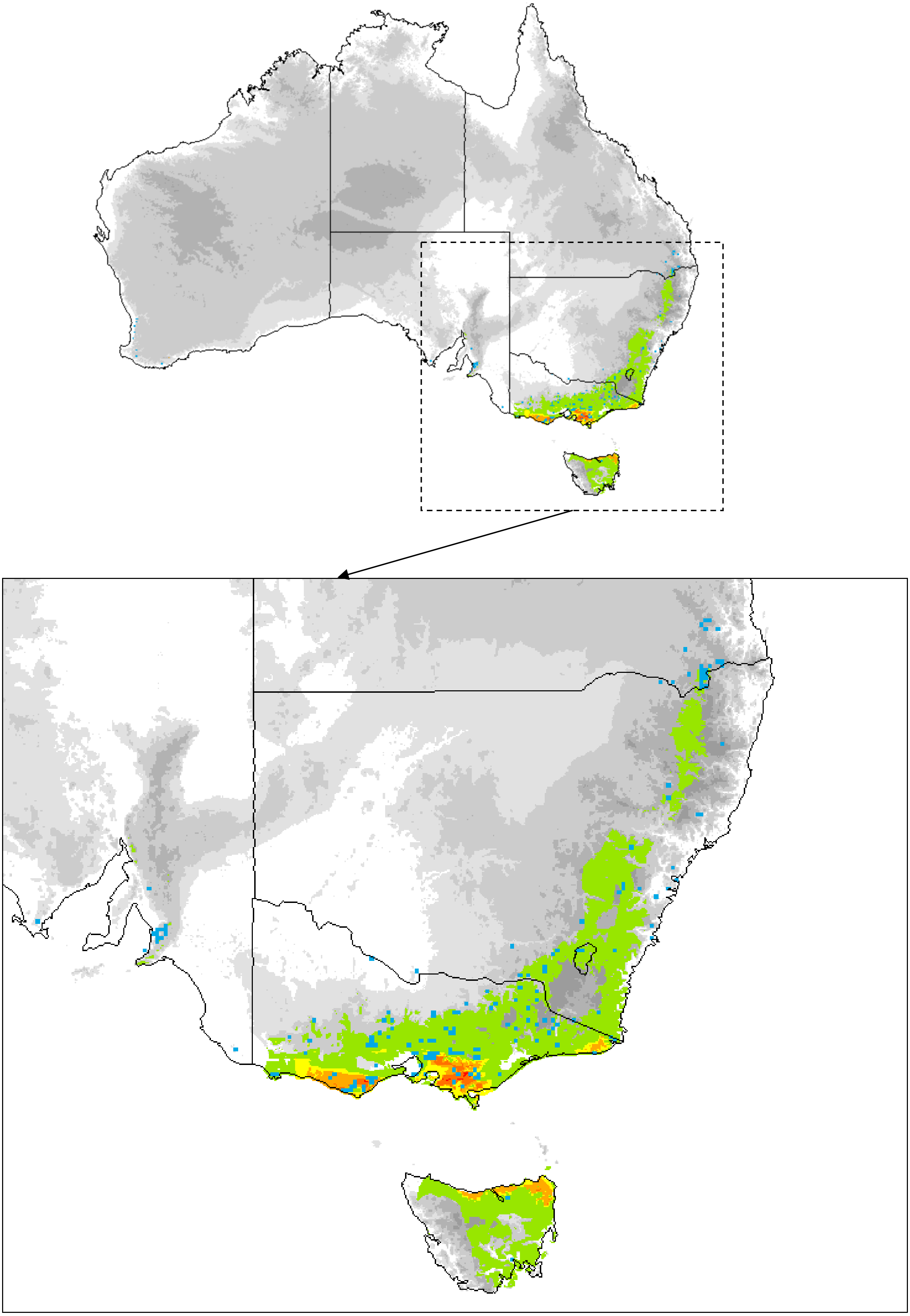


Figure 61. Comparison of current distribution with the baseline climate match

Figure 62a. ***Senecio jacobaea*** B1 scenario (low)

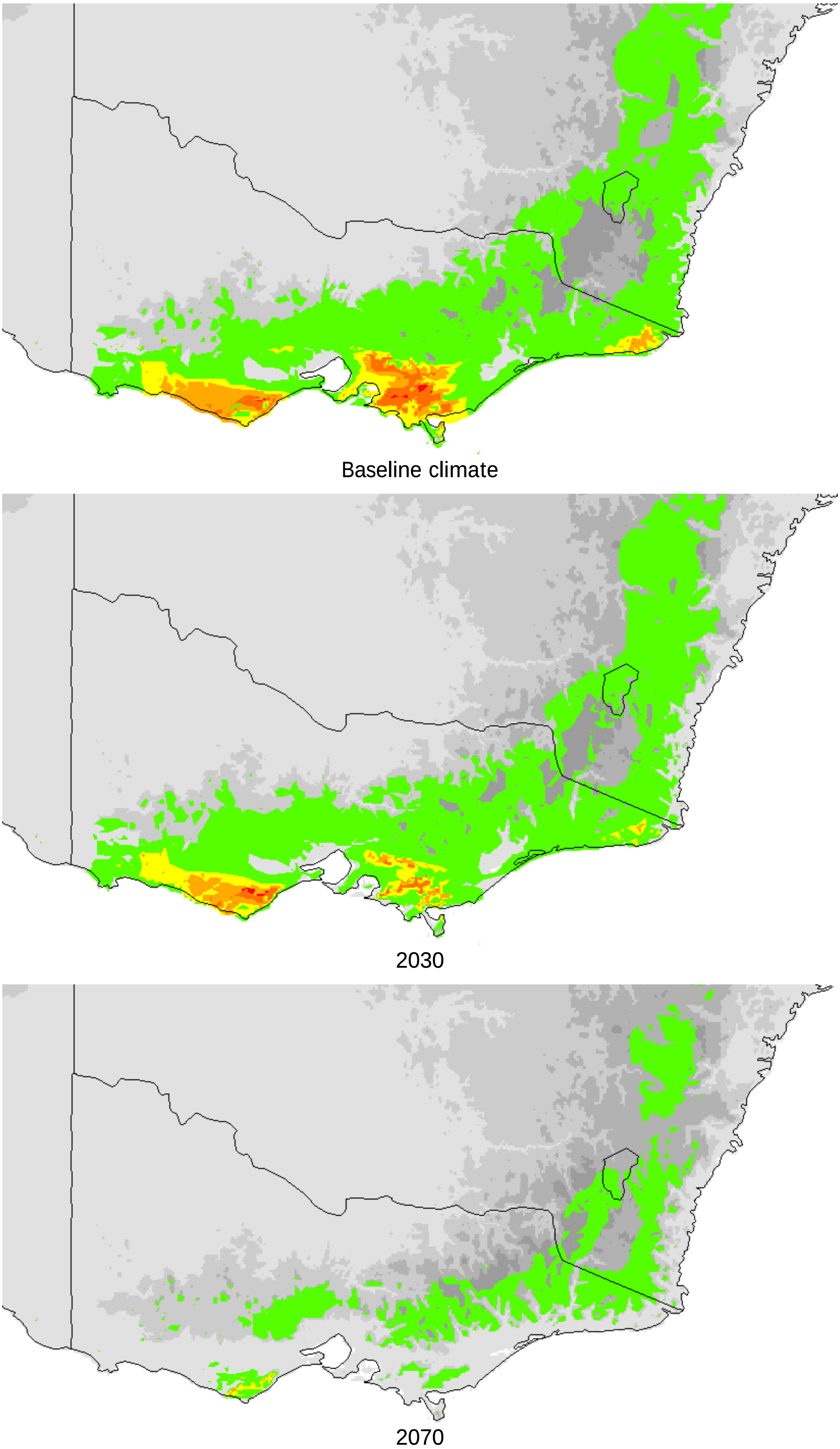
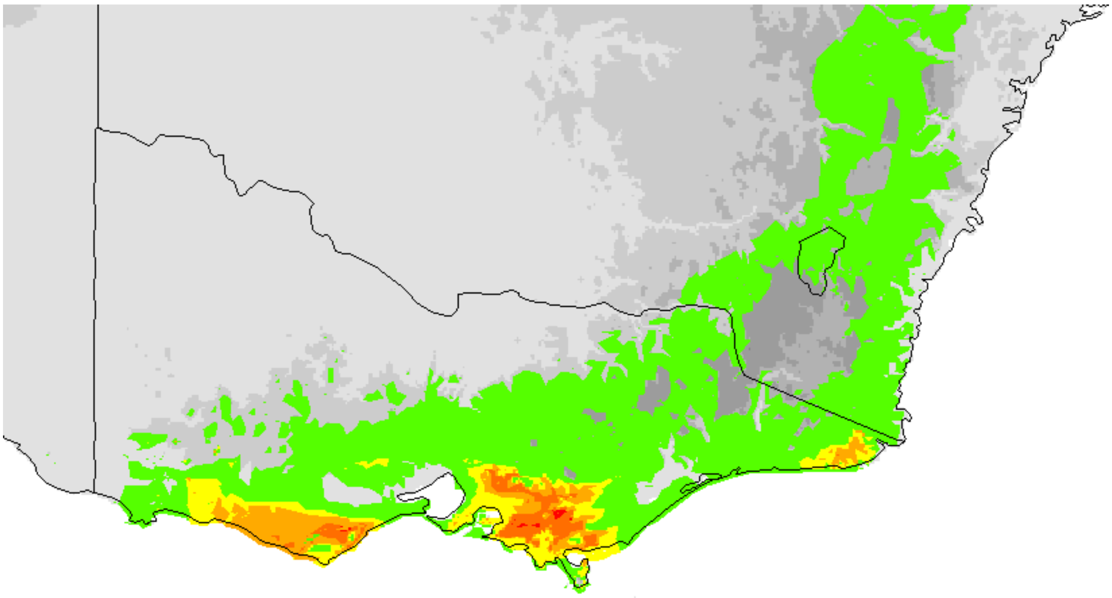
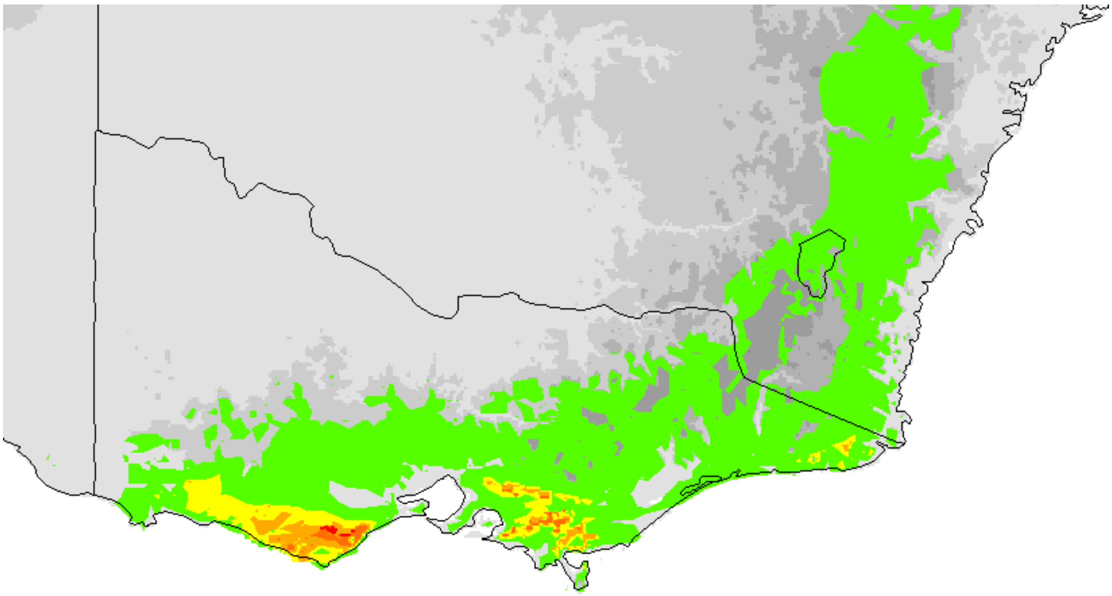


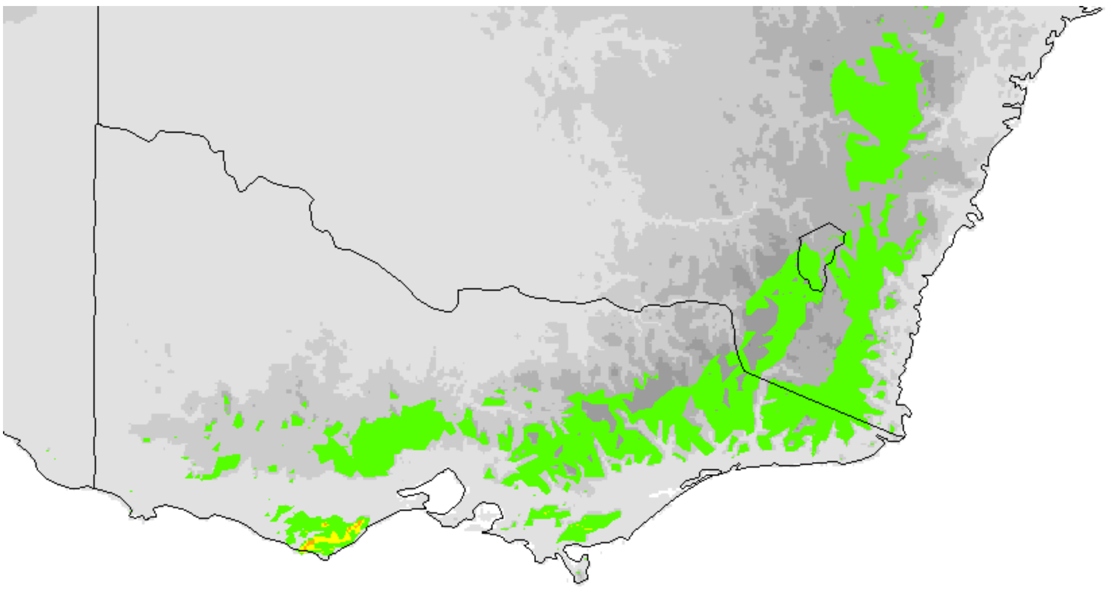
Figure 62b. *Senecio jacobaea* A1 scenario (mid)



Baseline climate

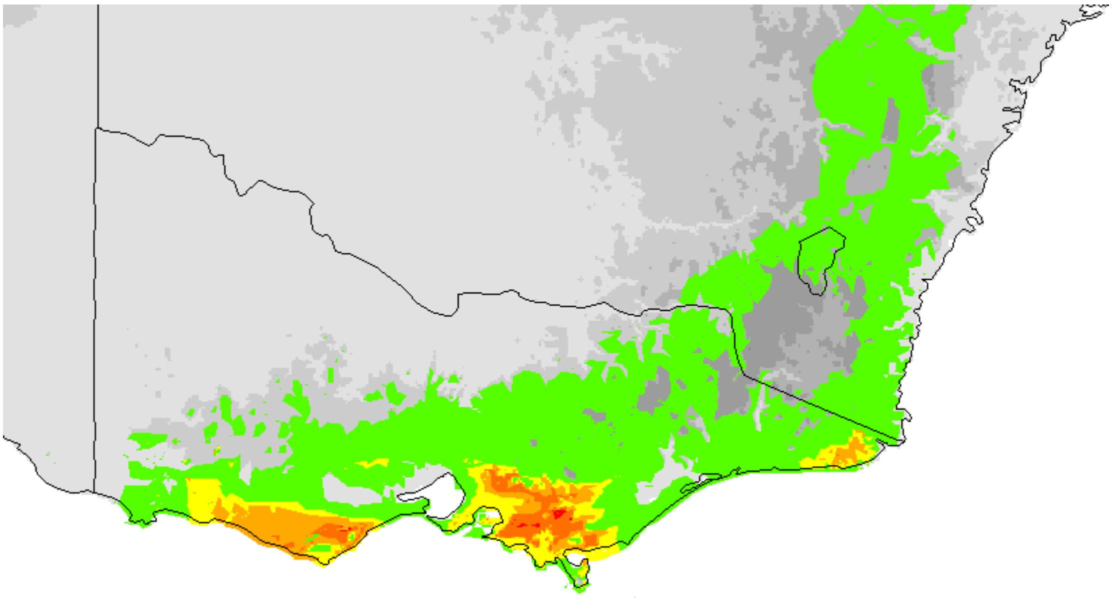


2030

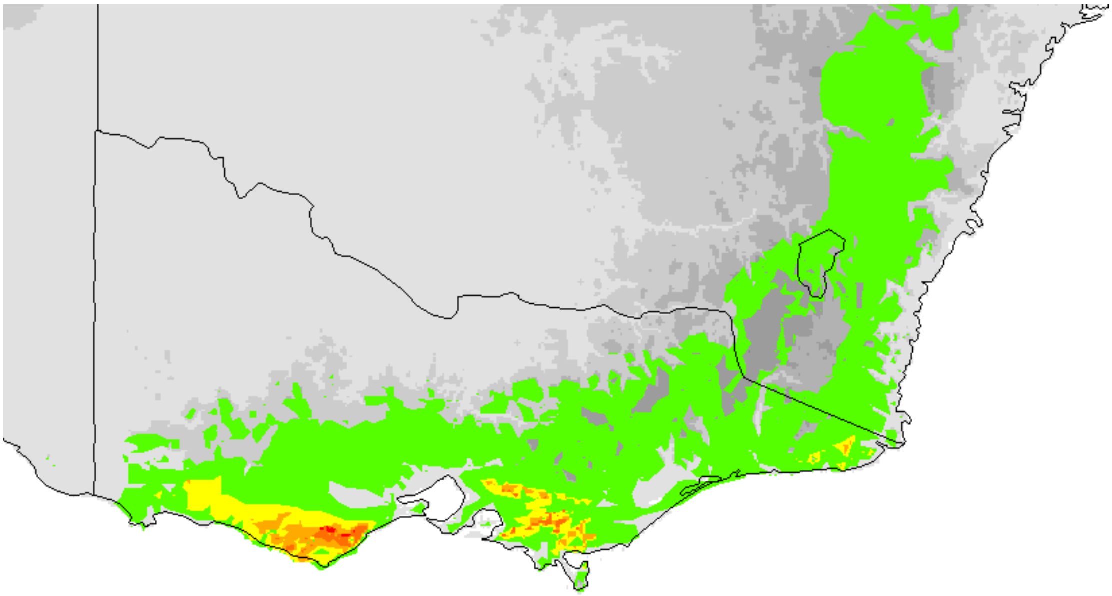


2070

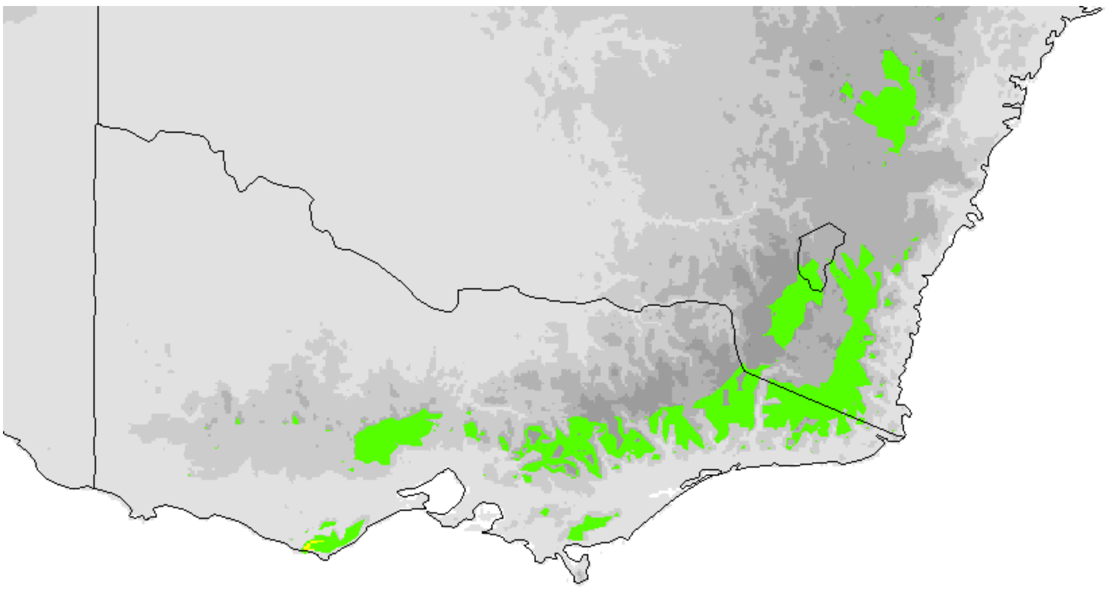
Figure 62c. *Senecio jacobaea* A1F scenario (high)



Baseline climate



2030



2070

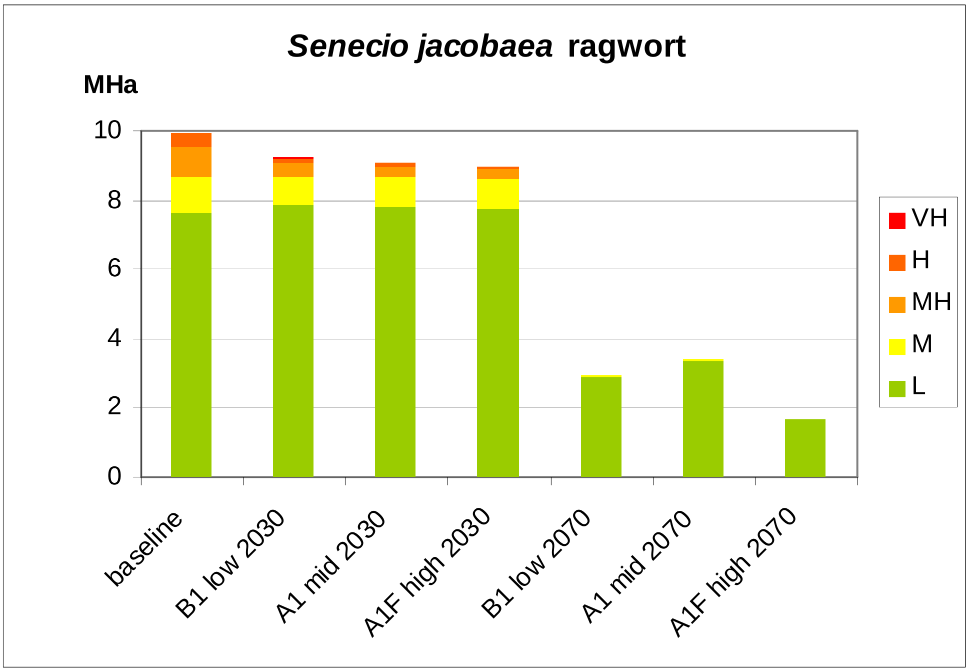


Figure 63. Area occupied by the climate envelope for *Senecio jacobaea* under a range of climate scenarios over time

Results summary for *Senecio jacobaea*

Conditions suited to the establishment and growth of *S. jacobaea* declined in Victoria under all climate change scenarios. At 2070 the area of the climate envelope reduced to less than a third under all scenarios, and under A1F high it was less than one fifth of the area under baseline climate, persisting only at high altitudes. The degree of climate match was also reduced, with mostly likely and some moderately likely climate matches at 2070 under all scenarios.

Ragwort B1 (low)

2030

The potential distribution contracted to the south.

2070

The remaining potential distribution was a likely climate match that was restricted to the southern slopes of the Great Dividing Range and around the Brisbane Ranges, with some moderate and moderately high climate match around Cape Otway.

Ragwort A1 (mid)

2030

As in the B1 low scenario, the potential distribution contracted to the south.

2070

As in B1 low, the remaining potential distribution was the likely climate match, restricted to the southern slopes of the Great Dividing Range and around the Brisbane Ranges and some moderate and moderately high climate match around Cape Otway. The suitable climates around Cape Otway and the Brisbane Ranges appeared to be larger in this scenario than in the previous one.

Ragwort A1F (high)

2030

As in the B1 low scenario, the potential distribution contracted to the south.

2070

The area of the climate envelope was dramatically reduced when compared to baseline climate, and was almost half of that observed under the other scenarios at 2070. As in B1 low, the remaining potential distribution was the likely climate match, restricted to the southern slopes of the Great Dividing Range and around the Brisbane Ranges and very little moderately likely climate match around Cape Otway. The moderately high climate match was not observed at 2070 under A1F high.

Sida rhombifolia L.

Paddy's lucerne

The origin of this species is not clear, but is considered to be native to the tropics, including Australia (Parsons & Cuthbertson 2001). Its naturalised range now includes NSW, Qld & NT (Mitchell & Norris 1990) and the Kerang-Swan Hill region of Victoria (Parsons & Cuthbertson 2001), although no herbarium records were found at this location.

It is a perennial sub-shrub that has low palatability and invades and competes with pasture and crops (Parsons & Cuthberson 2002) and may also become a weed of native grasslands (Miles 2002).

Sida rhombifolia occurs in tropical and warm temperate savannah. Germination can commence at 20, but optimal temperatures are between 25 ^{O}C and 32 ^{O}C. Growth occurs best at temperatures between 25 ^{O}C and 30 ^{O}C and plants are usually dormant over winter, except in the moister, warmer areas of northern Australia (Parsons & Cuthbertson 2001).

The parameters chosen to model this species were 3, 5, 17 & 34.

The baseline climate match for this species (Fig. 64) encompassed more than 99% of the current distribution data points. The quality of the climate match was worst in the NT, but very good in Qld and NSW with the highest concentration of data points concurring with the highest climate match.

Sida rhombifolia

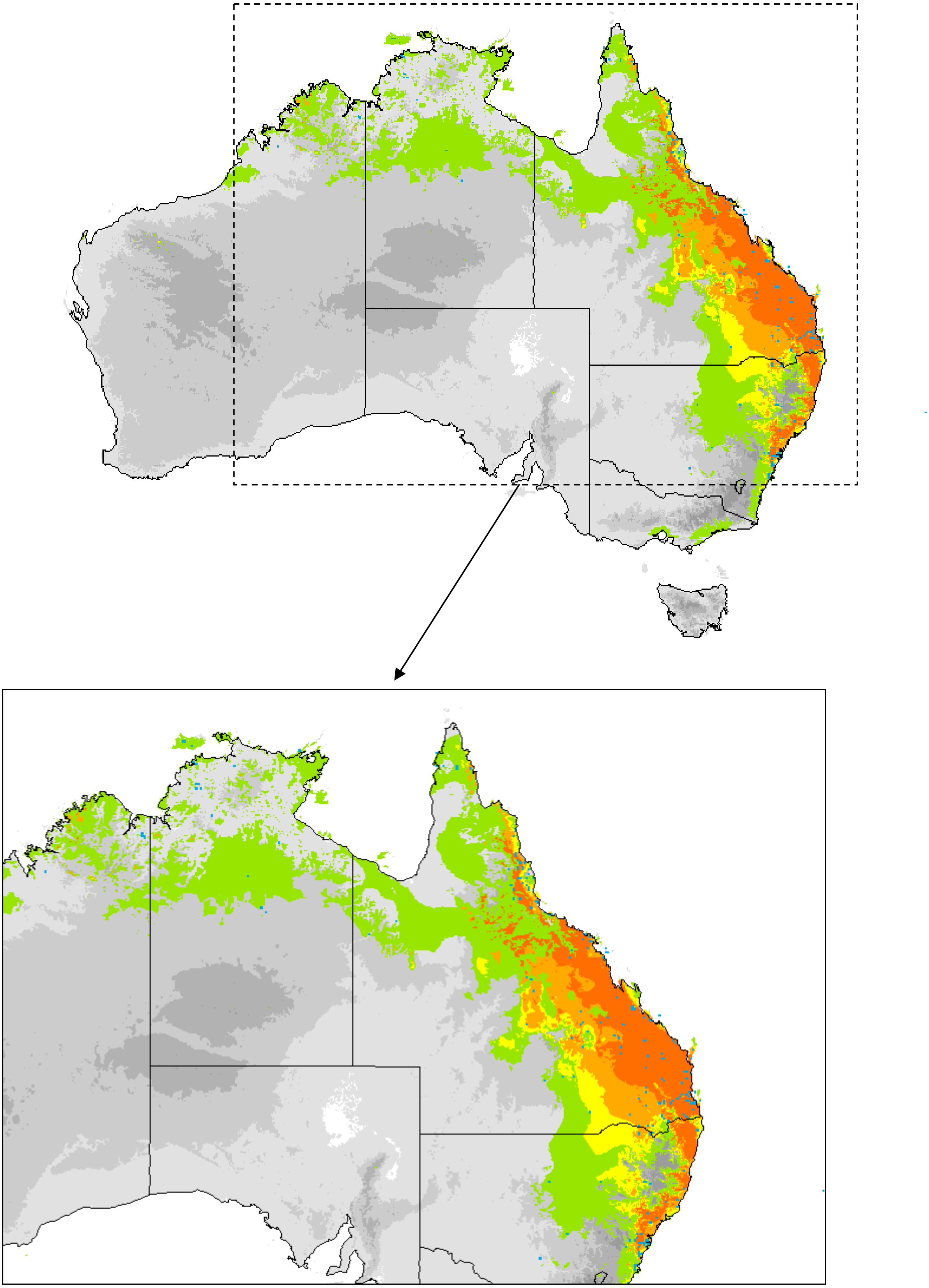


Figure 64. Comparison of current distribution with the baseline climate match

Figure 65a. ***Sida rhombifolia*** B1 scenario (low)

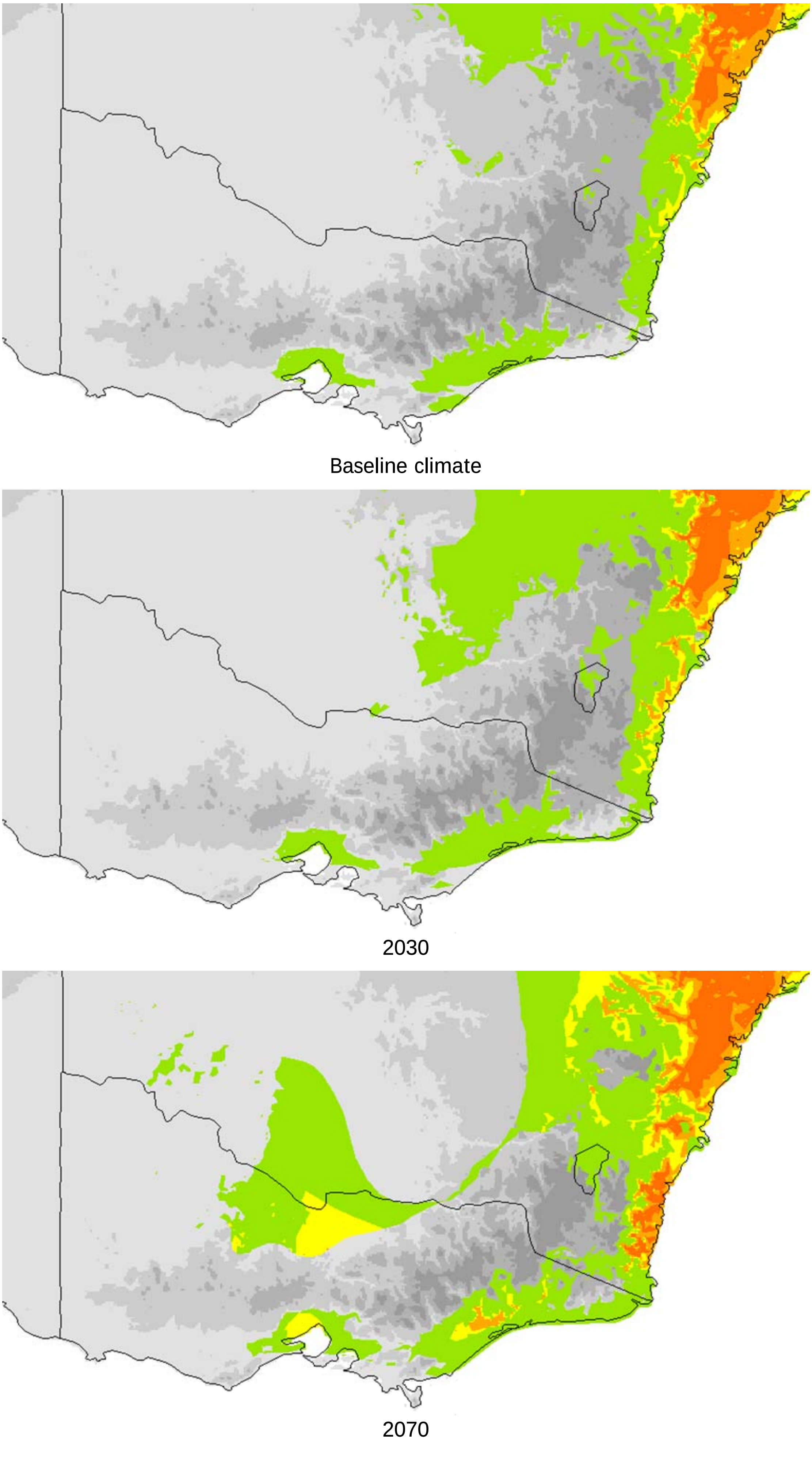


Figure 65b. ***Sida rhombifolia*** A1 scenario (mid)

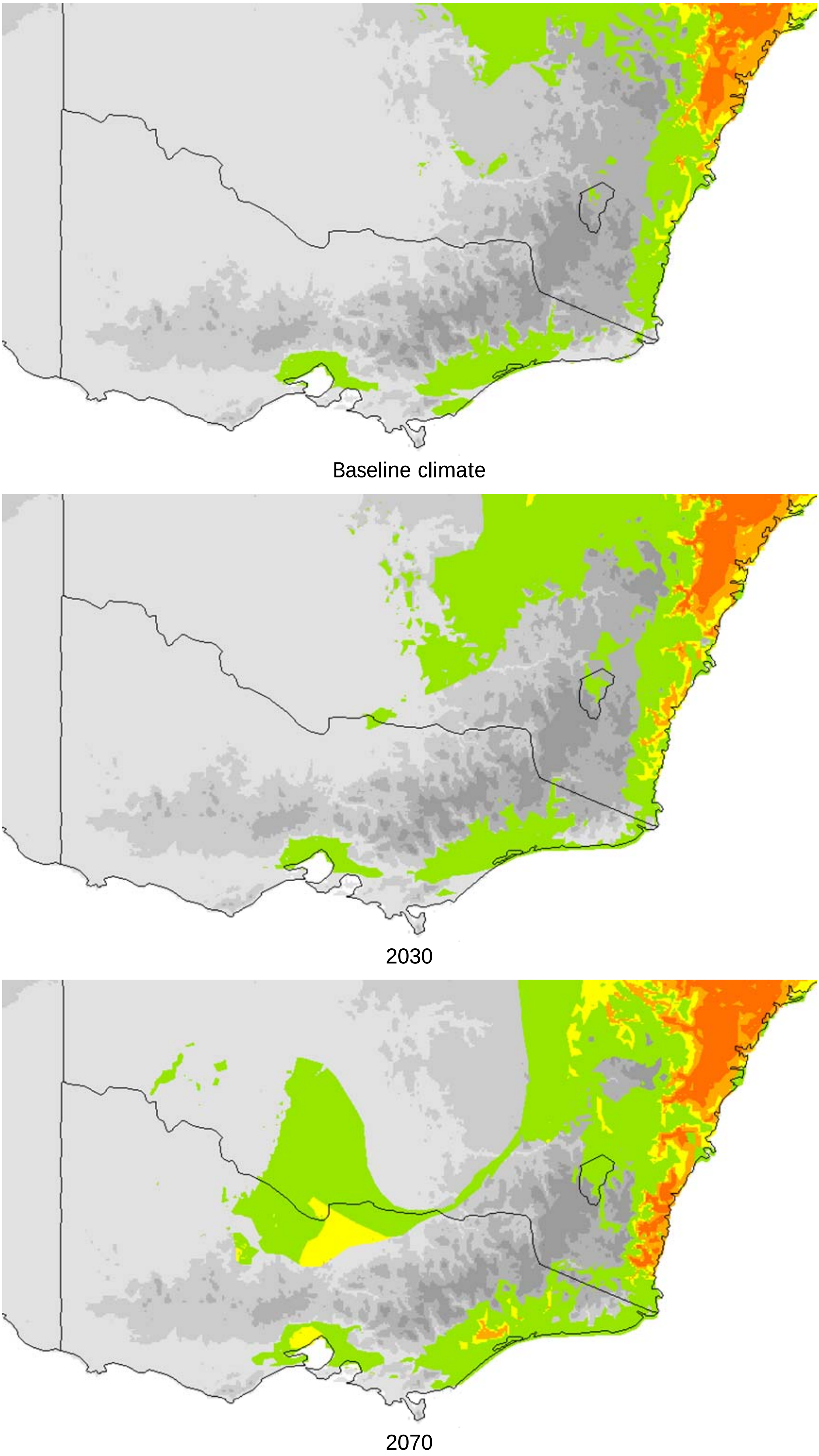
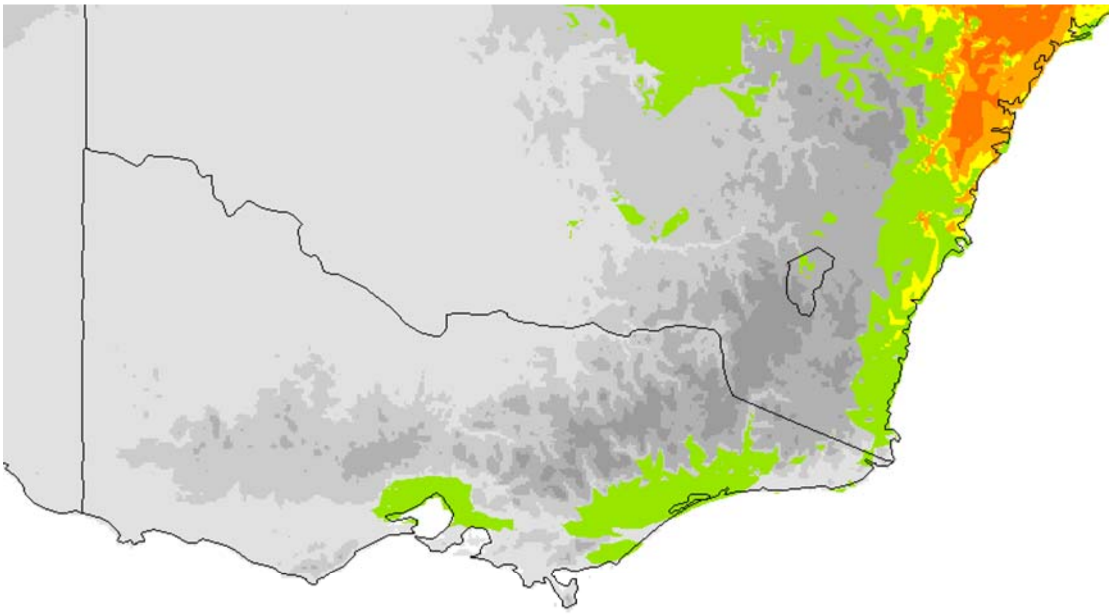
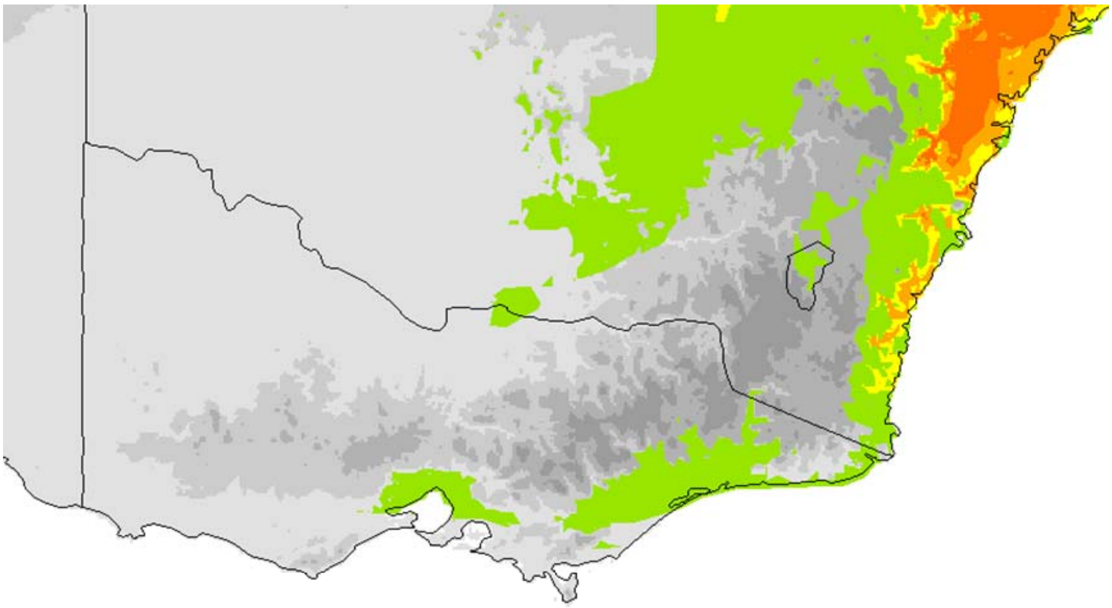


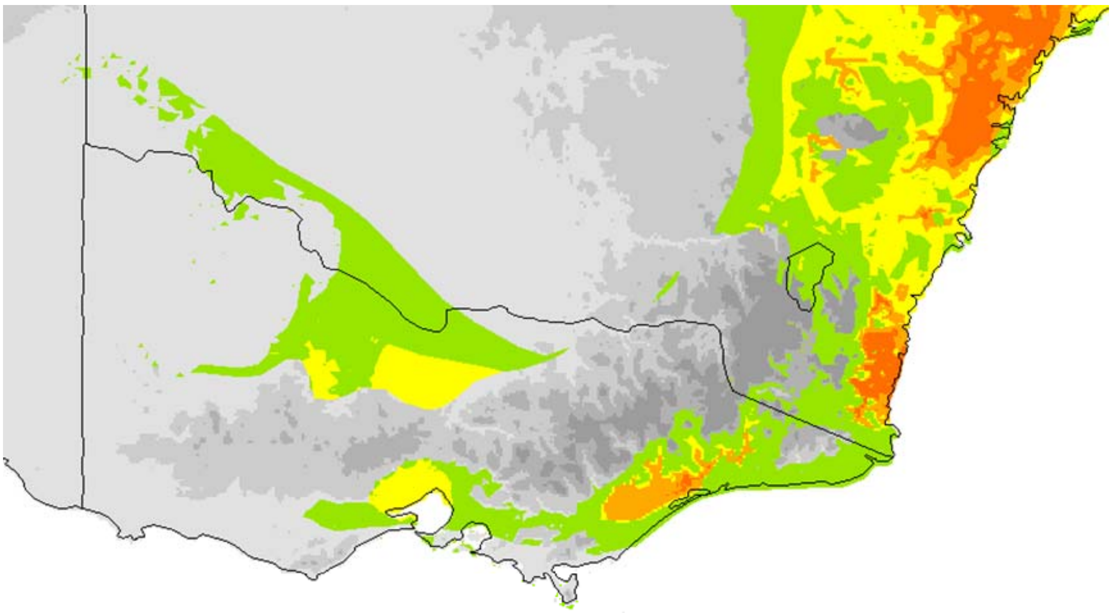
Figure 65c. ***Sida rhombifolia*** A1F scenario (high)



Baseline climate



2030



2070

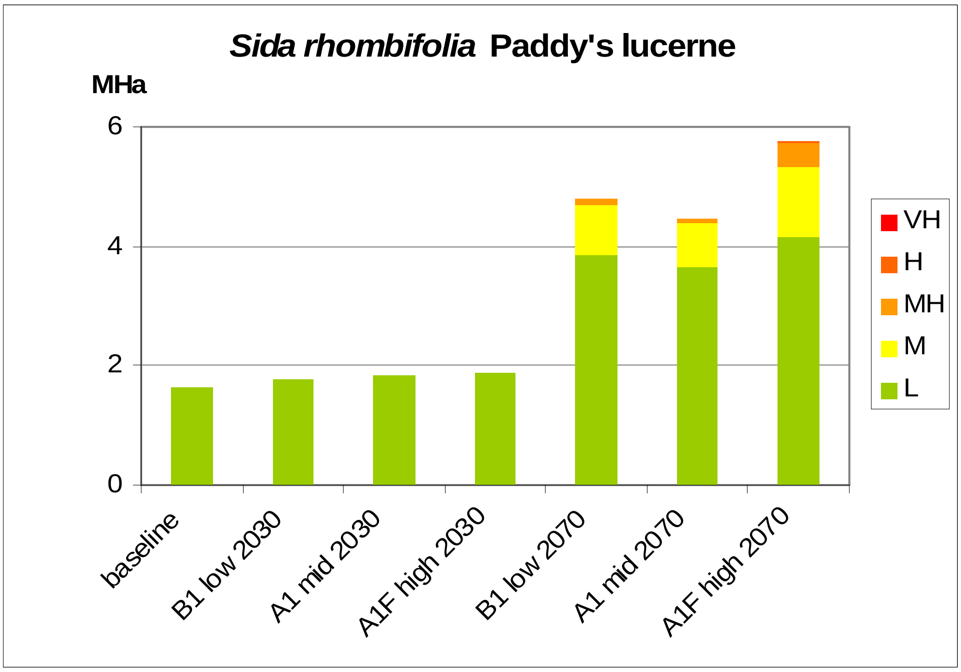


Figure 66. Area occupied by the climate envelope for *Sida rhombifolia* under a range of climate scenarios over time

Results summary for *Sida rhombifolia*

At 2030 there was little change in the area of the climate envelope and the climate match remained as only likely. At 2070, however, the size of the climate envelope more than doubled in area and parts of the state became moderate to highly suitable for the establishment and growth of this species.

B1 (low)

2030

The climate envelope expanded slightly to the south, remaining only a likely climate match.

2070

A large are of north-central Victoria became likely to moderately climatically-suited to this species. The climate envelope in Gippsland expanded north to occupy some higher altitudes. A large area of moderate to moderately high climate match appeared north of Bairnsdale.

A1 (mid)

2030

There was very little difference in the climate envelope under this scenario when compared with B1 low.

2070

The climate envelope under this scenario was similar to that under B1 low at 2070, however there was a slight contraction in area in the north-central region by comparison.

A1F (high)

2030

There was very little difference in the climate envelope under this scenario when compared with B1 low.

2070

Large areas in the north-central and greater Melbourne areas became climatically suitable, expanding the size of the climate envelope, whilst the climatic suitability of large parts of the Gippsland region increased.

Tamarix aphylla (L.) Karst. **Athel pine**

This species is native to northern Africa, the Arabian Peninsula, Iran and India. It has now become a weed in USA (Parsons & Cuthberston 1999) and has naturalised in all mainland states of Australia except Victoria, as well as NT (Gavin *et al.* 2003). Infestations are generally, but not exclusively, restricted to water courses (ARMCANZ, 2000). It outcompetes native vegetation (Parsons & Cuthbertson 2001) and affects the pastoral industry by reducing access to water for stock (Gavin *et al.* 2003).

Tamarix aphylla is drought and heat and frost tolerant. Its biophysical limit occurs at a mean annual temp of 10-50^{o}C (ARMCANZ, 2000). It grows in semi-arid to warm-temperate or subtropical regions (Parson & Cuthbertson 2001).

This species was modelled using parameter 10.

Tamarix aphylla

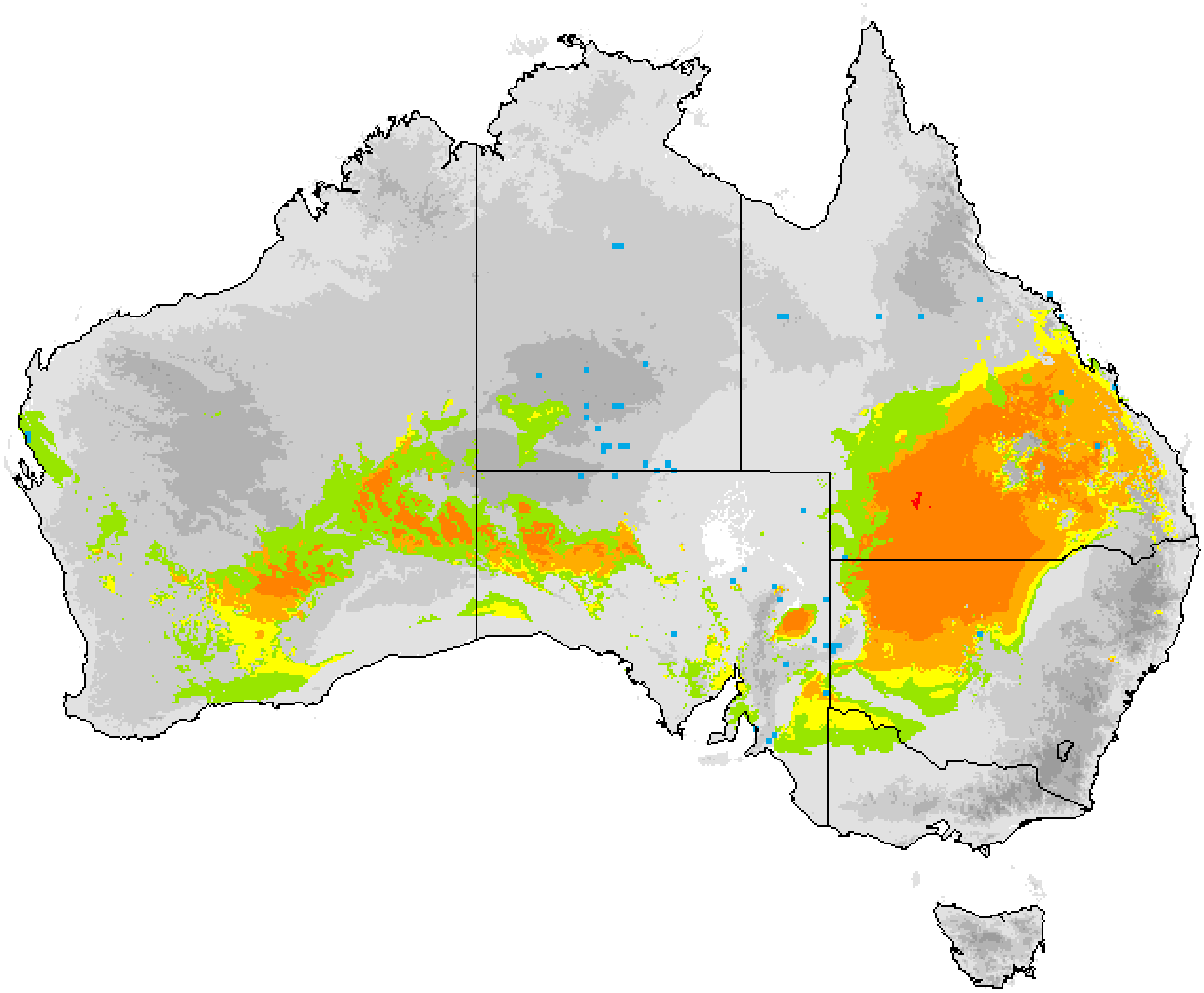
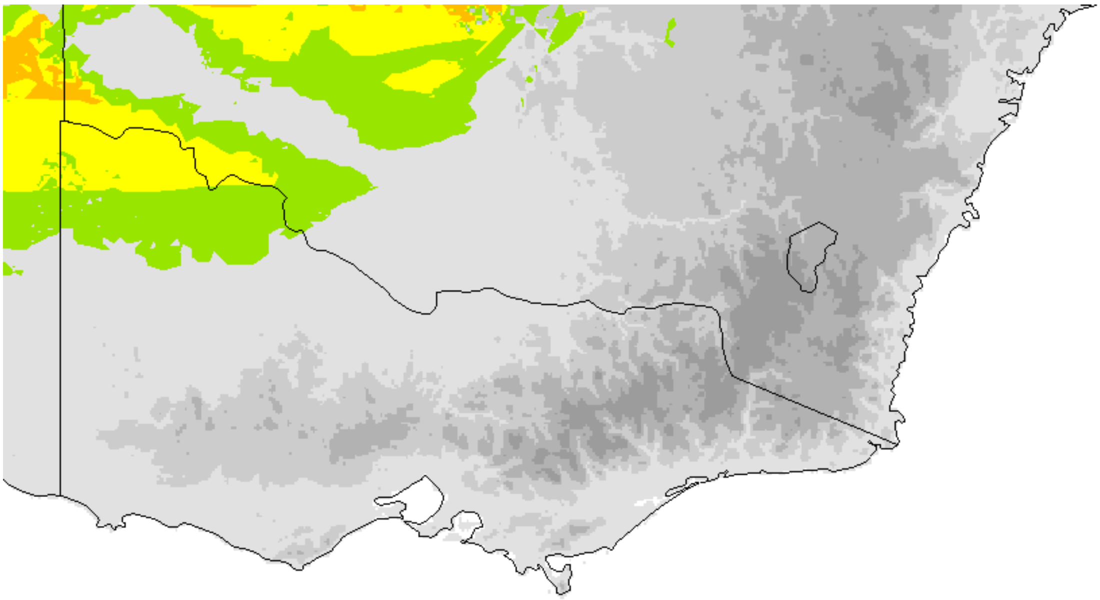
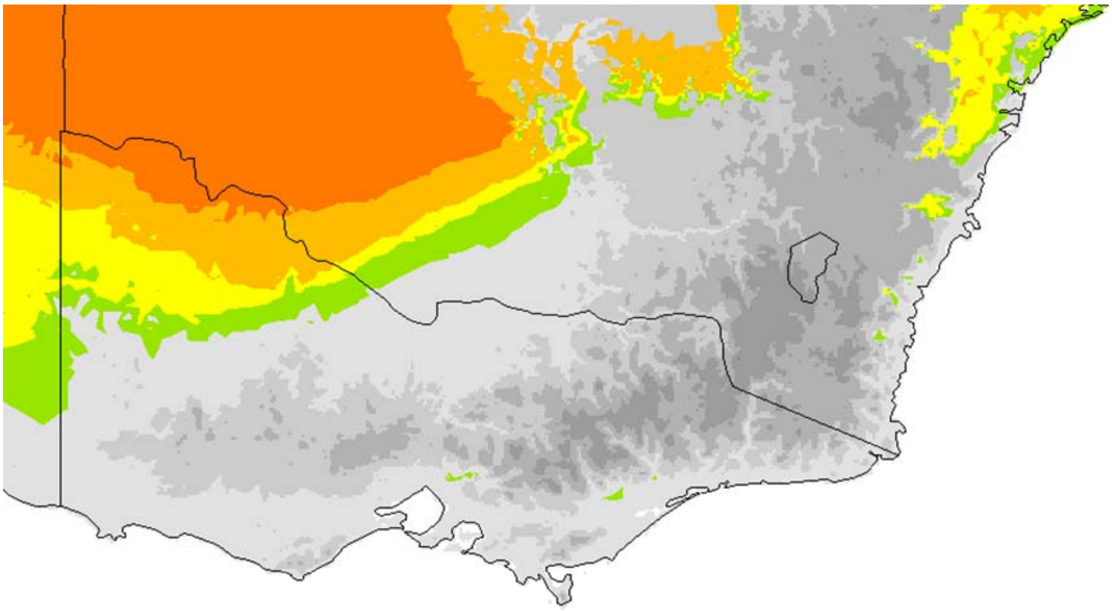


Figure 67. Comparison of current distribution with the baseline climate match
Some of this data was provided by the Western Australian Herbarium on 12 June 2007

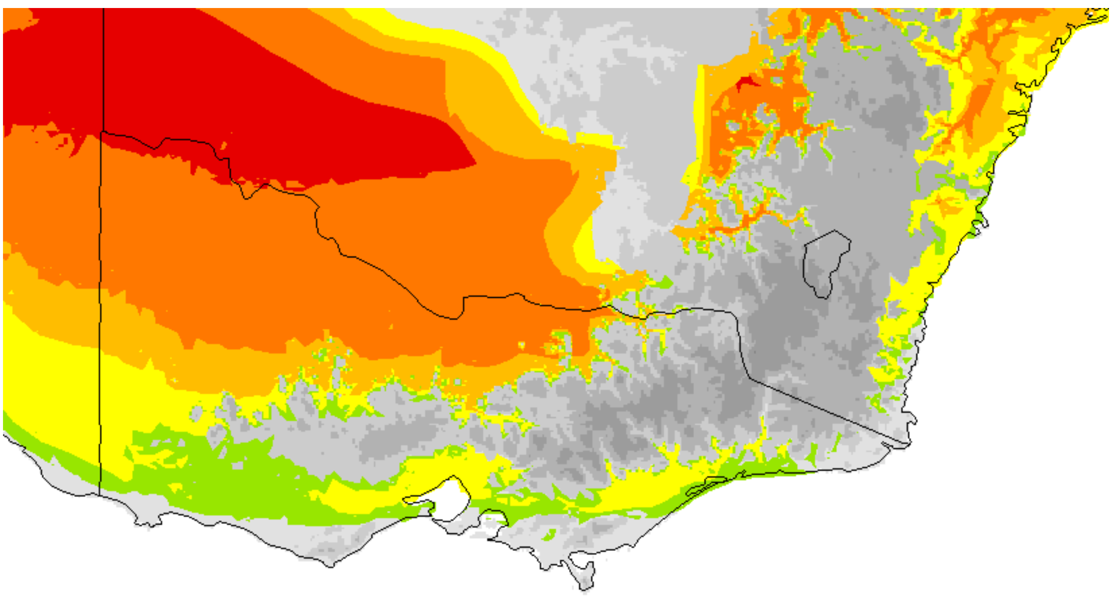
Figure 68a. *Tamarix aphylla* B1 scenario (low)



Baseline climate

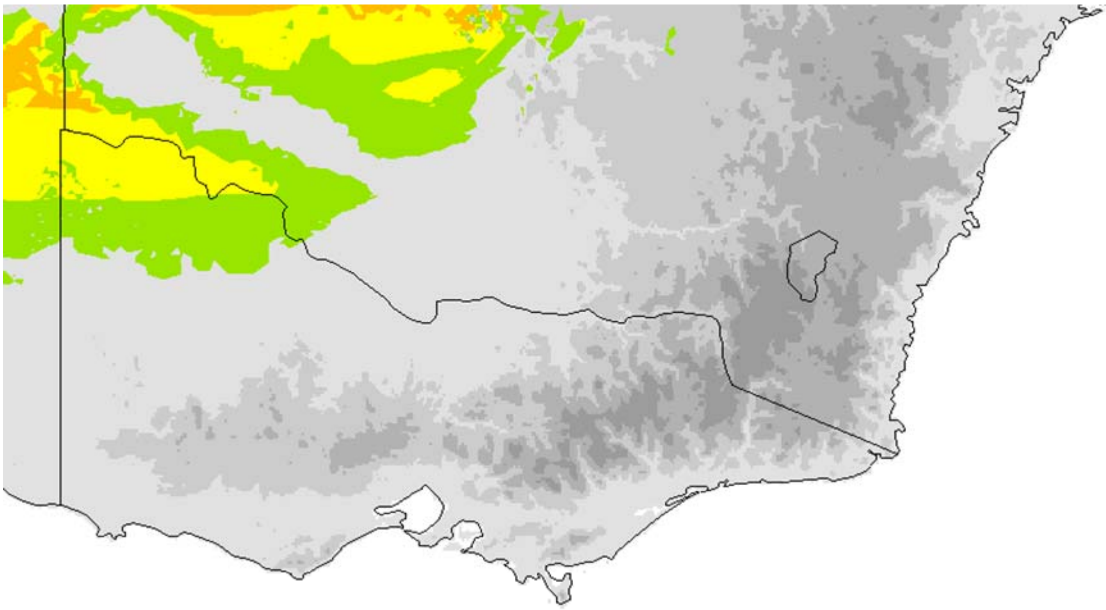


2030

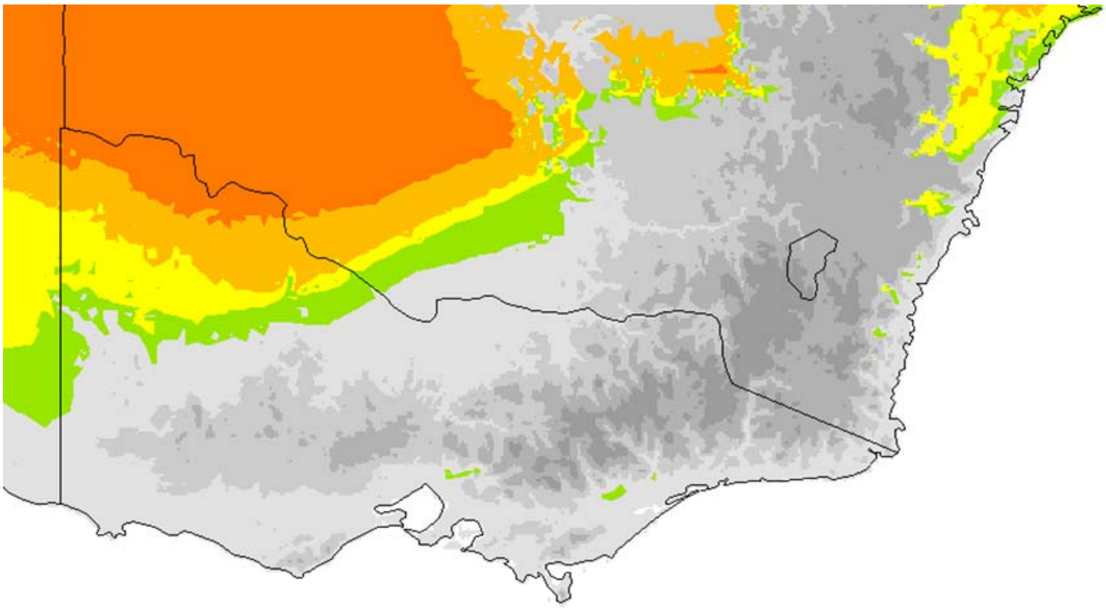


2070

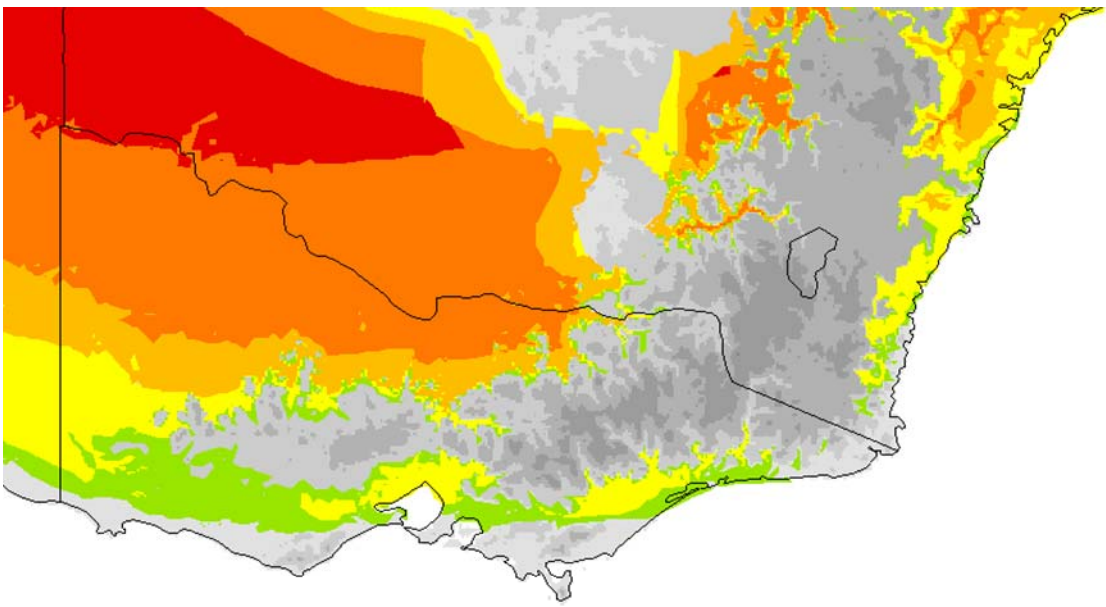
Figure 68b. *Tamarix aphylla* A1 scenario (mid)



Baseline climate

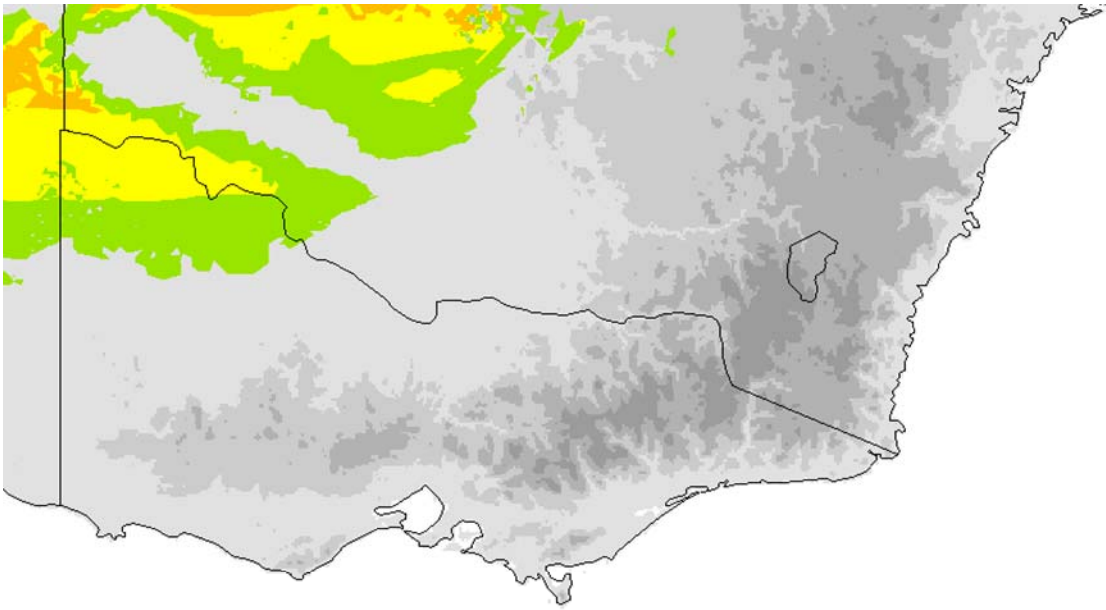


2030

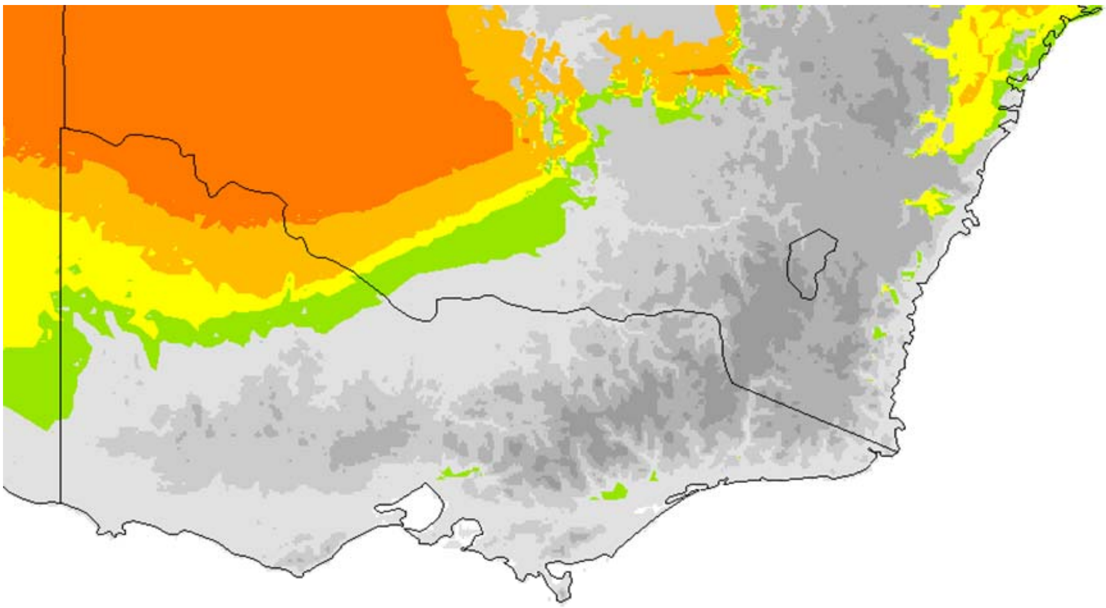


2070

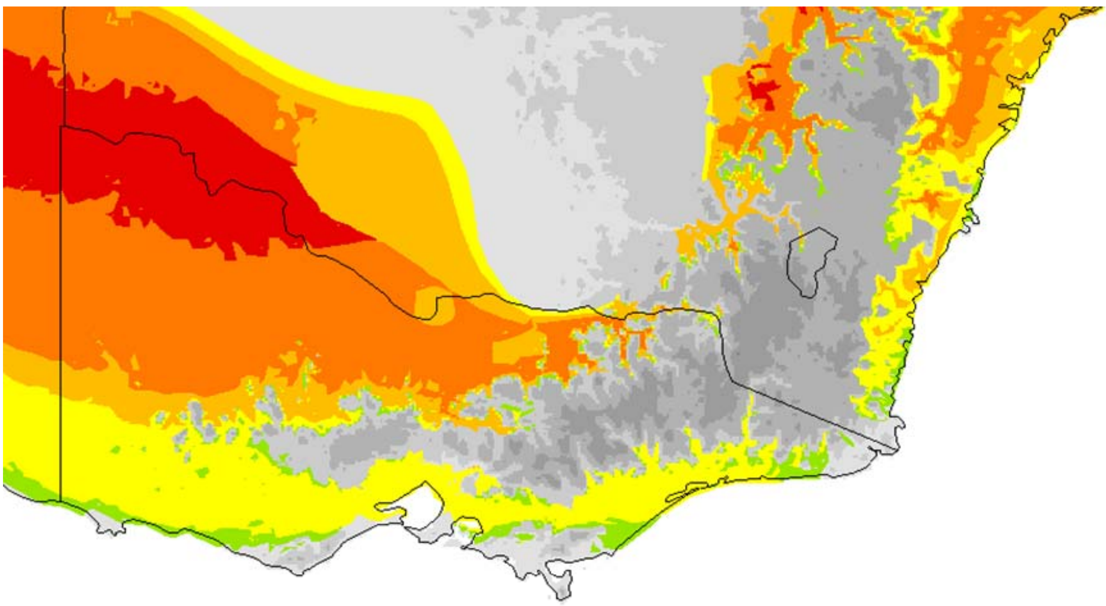
Figure 68c. *Tamarix aphylla* A1F scenario (high)



Baseline climate



2030



2070

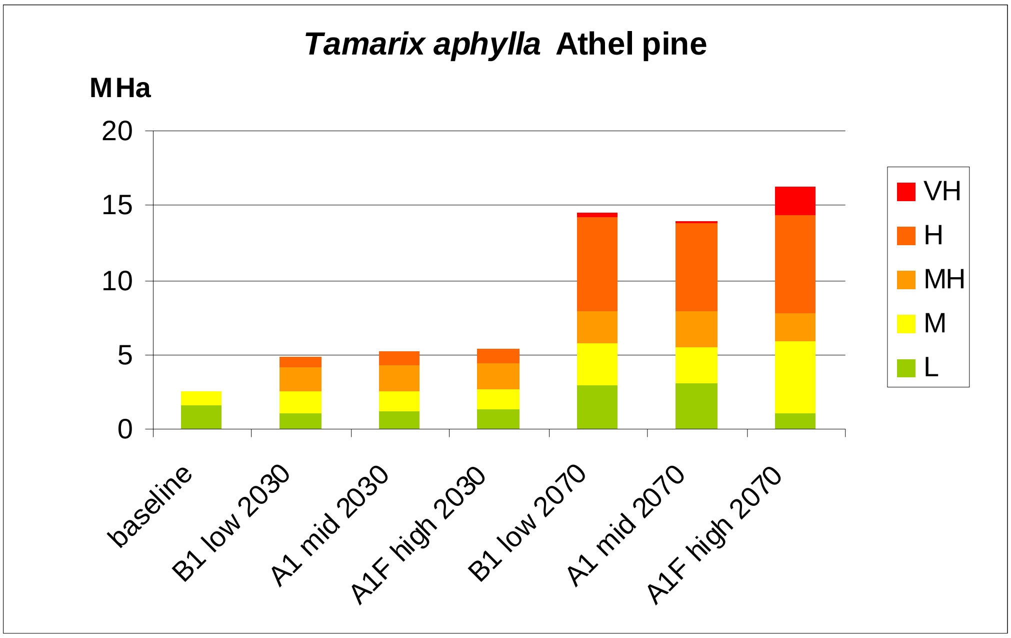


Figure 69. Area occupied by the climate envelope for *Tamarix aphylla* under a range of climate scenarios over time

Results summary for *Tamarix aphylla*

There was a dramatic increase in the size of the area and the quality of the climatic conditions suitable for the establishment and growth of *T. aphylla* in Victoria under all climate change scenarios. Of particular concern is the area of very high climate match that appeared along the Murray River in north-western Victoria under all scenarios, but at its greatest area under A1F high.

B1 (low)

2030

At baseline climate, there was a patch of relatively likely to moderate climate match in the far north-west of the state. At 2030, the southern border of the climate envelope expanded further south, and the climate match became more intense. A large area of moderate to moderately high climate match appeared within this envelope, and a patch of high climate match near the border of Vic and NSW.

2070

The climate envelope expanded dramatically to occupy all of the low-lying areas in the inland of the state. The north-west to north-central part of the state became wholly occupied by high climate match, save for a patch near the border of Vic and NSW that had a very high climate match.

A1 (mid)

2030 & 2070

The A1 mid scenario had very similar results to B1 low, except that in 2070 it appears the climate match was not quite as high, with the very high climate match appearing to be restricted further north than in B1 low at 2070.

A1F (high)

2030

The climate envelope appeared very similar to B1 low, but it extended somewhat further south into Victoria.

2070

The climate envelope was at its most extensive under A1F high at 2070 and it occupied higher altitudes. A much larger patch of very high climate match appeared in the north-west part of the state and the south of the state was mostly occupied by moderate, rather than likely climate match.

Baseline climate match – the iterative process (*Tamarix aphylla* as an example)

Appendix 2 shows the iterative process that was used to determine the potential distribution of *T. aphylla* under baseline climatic conditions.

Using all 35 bioclimatic parameters (a) gave a potential distribution that covered few current distribution points. After examining the histograms/cumulative frequency curves of each parameter in the climatic profile, any that did not appear to influence the climate profile were removed. The resulting potential distribution maps (b-d) show that the climate envelope changed very little, expanding NE further into Qld at iteration c, but then blowing out to cover a vastly larger area (d) when only parameter 1 was used (annual mean temperature). This climate envelope encompassed all the distribution points, but was not considered to be an accurate depiction of the species' potential distribution.

As Athel pine is confined to waterways, rainfall was not considered to be an important determinant of its distribution. When only the rainfall parameters were removed (e), a climate envelope similar to b emerged. The iterative process of removing parameters that did not appear to influence the climate was continued from this point (f-j). A similar pattern emerged, of very little change (f &g), some expansion NE further into Qld (h) and then the hugely expanded area (i & j) that was rejected as d was also rejected.

Only 58 records of this species' potential distribution were originally found. A further 3 records, from WA were sourced and added to the dataset. The same parameters from j were used to create a potential distribution that included these new data points (k). The climate envelope contracted slightly at the northern boundary, but it was still deemed too large. Further iterations showed no change (l & m).

The most accurate potential distribution until this point appeared to be h, so the same parameters were used with these new datapoints. A very similar climate envelope emerged that was considered the best climate match, however there was concern that it had been generated by using 15 climatic parameters. An examination of the two iterations that had produced the best climate matches (c & h) revealed that the only parameter that was used in both was 10 (mean temperature of the warmest quarter). When this parameter alone was used, with the full set of current distribution data points, the same potential distribution was generated. This iteration was chosen as the baseline climate for Athel pine.

The iteration process just described was repeated for each species to generate a baseline climate match for each one.

The baseline climate envelope for Athel pine did not enclose a large number of current distribution points, including the worst infestations in the Northern Territory. This may be due to the association that this species has with waterways. Its distribution is probably confined more by the availability of water than by prevailing climate. A climate analysis, such as this one, assumes that a species is located where it is because of climatic conditions, rather than geographic conditions, such as waterways. This reduces the effectiveness of the statistical analysis of the climate match for aquatic or riparian species. Due to this problem, no further species were assessed that have an association with waterways.

Xanthium spinosum

Bathurst burr

Xanthium spinosum is native to Southern America and has become a serious weed in every state of Australia and in over 30 other countries. It competes with summer crops and the seeds and seedlings are poisonous to stock and poultry (DPIWE 2002).

This species usually grows in temperate regions subject to summer rainfall, flooding or irrigation, but can extend into semi-arid areas by keeping close proximity to water courses. It is a weed of cultivation, grazing land and undeveloped areas (Parsons and Cuthbertson 2001).

The parameters chosen to model this species were 1, 3, 5, 6, 10, 11, 12, 20, 22 & 26.

The baseline climate match for this species (Fig. 70) was good for south and south-eastern Australia, but the climate envelope did not encompass the current distribution points in central and northern Qld and NT.

Xanthium spinosum

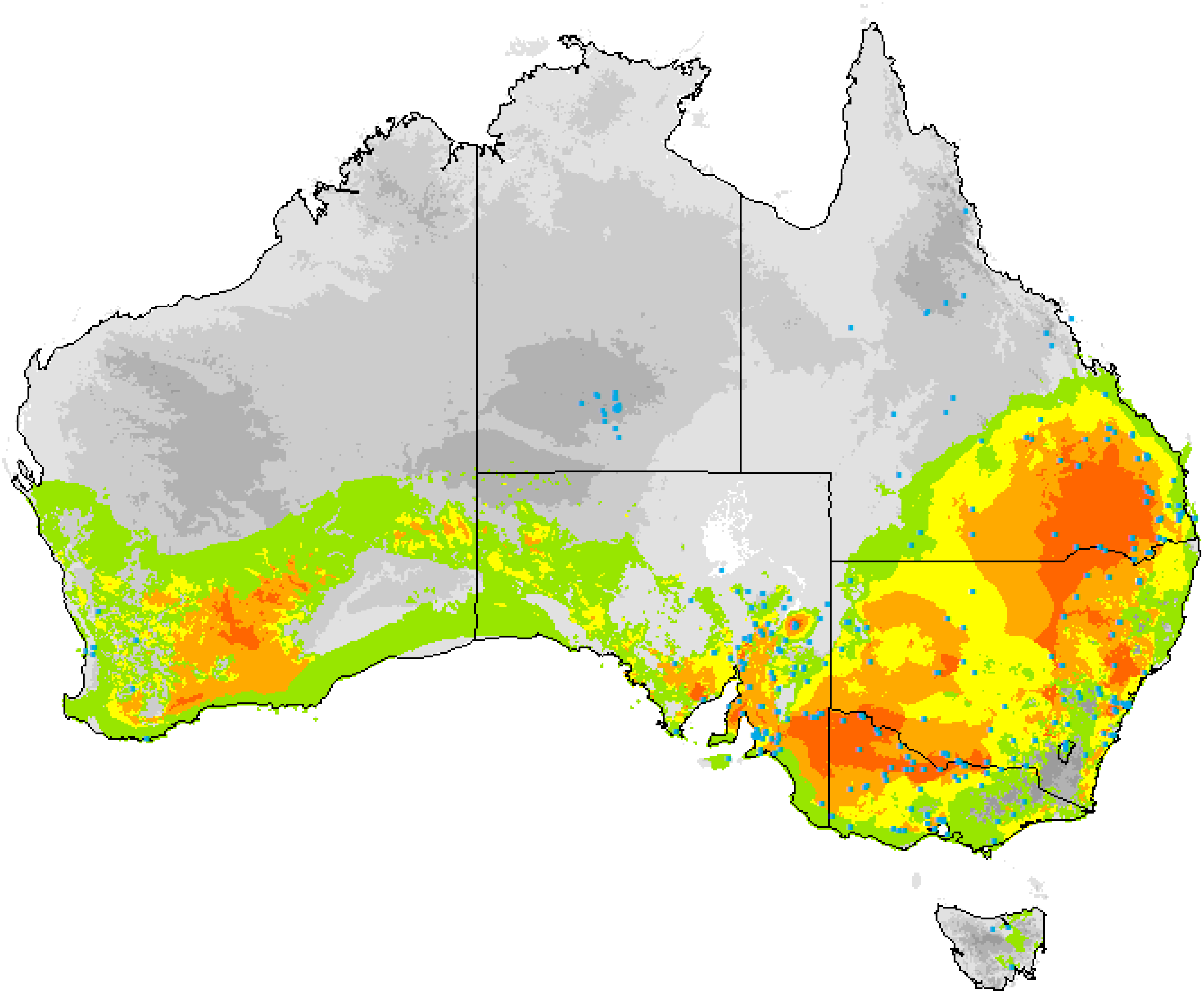
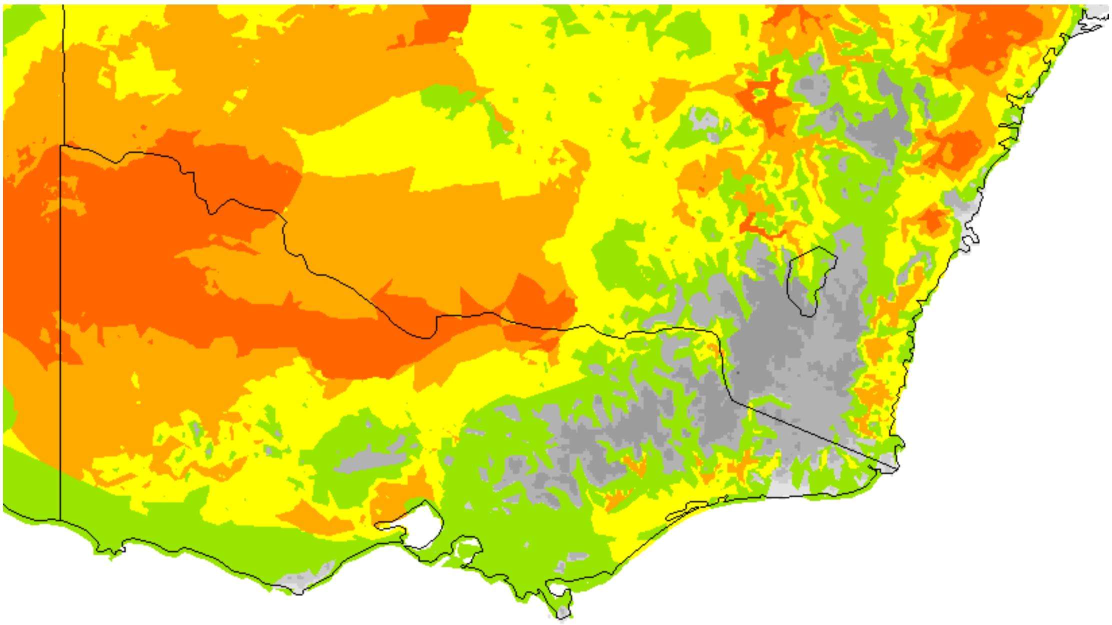
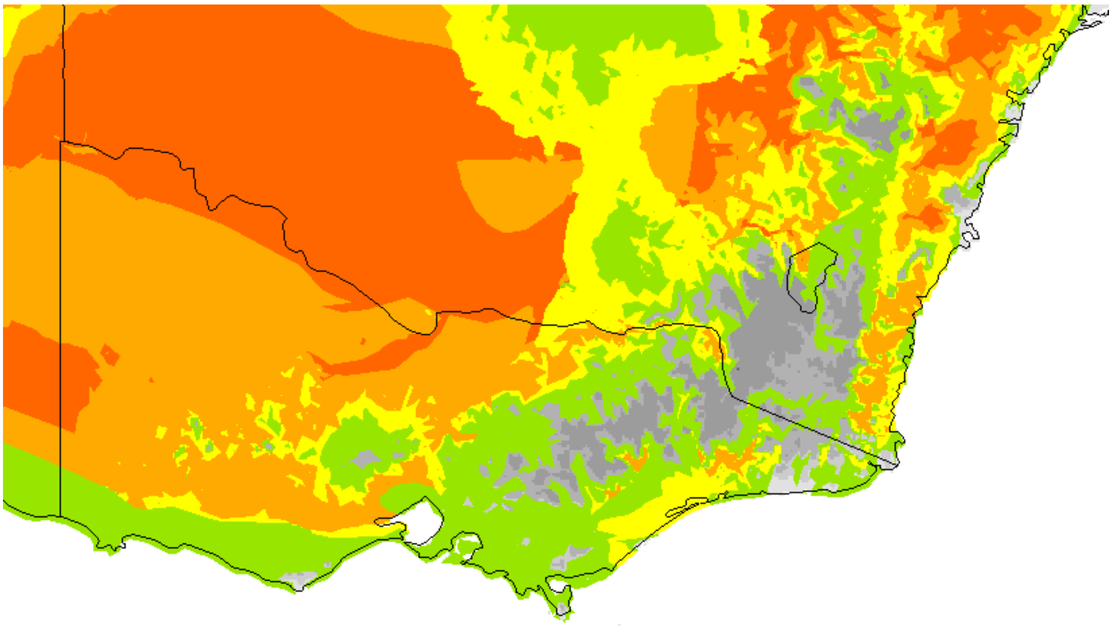


Figure 70. Comparison of current distribution with the baseline climate match

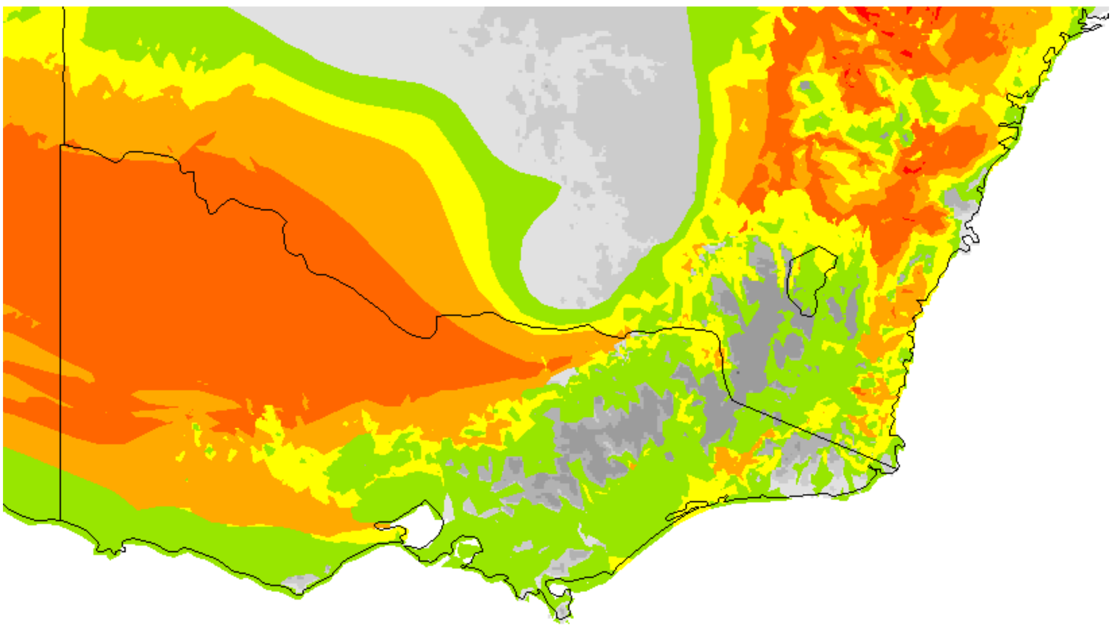
Figure 71a. *Xanthium spinosum* B1 scenario (low)



Baseline climate

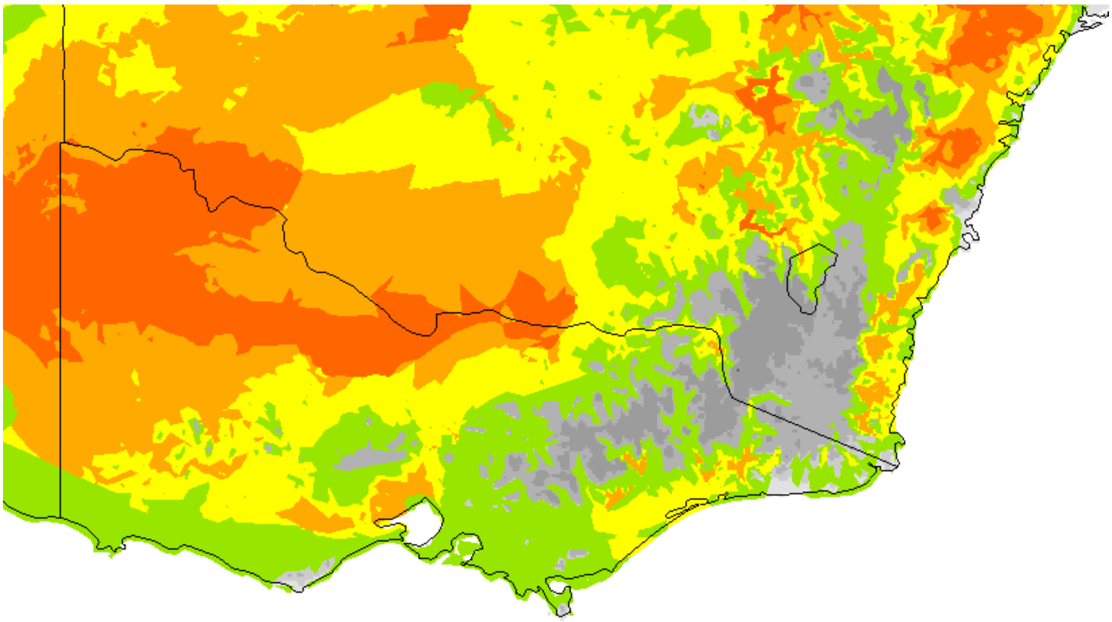


2030

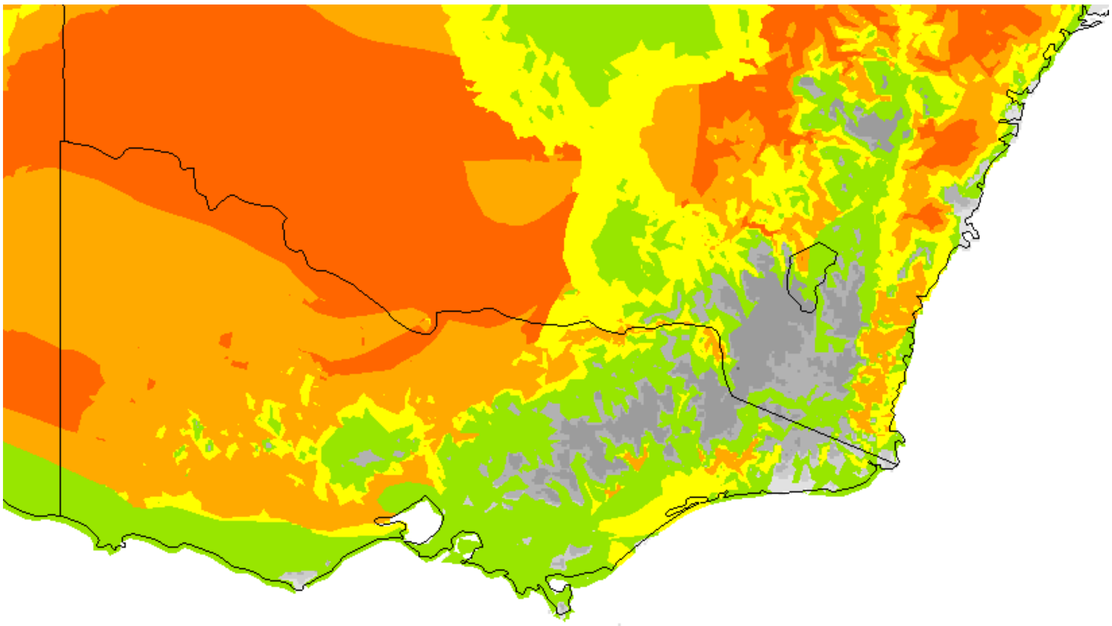


2070

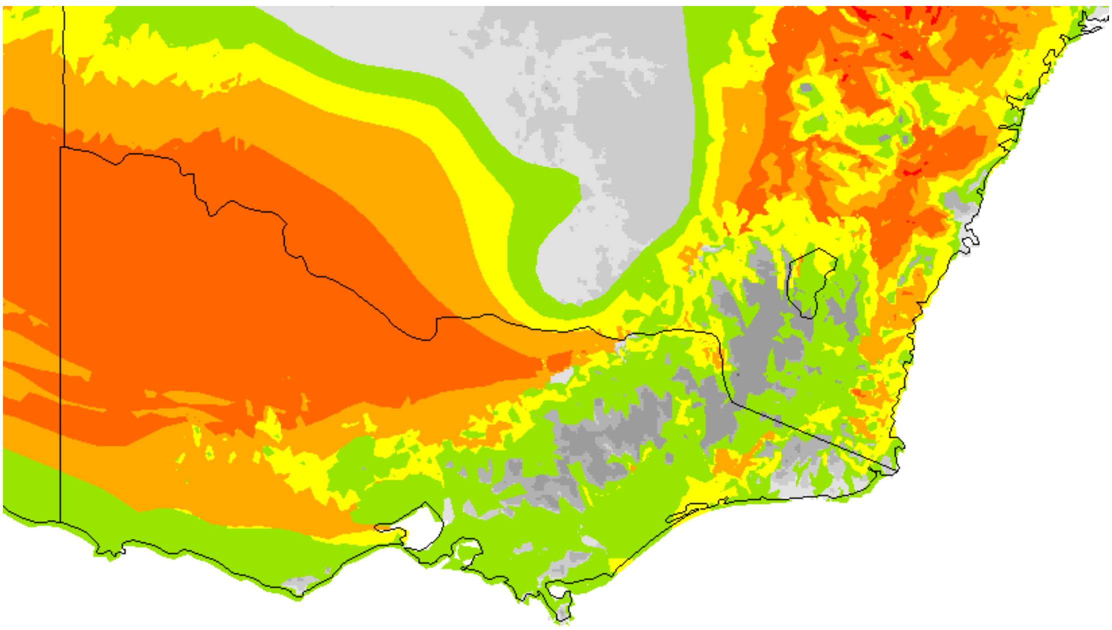
Figure 71b. *Xanthium spinosum* A1 scenario (mid)



Baseline climate

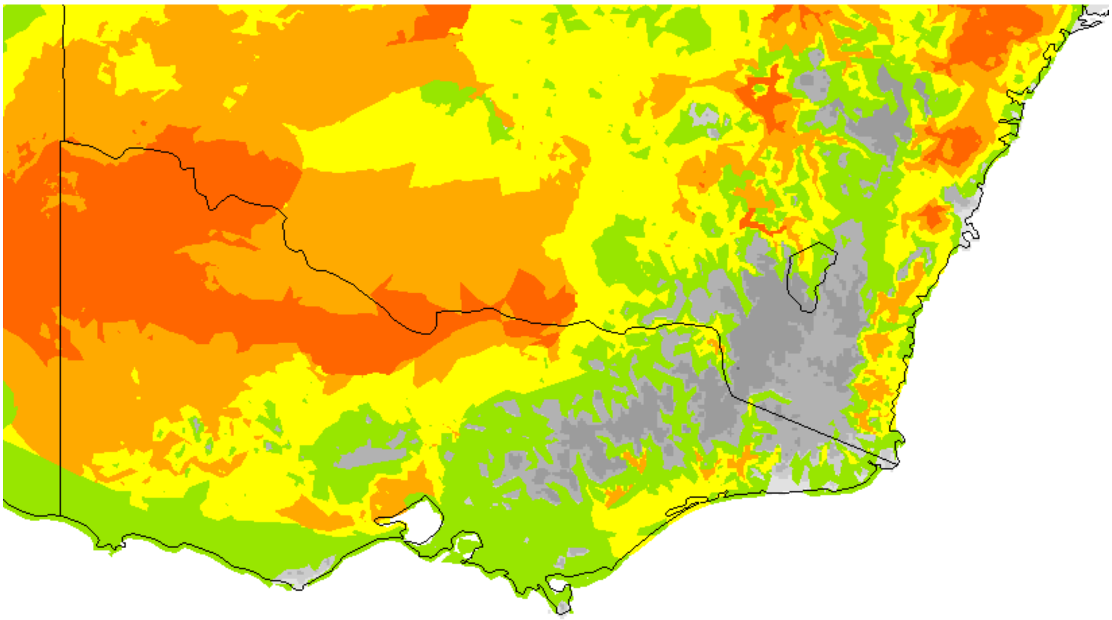


2030

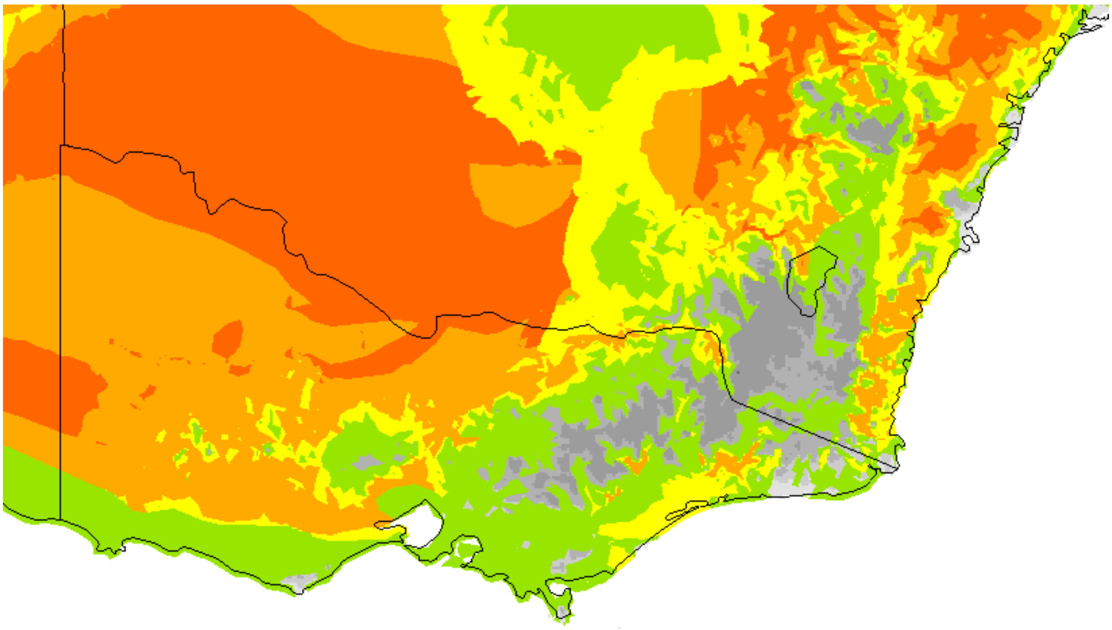


2070

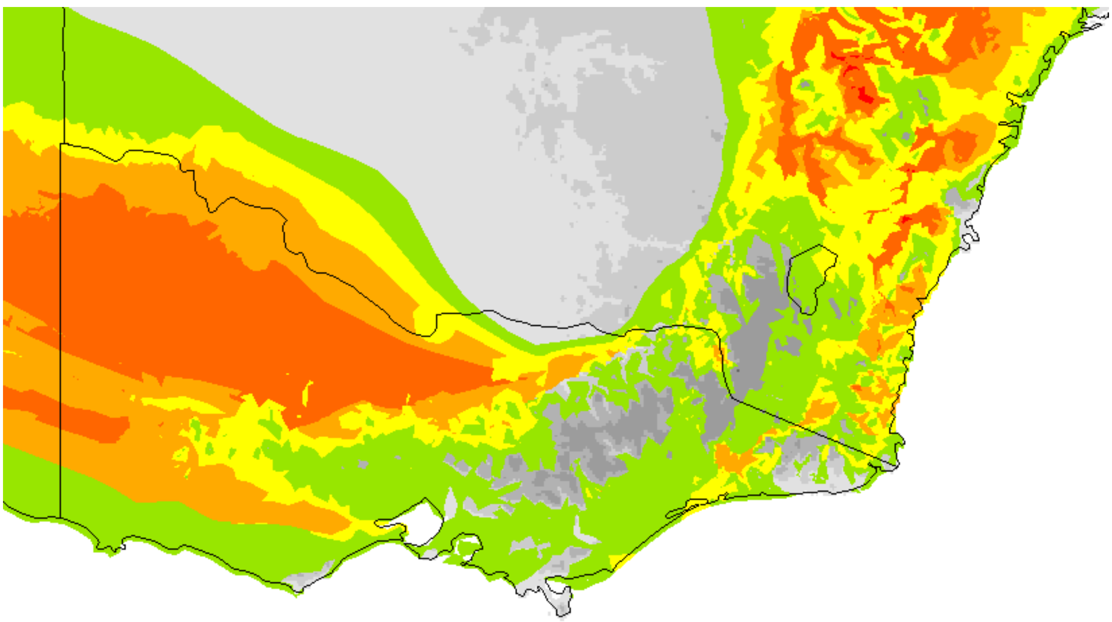
Figure 71c. *Xanthium spinosum* A1F scenario (high)



Baseline climate



2030



2070

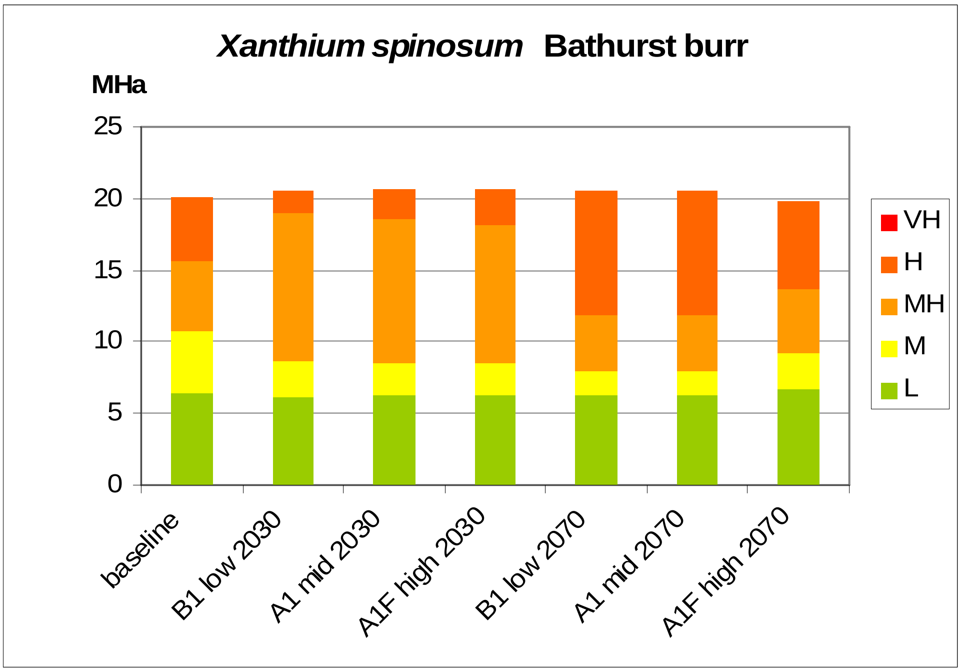


Figure 72. Area occupied by the climate envelope for *Xanthium spinosum* under a range of climate scenarios over time

Results summary for *Xanthium spinosum*

2030 for B1 low, A1 mid and A1F high

There was little change in the size of the climate envelope for this species; however the pattern of suitability changed at 2030 when large parts of the Mallee dropped from high to moderately high suitability.

2070 for B1 low, A1 mid and A1F high

At 2070 the north-west corner of the state became highly climatically suitable, although under A1F high this area of high climate suitability had contracted to the north somewhat.

Species	Current distri-bution	Baseline potential distri-bution	Potential distribution at 2030		Potential distribution at 2070	
	Number of locations in Victoria	Area of Victoria	Ratio of area baseline: climate change	Area of Victoria	Ratio of area baseline: climate change	Area of Victoria
Asparagus aethiopicus #	<10*	6 %	**2.11**	13 %	2.23	14 %
Heliotropium amplexicaule	1	49 %	**1.46**	72 %	1.44	71 %
Bidens pilosa #	≈10	39 %	**1.41**	55 %	1.76	69 %
Acetosa vesicaria	0	35 %	**1.34**	47 %	2.32	81 %
Euphorbia terracina #	<10	46 %	**1.23**	56 %	0.88	41 %
Ligustrum sinense #	0*	39 %	**1.21**	47 %	0.95	37 %
Medicago laciniata	≈2	18 %	**1.20**	21 %	1.55	27 %
Sida rhombifolia	0	7 %	**1.15**	8 %	3.53	25 %
Echium plantagineum (Nox)	100s	93 %	**1.00**	93 %	0.96	89 %
Hordeum glaucum	≈10	82 %	**0.99**	80 %	1.03	84 %
Nasella neesiana (Nox WoNS)	50-100	58 %	**0.99**	58 %	0.65	38 %
Rubus fruticosus agg (NOX-WoNS)	100s	82 %	**0.97**	80 %	0.61	51 %
Nasella trichotoma (Nox WoNS)	50-100	44 %	**0.97**	43 %	0.48	21 %
Billardiera heterophylla #	≈30*	53 %	**0.93**	49 %	0.46	24 %
Senecio jacobaea (Nox)	100s	44 %	**0.90**	40 %	0.17	7 %
Cotoneaster glaucophyllus	100s*	53 %	**0.89**	47 %	0.39	20 %
Leycesteria formosa	≈20	39 %	**0.84**	33 %	0.29	11 %
Lantana camara (Nox WoNS)	0*	0.01 %	**0.23**	0.00 %	49.42	0.41 %
Passiflora suberosa	0*	0 %	**0.00**	0 %	0.00	0
Prosopis pallida (Nox WoNS)	0	0 %	**0.00**	0 %	0.00	0

Figure 73. Difference in potential distribution under A1F scenario climate change, in order from largest increase through to largest decrease at 2030.
Final two results show no change. Species that did not respond well to modelling are not presented in this table as their results were not reliable.

# Under consideration for declaration under the CaLP Act in Victoria.
NOX = Declared Noxious under the CaLP Act in Victoria.
WoNS = Weed of National Significance.
* Is or has been in horticultural trade. Likely to be widespread in the state in large numbers of gardens.

Discussion

Increased climate envelopes at 2030

All of the species that showed an increase in the size of the climate envelope had potential distributions under baseline conditions of less than 12 MHa. These are species that tend to be better suited to climatic conditions further north in Australia and many have not naturalised in Victoria, or are present in low numbers. Climate modelling shows that conditions are likely to favour their establishment and if they can be eradicated from the state (based on the principles outlined by Groves and Panetta, 2002, vis: 3 or fewer locations, less than 100 Ha, ease of accessibility and detection, short soil seed longevity, not in trade), or prevented entry, their increased potential distribution may never eventuate.

Some had very small potential distributions of less than 2 MHa to start with: *Asparagus aethiopicus* and *Sida rhombifolia*. Clearly, the baseline climate match did not reflect the risk that these species pose in the future, with suitable climate for *A. aethiopicus* likely to more than double by 2030; and by 2070, *S. rhombifolia* could have the potential to occupy almost 6 MHa. Both species have naturalised in Victoria (Walsh and Stasjik 2007) (although no herbarium records were found for *S. rhombifolia*). A greater emphasis on their management is warranted by this research. *Sida rhombifolia* might be considered a candidate for eradication, and successful campaign to remove *A. aethiopicus* from gardens would support attempts to control this species.

Several other species in this group had no recorded naturalised presence in Victoria, including *Acetosa vesicaria* and *Ligustrum sinense* (Walsh and Stasjik 2007). Whilst both had relatively large potential distributions under baseline conditions, climate change expanded this risk even further. Efforts should be made to prevent the increasing likelihood of the naturalisation of these species in Victoria, including a campaign to remove *L. sinense* from gardens. *A. vesicaria* is not easily distinguished from native vegetation which will make its detection difficult should it establish here.

Heliotropium amplexicaule had a relatively large potential distribution under baseline conditions, whilst *Medicago laciniata* had a relatively small potential distribution under baseline conditions. Both are likely to become an increased risk under climate change. The small number of infestations of these two species recorded by the herbarium could probably be eradicated, but without a legislative imperative this may not be seen as a priority. These species should be assessed for possible declaration as a noxious weed.

Interestingly, none of the species in this study that are predicted to pose a larger threat under climate change are currently declared noxious weeds, although several have been nominated for inclusion. An assessment process that considered the increased risk posed by these species under climate change would be more robust and risk-averse than the current method (Weiss 2004) that does not consider climate change factors.

The two remaining species in this group, *Euphorbia terracina* and *Bidens pilosa* have probably established beyond the point of successful eradication, but also had relatively large baseline potential distributions that are likely to increase under climate change. Interestingly, after an initial increase, the potential distribution for *E. terracina* is predicted to contract by 2070 to an area smaller than baseline conditions. This is also the case for *L. sinense*, although climatic suitability within this reduced area was predicted to increase. Whilst the projected increase in climate suitability to 2030 raised the risk of these species, the decrease by 2070 shows that plant responses to climate change are by no means clear cut.

The opposite was the case for *Lantana camara*, with a very small area climate match in Victoria under baseline conditions that disappeared at 2030. A longer period of time, to 2070, saw the reappearance of climatic conditions likely to allow this species to naturalise over a larger area of the state than under baseline conditions. There are no naturalised records for this species in Victoria. Walsh & Stasjik (2007) consider it incipiently naturalised and it is declared a weed of national significance (WoNS), however it has been in horticultural trade for decades and is widespread in gardens. It may be worthwhile to prevent the establishment of this species via a campaign to remove this species from public and private gardens in the areas of likely climate match.

The rate of expansion of these species may lag behind the emergence of suitable climatic conditions. The extent of this lag phase will be determined by biological and ecological factors that have not been modelled here: propagule pressure, dispersal ability and suitable habitats, including climate-induced changes to these factors, and others such as fire frequency and other climate-related disturbances.

Decreased climate envelopes

All of the species that showed a consistent decline in the area of climatic envelope are currently widespread and beyond eradication in Victoria. They all had potential distributions under baseline conditions of more than 8 MHa, up to 19MHa for *Rubus fruticosus* agg. Generally, decreases were not large at 2030, but by 2070, the climate envelopes for *Cotoneaster glaucophyllus*, *Billardiera heterophylla* and *Nassella trichotoma* declined to about half the size of the potential distribution under baseline conditions. Sometimes the decline was more dramatic, as with *Senecio jacobaea*, which declined from 10 MHa to 2 MHa, and *Leycesteria formosa*, from 9 MHa to 3 MHa. All of the remaining decreasing species maintained a relatively large potential distribution, from around five to 12 MHa.

Most of the species with declining climate envelopes are either declared noxious, or have been nominated for assessment for declaration. Despite the indication that their potential distributions will be smaller under climate change, they still pose an invasion risk to large parts of the state. As climatic conditions become less suitable for these species, leading to a decline in vigour, management techniques may become more successful. This success may be undermined, however by climate change impacts on the feasibility of management, such as predicted reduction in the number of days that will be suitable for spraying (in Kriticos 2007).

Despite a decline in climate suitability, these weeds may remain a problem for an extended period even after the climate has become much less suitable. Long-lived perennials may persist for decades after the climate has become unsuitable for further recruitment. Climatic variability across the years may allow further establishment from long-lived seed banks in climatically suitable years. Species that have been competing with the weed may be eliminated by climate change, releasing the weed from competition and allowing it to continue to have a significant impact. These lag phase factors have not been modelled in this study.

Little change in the size of the climate envelope

The species that showed little change in potential distribution were less homogenous than the increasing or decreasing groups. *Passiflora suberosa* and *Prosopis pallida* both lacked climatically suitable areas in Victoria under baseline conditions and under climate change their climate envelopes did not extend into Victoria either. *P. pallida* is declared noxious in Victoria and despite not appearing to be naturalised or present in the state, it is a WoNS, so its declaration in Victoria might be considered in the national interest. *P. suberosa* is not recorded as naturalised in Victoria, but it is likely to be present in gardens and unlikely to become weedy in Victoria under the climate change scenarios considered in this report.

A further three species showed little change in the size of their climate envelopes at 2030. *Echium plantagineum* is a widespread weed that has probably reached its climatic limits in Victoria, and climate change is unlikely to alter its distribution. At 2070 the climate envelope did not decrease by much and whilst the degree of climatic suitability declined, the climate match still ranged from likely to highly suitable.

Hordeum glaucum also had a large baseline potential distribution that remained large under climate change, increasing a little at 2070. This species is only present at around ten locations around the state and has not yet been considered for noxious weed declaration. This may be an oversight regardless of climate change impacts.

By comparison, *Nassella neesiana* did not appear to respond to climate change at 2030, but by 2070 the climate envelope had decreased to two thirds of that under baseline conditions. Management of this species could be focussed on areas where climate is likely to remain suitable by eradicating these populations and preventing new introductions to these long-term high risk areas.

Poor climate matches

For five species, the baseline climate match did not fit well with the current distribution of the species, where a large number of the current distribution points lay outside the climate envelope, and/or where the largest numbers of infestations were not concurrent with a high degree of climate match. There was consequently little confidence in the ability of the model to predict the potential distribution of these species under climate change. They were not considered in the discussion of the results for this reason.

These species require further work to improve the performance of the model. The following hypotheses for the poor climate matches achieved with these species may suggest ways that the modelling could be improved.

As a species that is strongly associated with waterways, *Tamarix aphylla* may be constrained less by climatic conditions and more by availability of a reliable water supply than other species. Other climate modelling techniques (Weiss *et al*. 2004) for aquatic species have eliminated rainfall parameters from the analysis and, as described in the methodology, this species was modelled using only mean temperature of the warmest quarter. This suggests that a new modelling technique for aquatic and riparian species would be useful, making consideration of the differences between air and water in thermal conductivity.

Eremophila sturtii, had a disjunct distribution, however there was no obvious climatic or historic reason for the obvious gap between the two parts of the distribution. The climate match for *E. sturtii* was very good in the east of the country but was very poor for the western population that ranged from the Northern Territory through to South Australia. This suggests that the current distribution for this species is not an accurate reflection of climatic constraints, but may indicate that either the species is yet to reach its potential distribution, or that what is recognised as *E. sturtii* may be two or more species, occupying distinct ecological zones.

The remaining species *Cenchrus ciliaris*, *Xanthium spinosum* and *Acacia farnesiana*, all had very widespread distributions that spanned very disparate climatic zones from the tropics to the arid interior. *A. farnesiana* may still be spreading in Australia. Indeed, the climate match for this species was created using herbarium records from prior to 1970 as there appears to have been a southward shift in this species distribution over time.

Xanthium spinosum in particular had a distribution that ranged from Tasmania to northern Queensland. Taxonomic confusion about this species may explain its oddly disparate distribution. This species is sometimes referred to in the literature as a "complex" of species. *C. ciliaris*, too is not taxonomically stable. It is possible that this taxon is two species (Hussey *et al*. 1997).

Improvements to the modelling technique may reduce the incidence of these poor climate matches in the following ways:

1. The ability to use distribution data from locations outside Australia, especially from a species' native range, may better inform the models for species that have yet to reach their climatic limits in Australia. This will be particularly useful for new and emerging species that have become the recent focus for weed management.
2. Species that are under taxonomic confusion should not be chosen for modelling. Species complexes may respond better to modelling if datasets for subspecific taxa are used independently to build up a composite picture of the complex from several models.
3. A technique for modelling aquatic and riparian species needs to be developed.

Further research

Recent modelling of climate change impacts on land use (Hood *et al.* 2006) suggests that, over time, agricultural areas that traditionally supported a particular land use may convert to a crop or farming system better suited to changed temperatures and water availability. Socio-economic factors have also been modelled to assess regional capacity for change (Sposito *et al.* 2005), and economic factors such as changes in commodity prices for biofuel-suitable crops may also influence land use changes. Similarly, native vegetation is likely to change, and indeed observed range changes have already been linked to climate change (Parmeson 2006). Predicted changes in weed distributions should be assessed in light of predicted land use and vegetation changes.

Land use and vegetation were not considered in this simple climate model, nor were important factors that constrain weed invasion such as soil type, frequency of disturbances such as fires and climate change response of major competing native species and biocontrols. All of these factors could be incorporated into a more sophisticated model of weed distribution.

In order to apply this model to decisions about weed management, the modelled climate suitability needs to be linked to likely ecological outcomes. It is assumed that, where climatic conditions most suit a weed's invasion, that the plant has the potential to achieve maximum vigour (invasiveness) and density (impact) and that a decline in climate match will be associated with a relative decline in these factors. In order to interpret the degree of modelled climatic suitability, we need a quantitative analysis of differences in the biology and ecology of species that are present in climatic zones of varying suitability.

This analysis could be approached from two perspectives:

- a desktop analysis of the climatic data that lies behind the model, comparing the values of the climatic parameters within each class of suitability with data relating to optimal temperatures for germination, growth, flowering and seed set.
- The establishment of long-term monitoring sites to detect any early signs of predicted changes to weed distributions. This would be most successful for widespread weeds that are predicted to experience a dramatic range contraction, such as *Leycesteria formosa* or *Senecio jacobaea*. These trials would be best located where a weed infestation occurs in a locale that is predicted to decline in suitability from highly to very highly suitable, down to not suitable (where there is no climate match indicated).

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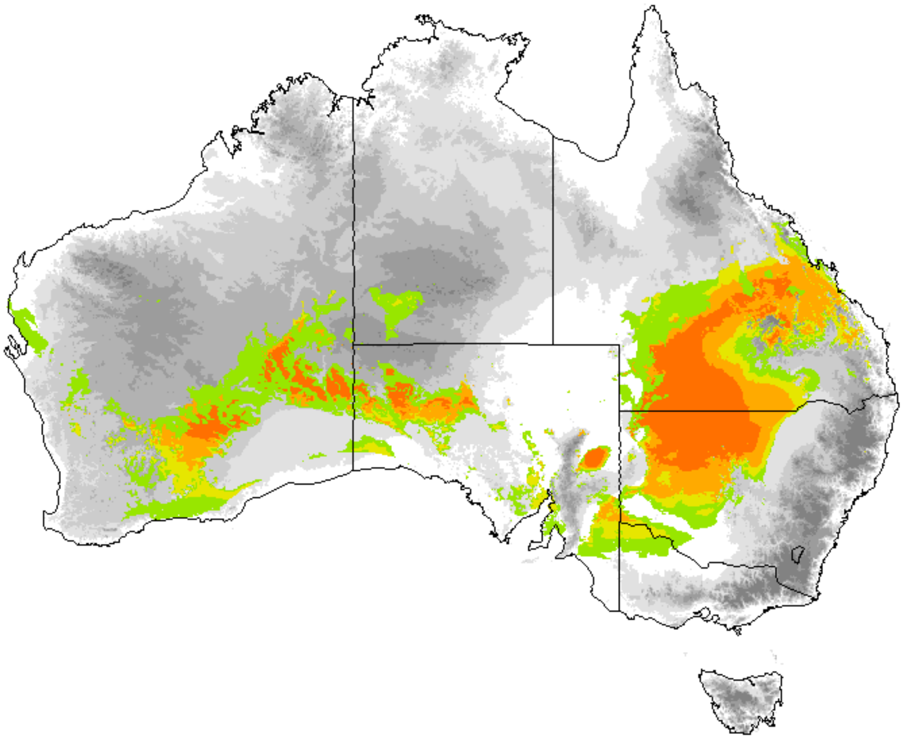
Appendix 1 Climate Parameters available in Anuclim

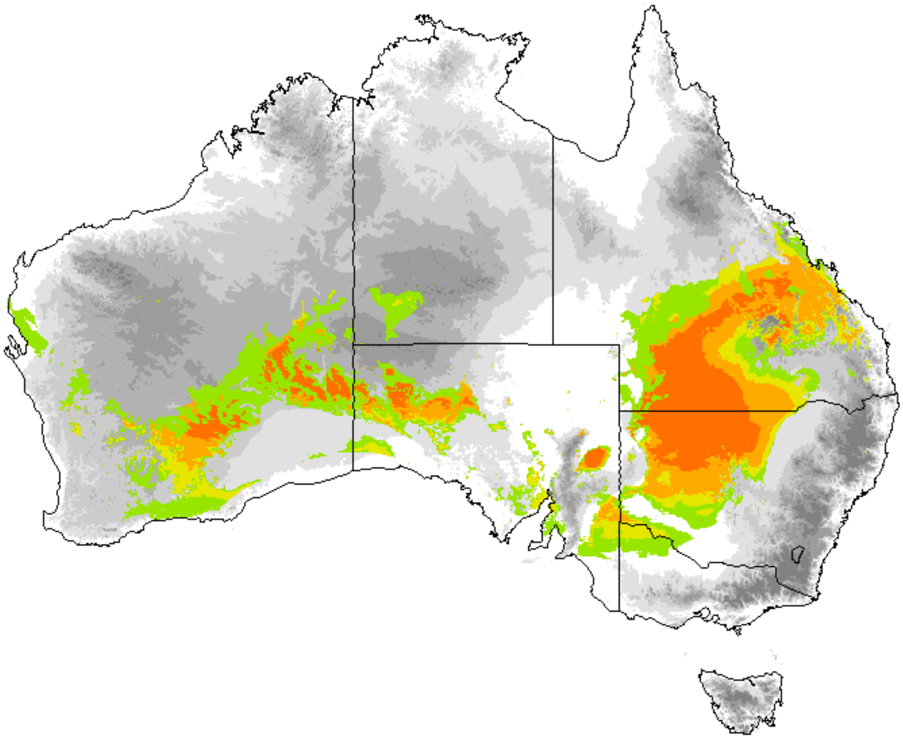
#	Climate Variable
1	Annual Mean Temperature
2	Mean Diurnal Range (Mean(period max - min))
3	Isothermality
4	Temperature Seasonality (Coefficient of Variation)
5	Max. Temperature of Warmest Period
6	Min. Temperature of Coldest Period
7	Temperature Annual Range
8	Mean Temperature of Wettest Quarter
9	Mean Temperature of Driest Quarter
10	Mean Temperature of Warmest Quarter
11	Mean Temperature of Coldest Quarter
12	Annual Precipitation
13	Precipitation of Wettest Period
14	Precipitation of Driest Period
15	Precipitation Seasonality(Coefficient of Variation)
16	Precipitation of Wettest Quarter
17	Precipitation of Driest Quarter
18	Precipitation of Warmest Quarter
19	Precipitation of Coldest Quarter
20	Annual Mean Radiation
21	Highest Period Radiation
22	Lowest Period Radiation
23	Radiation Seasonality (Coefficient of Variation)
24	Radiation of Wettest Quarter
25	Radiation of Driest Quarter
26	Radiation of Warmest Quarter
27	Radiation of Coldest Quarter
28	Annual Mean Moisture Index
29	Highest Period Moisture Index
30	Lowest Period Moisture Index
31	Moisture Index Seasonality (Coefficient of Variation)
32	Mean Moisture Index of High Quarter
33	Mean Moisture Index of Low Quarter
34	Mean Moisture Index of Warm Quarter
35	Mean Moisture Index of Cold Quarter

Appendix 2 Baseline climate match- the iterative process

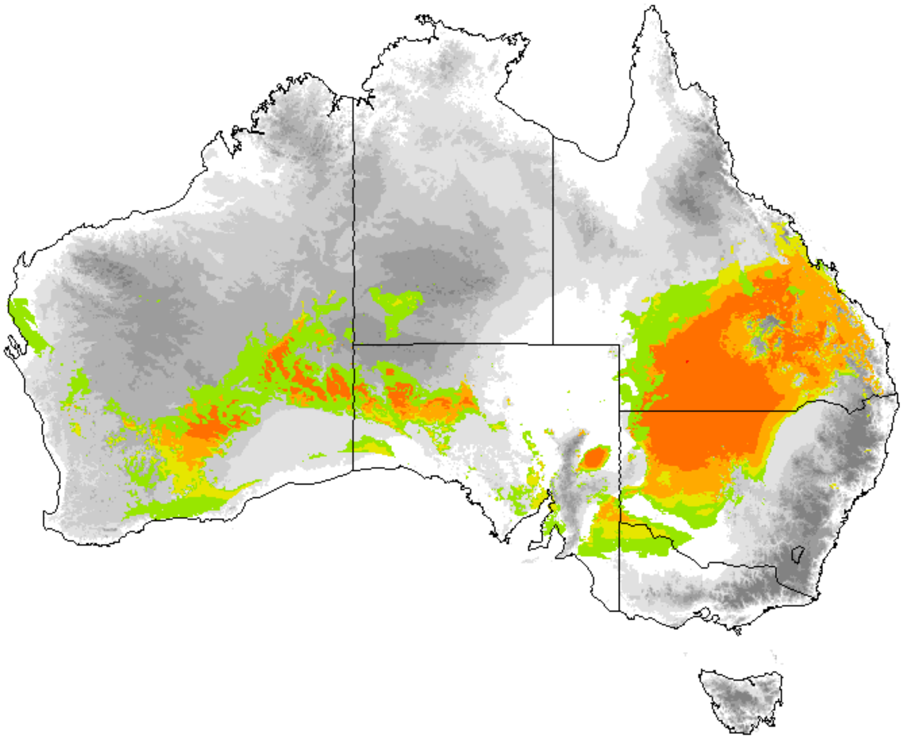
Some of [the current distribution] data has been provided by the Western Australian Herbarium on 12 June 2007



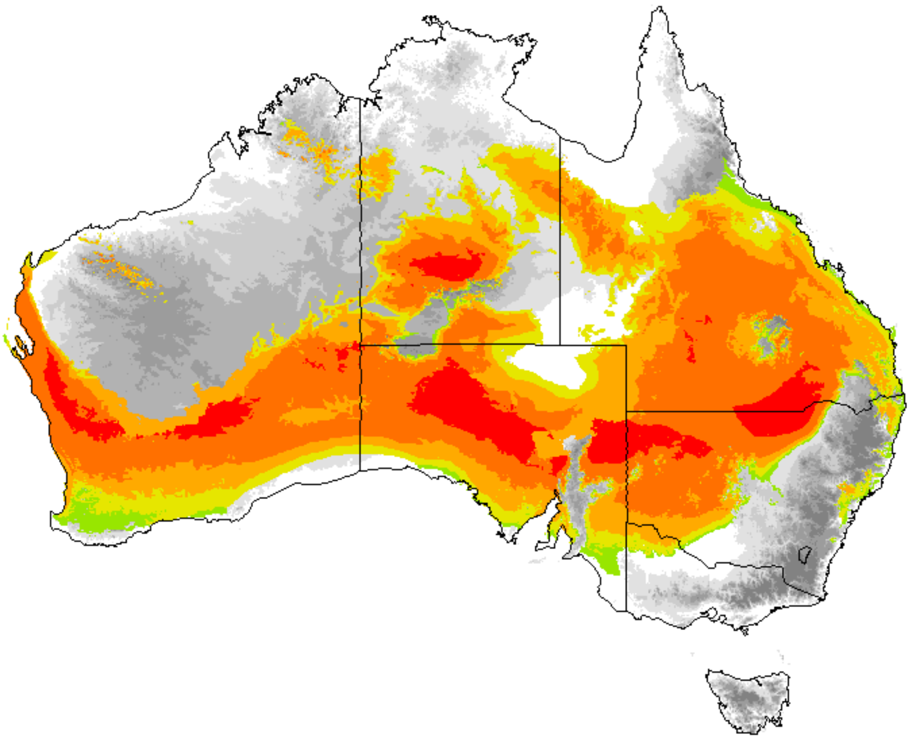
a. All 35 parameters



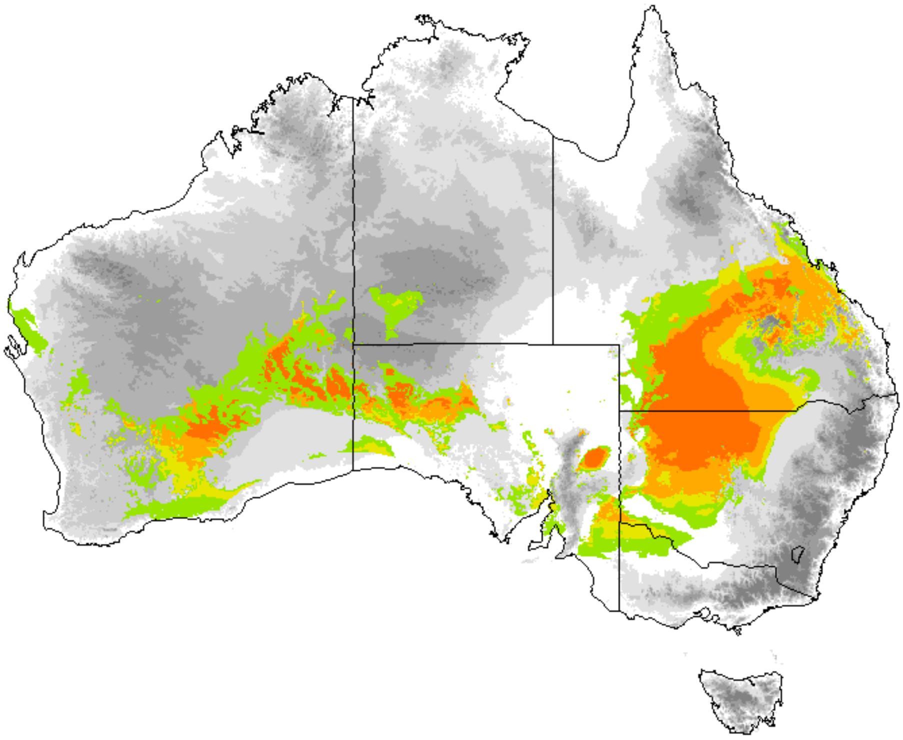
b. Remove 4, 14, 20, 24



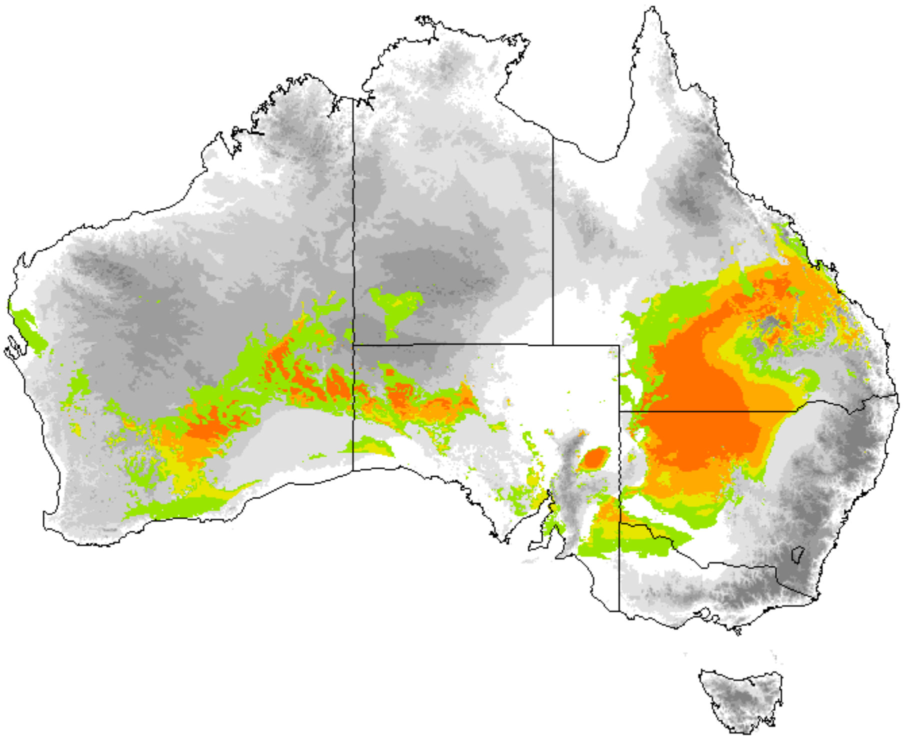
c. Keep only 8, 10, 21



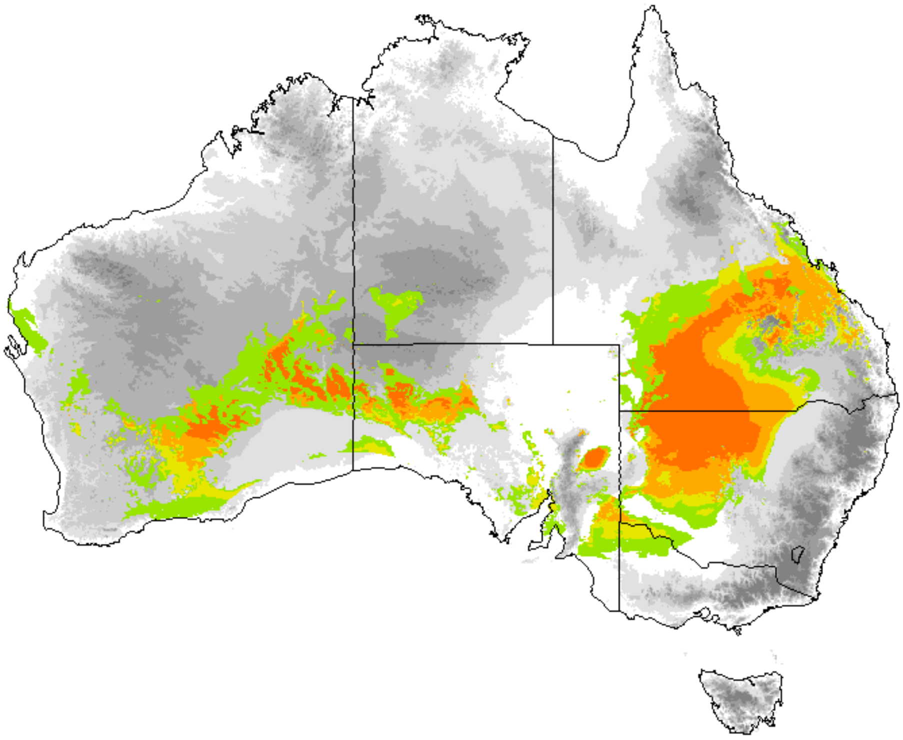
d. Keep only 1



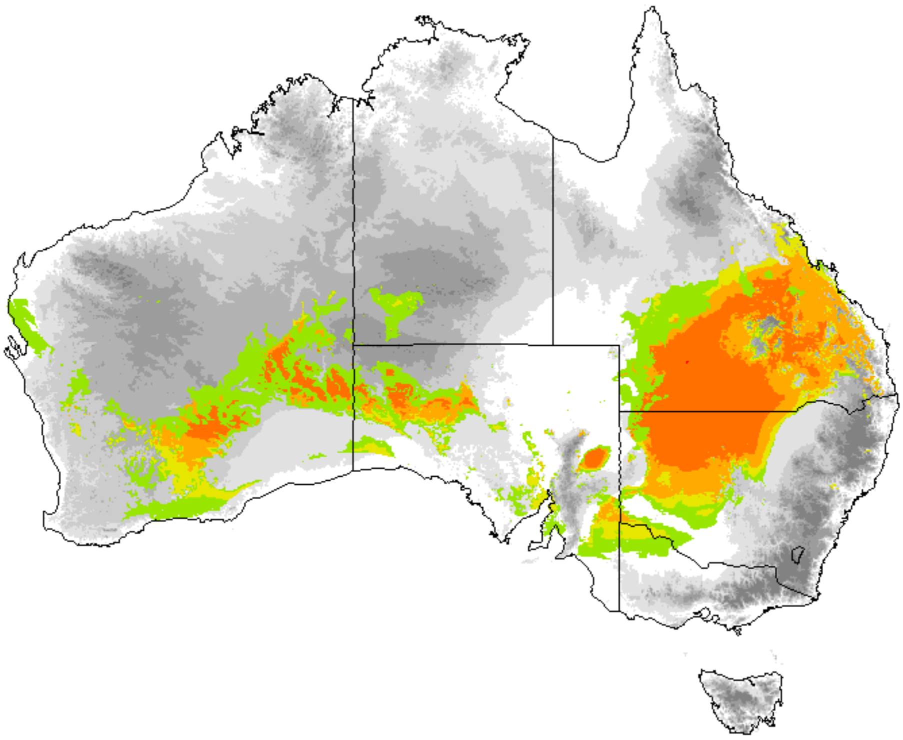
e. Remove 13-19 (rainfall parameters)



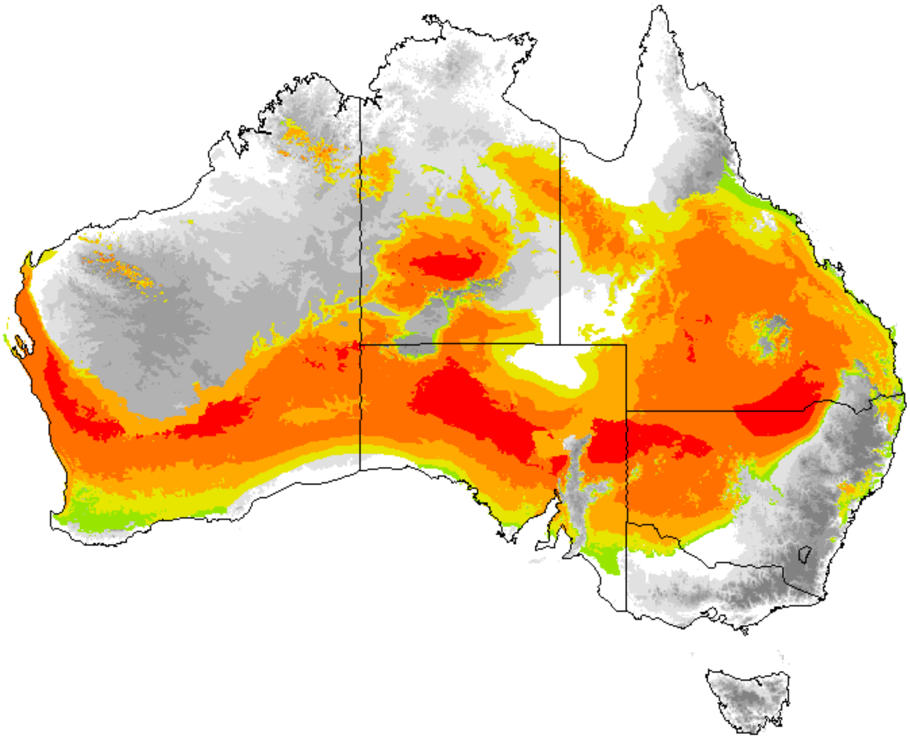
f. Remove 12-19



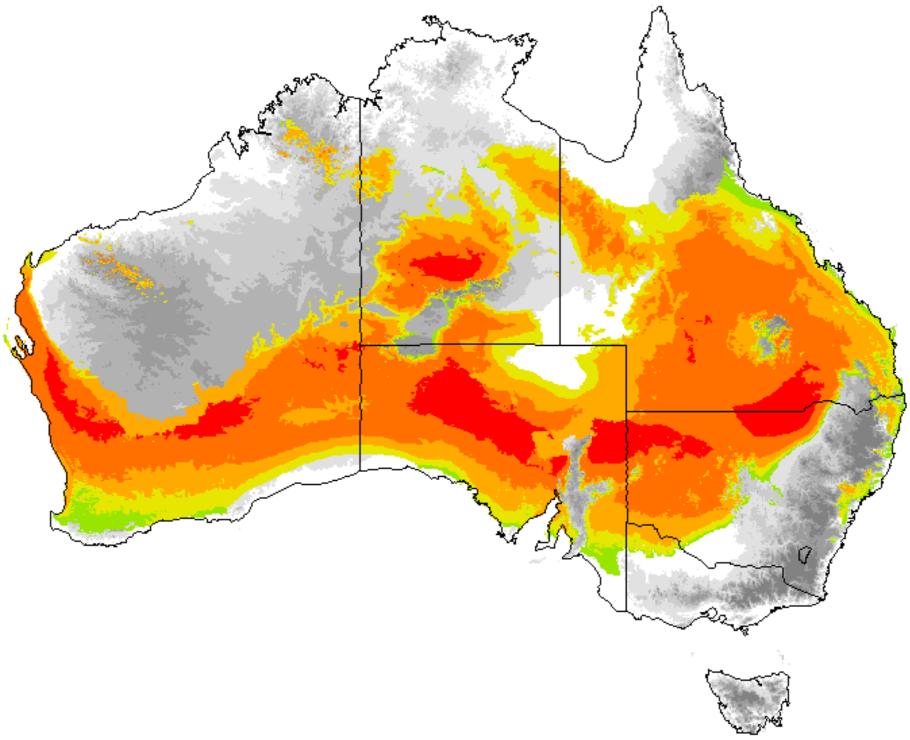
g. Remove 8, 9, 12-19



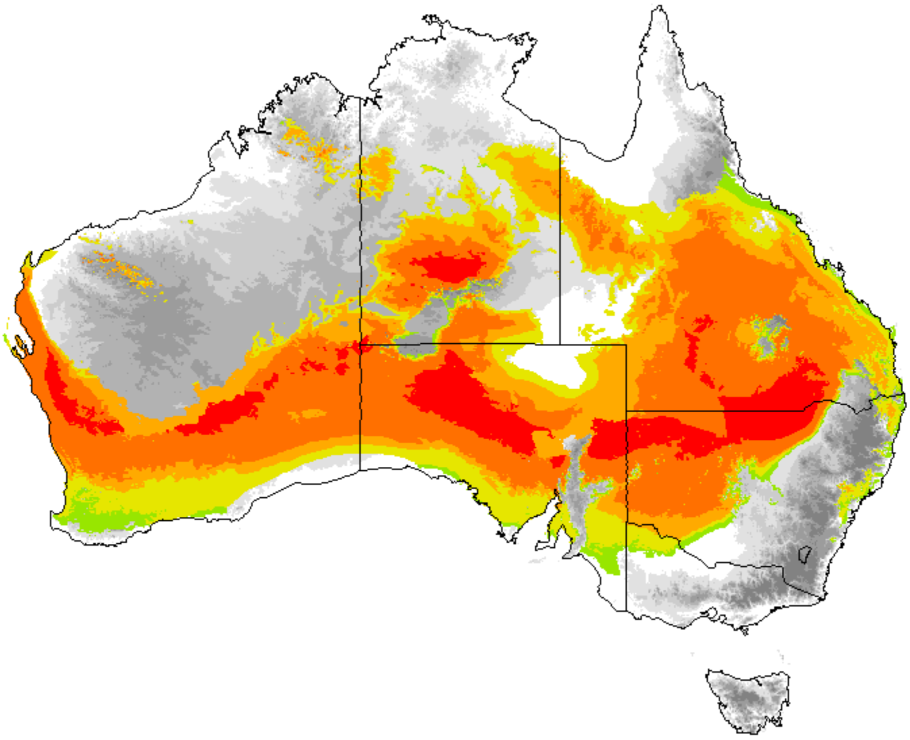
h. Remove 8, 9, 13-19, 24, 25, 28-35



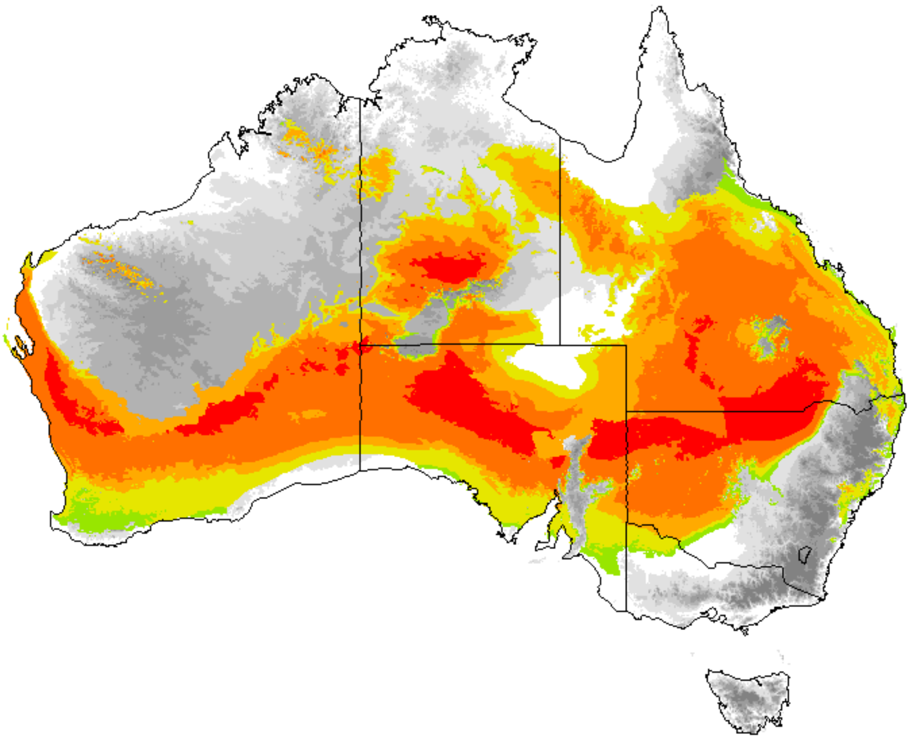
i. Keep only 1, 2, 7, 10



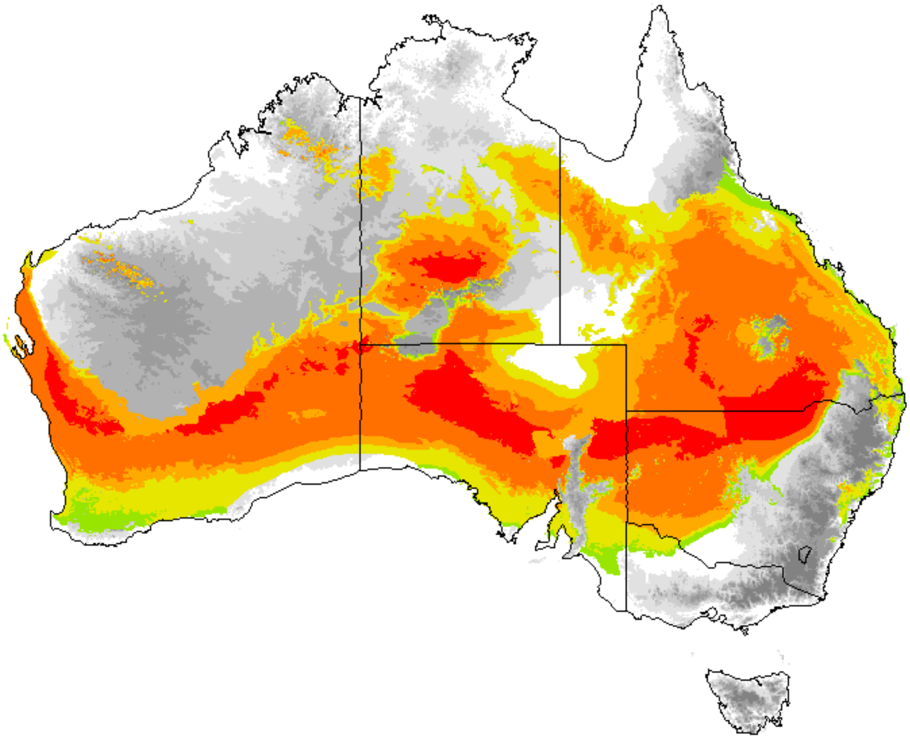
j. Keep only 1, 2



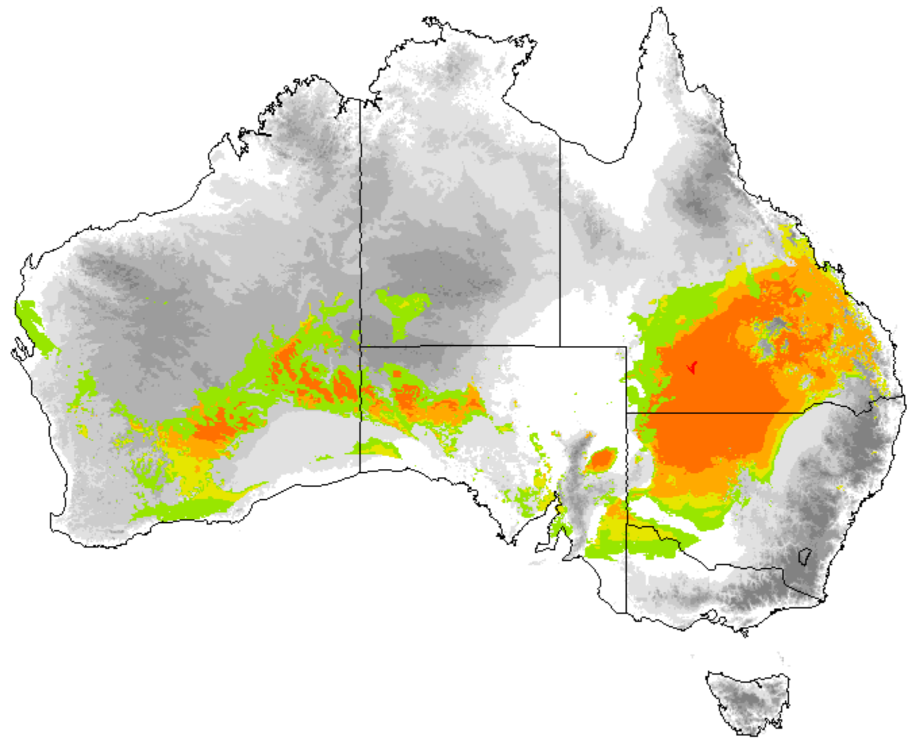
k. Keep only 1,2



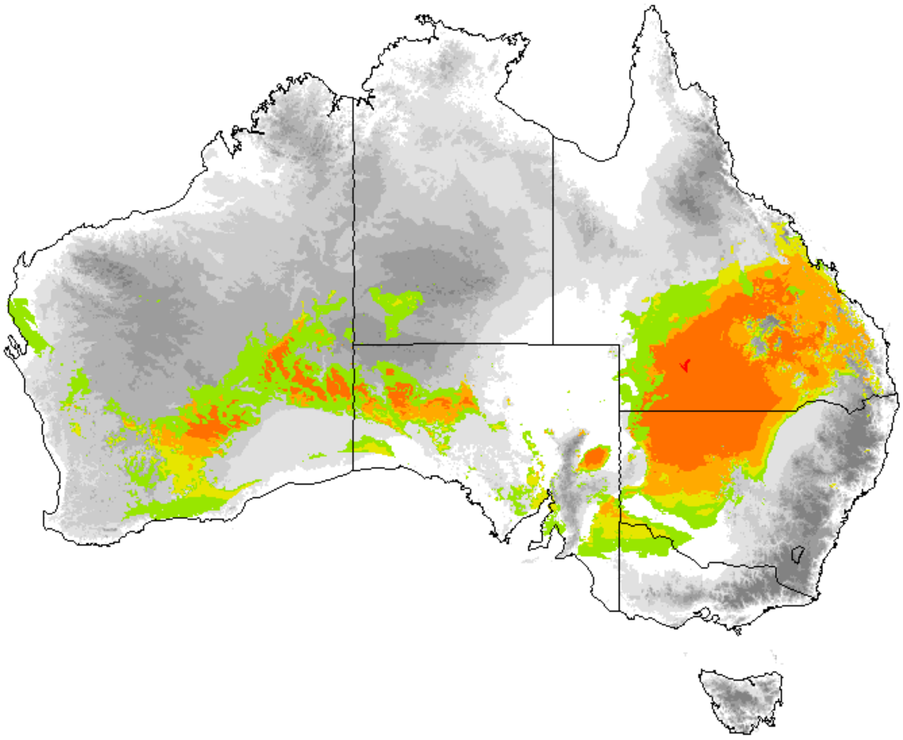
l. Keep only 1, 2, 7, 10



m. Keep only 1



n. Remove 8, 9, 13-19, 24, 25, 28-35



o. Keep only 10

Appendix 3 Climatic suitability

Key for the potential distribution maps

Descriptor from the key	Percentage of data points where the species occurs for all variables:
High	25-75%; best climate match
Moderately high	10-90%
Moderate	5-95%
Moderately low	2.5-97.5%
Low	0-100%; least accurate climate match

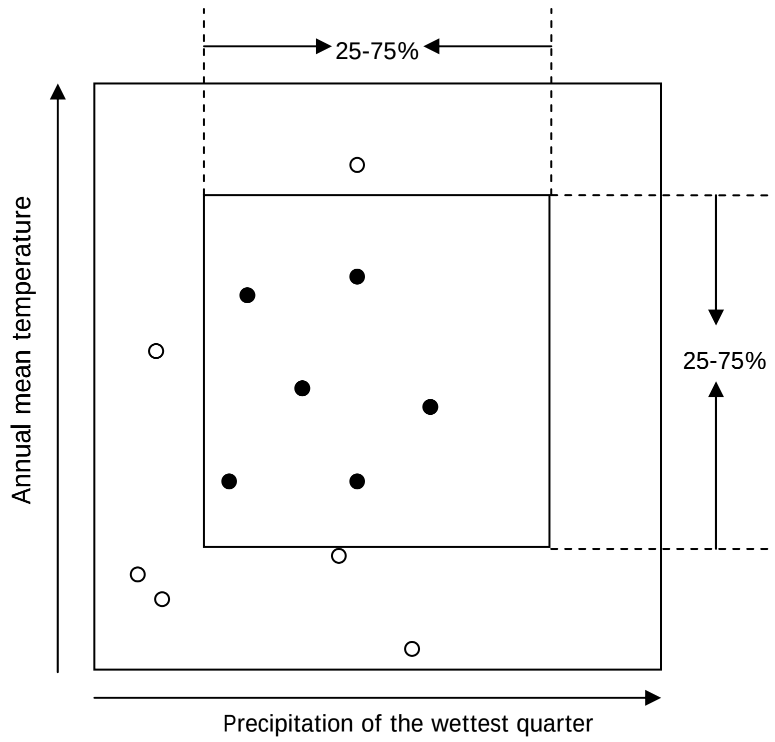
Interpreting the key

For each of the selected bioclimatic parameters, the Anuclim package compares the bioclimatic parameter value in a given location with the statistical distribution of that same parameter in the species profile. If all selected bioclimatic parameters for a given location (grid square) fall within a given span (e.g. between the 10th and 90th percentile, between the 25th and 75th percentile), the grid square is given the colour that indicates which percentile span it represents.

So for example, the climate match for species could be created using two parameters: annual mean temperature and precipitation of the wettest quarter. The areas that achieve the highest climatic suitability must match at least all of the following criteria:

- the annual mean temperature must fall within the 25th and 75th percentile of the statistical distribution of annual mean temperature for the species, and
- the precipitation of the wettest quarter must fall within the 25th and 75th percentile of the statistical distribution of the precipitation of the wettest quarter for the species.

A schematic illustration of this appears below (after Farber & Kadmon 2003). The solid dots indicate locations where the highest climatic suitability occurs.



Appendix 4 The degree of climatic suitability of the area occupied by the climate envelope under a range of climate change scenarios over time.

Acacia farnesiana

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	1.70	0.44	0.56	0.77	2.04	1.83	3.18
ML	0.00	0.00	0.00	0.00	3.86	4.16	1.68
M	0.00	0.00	0.00	0.00	1.22	1.04	3.61
MH	0.00	0.00	0.00	0.00	1.36	1.08	1.84
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	1.70	0.44	0.56	0.77	8.47	8.10	10.32

Acetosa vesicaria

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	3.48	2.50	2.50	2.52	5.42	5.34	4.44
ML	2.35	1.83	1.75	1.72	1.16	1.13	2.25
M	1.50	3.16	3.23	3.15	1.27	1.31	1.39
MH	0.61	2.70	2.95	3.22	6.51	6.78	5.71
H	0.00	0.00	0.00	0.00	2.79	2.22	4.63
total	7.94	10.20	10.43	10.61	17.16	16.77	18.42

Asparagus aethiopicus

Climate match	1990	2030 B1_low	2030 A1_mid	2030 A1F_high	2070 B1_low	2070 A1_mid	2070 A1F_high
	Area occupied by degree of climate suitability (MHa)						
L	1.33	2.42	2.47	2.51	2.35	2.47	1.82
ML	0.11	0.48	0.51	0.53	1.11	1.05	1.32
M	0.00	0.00	0.00	0.00	0.06	0.06	0.07
MH	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	1.44	2.90	2.98	3.04	3.52	3.58	3.21

Bidens pilosa

Climate match	1990	2030 B1_low	2030 A1_mid	2030 A1F_high	2070 B1_low	2070 A1_mid	2070 A1F_high
	Area occupied by degree of climate suitability (MHa)						
L	12.62	14.51	14.49	14.50	12.31	12.06	14.23
ML	0.95	1.88	2.07	2.17	5.45	5.64	3.81
M	0.02	0.54	0.57	0.59	1.77	1.73	1.93
MH	0.00	0.00	0.00	0.00	0.24	0.19	0.44
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	13.59	16.93	17.13	17.26	19.78	19.62	20.40

Billardiera heterophylla

Climate match	1990	2030 B1_low	2030 A1_mid	2030 A1F_high	2070 B1_low	2070 A1_mid	2070 A1F_high
	Area occupied by degree of climate suitability (MHa)						
L	2.87	2.54	2.51	2.47	1.60	1.67	1.18
ML	3.19	2.21	2.21	2.21	2.38	2.39	1.66
M	4.12	4.11	4.08	4.05	2.05	2.34	1.20
MH	1.83	2.52	2.51	2.50	1.82	1.83	1.52
H	0.00	0.01	0.01	0.01	0.01	0.01	0.00
total	12.02	11.40	11.31	11.23	7.86	8.25	5.56

Cenchrus ciliaris

Climate match	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	0.92	1.00	1.04	1.06	2.39	2.24	2.78
ML	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MH	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	0.92	1.00	1.04	1.06	2.39	2.24	2.78

Cotoneaster glaucophyllus

Climate match	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	2.85	2.39	2.36	2.35	2.14	2.14	2.10
ML	3.60	3.23	3.22	3.16	1.99	2.03	1.32
M	5.03	4.75	4.69	4.68	2.28	2.58	1.11
MH	0.46	0.49	0.48	0.46	0.18	0.18	0.10
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	11.94	10.87	10.76	10.66	6.59	6.93	4.63

Echium plantagineum

Climate match	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	6.16	5.13	5.09	5.06	6.01	5.64	10.21
ML	3.41	4.26	4.42	4.51	7.72	7.17	5.92
M	3.89	8.07	7.79	7.49	5.61	6.30	3.78
MH	7.65	3.64	3.78	4.00	1.37	1.64	0.34
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	21.11	21.10	21.08	21.07	20.71	20.76	20.26

Eremophila sturtii

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	6.52	6.44	6.25	6.11	3.89	3.94	4.54
ML	0.44	0.57	0.74	0.84	1.21	1.21	2.36
M	0.00	0.26	0.28	0.32	2.82	2.71	1.24
MH	0.00	0.00	0.01	0.02	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	6.97	7.26	7.28	7.29	7.93	7.86	8.15

Euphorbia terracina

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	7.70	10.79	10.96	11.06	10.61	10.90	9.14
ML	2.67	1.85	1.73	1.68	0.47	0.53	0.09
M	0.05	0.07	0.06	0.05	0.02	0.05	0.00
MH	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	10.42	12.71	12.76	12.79	11.10	11.49	9.22

Heliotropium amplexicaule

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	7.86	7.63	7.27	6.92	3.21	3.03	5.13
ML	2.43	6.89	7.38	7.75	4.74	5.15	2.83
M	0.86	1.22	1.40	1.59	8.48	8.61	6.31
MH	0.00	0.00	0.00	0.00	1.54	1.31	1.82
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	11.15	15.74	16.05	16.26	17.96	18.09	16.09

Hordeum glaucum

Climate match	1990	2030 B1_low	2030 A1_mid	2030 A1F_high	2070 B1_low	2070 A1_mid	2070 A1F_high
	Area occupied by degree of climate suitability (MHa)						
L	12.20	9.94	9.79	9.67	9.57	9.48	10.25
ML	1.58	2.85	2.86	2.84	1.87	1.75	3.39
M	1.91	3.51	3.70	3.86	4.61	4.63	5.47
MH	2.88	2.07	1.99	1.93	2.55	2.61	0.01
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	18.57	18.36	18.33	18.30	18.60	18.48	19.12

Lantana camara

Climate match	1990	2030 B1_low	2030 A1_mid	2030 A1F_high	2070 B1_low	2070 A1_mid	2070 A1F_high
	Area occupied by degree of climate suitability (Ha)						
L	1888	0	0	428	16984	13476	93301
ML							
M							
MH							
H							
total	1888	0	0	428	16984	13476	93301

Leycesteria formosa

Climate match	1990	2030 B1_low	2030 A1_mid	2030 A1F_high	2070 B1_low	2070 A1_mid	2070 A1F_high
	Area occupied by degree of climate suitability (MHa)						
L	4.96	4.17	4.10	4.03	2.19	2.31	1.36
ML	1.12	1.36	1.36	1.36	1.16	1.27	0.61
M	1.86	1.65	1.64	1.64	0.90	0.93	0.61
MH	0.90	0.57	0.53	0.48	0.01	0.02	0.00
H	0.07	0.02	0.01	0.01	0.00	0.00	0.00
total	8.92	7.77	7.64	7.52	4.27	4.54	2.60

Ligustrum sinense

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	8.14	7.14	6.97	6.83	3.73	3.80	3.79
ML	0.62	2.62	2.75	2.81	2.76	2.91	2.16
M	0.04	0.77	0.89	1.02	2.58	2.59	2.02
MH	0.00	0.00	0.00	0.00	0.37	0.36	0.35
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	8.80	10.52	10.61	10.66	9.43	9.66	8.33

Medicago laciniata

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	1.18	3.13	3.08	3.03	1.27	1.31	1.05
ML	1.72	0.81	0.81	0.83	1.73	1.75	1.99
M	0.99	0.77	0.83	0.85	1.83	1.66	3.13
MH	0.13	0.04	0.08	0.11	1.21	1.25	0.05
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	4.01	4.75	4.80	4.83	6.04	5.98	6.20

Nassella neesiana

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	9.86	8.94	8.88	8.84	8.39	8.46	7.56
ML	2.05	2.15	2.18	2.21	1.79	2.03	0.82
M	1.17	2.01	2.02	2.02	0.36	0.44	0.15
MH	0.13	0.05	0.06	0.05	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	13.21	13.15	13.14	13.12	10.54	10.93	8.53

Nassella trichotoma

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	6.26	5.54	5.47	5.43	5.55	5.63	4.59
ML	1.93	2.35	2.36	2.36	0.52	0.61	0.25
M	1.34	1.74	1.73	1.73	0.11	0.13	0.01
MH	0.51	0.29	0.26	0.24	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	10.04	9.92	9.82	9.76	6.17	6.38	4.85

Rubus fruticosus agg.

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	5.86	5.99	6.02	6.05	3.66	3.79	3.54
ML	2.94	2.79	2.79	2.77	3.43	3.34	4.24
M	5.98	5.42	5.36	5.38	4.96	5.07	3.43
MH	3.90	4.12	4.11	4.05	1.28	1.56	0.31
H	0.06	0.01	0.01	0.00	0.00	0.00	0.00
total	18.74	18.33	18.28	18.25	13.34	13.76	11.52

Senecio jacobaea

	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
Climate match		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	7.65	7.85	7.80	7.75	2.92	3.33	1.67
ML	1.01	0.83	0.85	0.85	0.05	0.06	0.01
M	0.86	0.41	0.33	0.28	0.01	0.01	0.00
MH	0.39	0.12	0.10	0.09	0.00	0.00	0.00
H	0.02	0.02	0.01	0.01	0.00	0.00	0.00
total	9.94	9.22	9.09	8.98	2.97	3.40	1.68

Sida rhombifolia

Climate match	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	1.63	1.79	1.83	1.87	3.84	3.65	4.14
ML	0.00	0.00	0.00	0.00	0.87	0.74	1.19
M	0.00	0.00	0.00	0.00	0.09	0.06	0.39
MH	0.00	0.00	0.00	0.00	0.00	0.00	0.02
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	1.63	1.79	1.83	1.87	4.80	4.46	5.75

Tamarix aphylla

Climate match	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	1.64	1.10	1.22	1.30	2.99	3.05	1.10
ML	0.89	1.40	1.38	1.33	2.75	2.47	4.83
M	0.00	1.64	1.68	1.74	2.23	2.36	1.90
MH	0.00	0.71	0.91	1.06	6.30	5.96	6.57
H	0.00	0.00	0.00	0.00	0.25	0.11	1.82
total	2.53	4.85	5.20	5.43	14.52	13.96	16.22

Xanthium spinosum

Climate match	Area occupied by degree of climate suitability (MHa)						
	1990	2030			2070		
		B1_low	A1_mid	A1F_high	B1_low	A1_mid	A1F_high
L	6.36	6.21	6.23	6.25	6.28	6.29	6.69
ML	4.44	2.38	2.32	2.28	1.73	1.70	2.51
M	4.78	10.34	9.95	9.57	3.90	3.85	4.54
MH	4.46	1.64	2.10	2.53	8.61	8.76	6.15
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	20.05	20.57	20.60	20.63	20.52	20.60	19.89