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Modelling suggests minimal impact of climate change expected on vegetation communities in southern Australian Mediterranean ecosystem

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1. Abstract

Bioclimatic modelling studies aimed at projecting climate change impacts have been largely focused at the species level with few attempts at applying this approach to whole communities or vegetation groups. Climate is a major driver of vegetation type within Mediterranean ecosystems. In this study we modelled the impact of climate change on vegetation communities, rather than on individual species, occurring within the Australian Mediterranean ecosystem. Our results showed that within the study area, for all time frames and scenarios, 87% or more of current distribution records occur within future bioclimatic envelopes for the vegetation sub groups modelled. Where vegetation types were projected to experience decline in bioclimatic envelope area and a southerly shift in distribution, this occurred mostly outside of the Mediterranean climate area.

2. Introduction

2.1 Introduction

Mediterranean climate ecosystems contain almost 20% of the world's vascular plant species (Cowling *et al.*, 1996). Globally these ecosystems can be found in five regions, southern Australia, southern Europe, South Africa, Chile and California. In Australia, Mediterranean ecosystems occur in the south-west corner of the state of Western Australia and in the south of the state of South Australia. These areas have been identified as areas of high floristic endemism (Crisp *et al.*, 2001), thought to be the result of adaptation to nutrient-poor soils (Beard *et al.*, 2000). Climate is a major driver of vegetation type within Mediterranean ecosystems, with vegetation distribution showing a significant response to the amount and seasonality of rainfall (Allen, 2001; Dirnböck *et al.*, 2002). Two of the characteristics that define a Mediterranean ecosystem are winter rainfall and the occurrence of a summer drought (di Castri, 1981). The Australian Mediterranean-climate region has been projected to become warmer and drier under a changing climate, with temperature projected to increase by 0.5-1.1°C by 2030 and up to 1.2-2.0°C by 2090, and rainfall projected to decrease, particularly in spring and winter (Hope *et al.*, 2015). Although globally, the overall extent of Mediterranean ecosystems has been predicted to expand slightly under future climate scenarios, the extent of the ecosystem in Australia has been projected to contract in response to these changes (Klausmeyer & Shaw, 2009). Simulations based on three carbon emission scenarios project that the Mediterranean climate extent in Australia will contract to only 49-77% of its current size by the end of the 21st century (Klausmeyer & Shaw, 2009). Models predict a contraction of the extent of the Mediterranean climate in the northern coastal and eastern part of its current extent, particularly in south-western Australia. In South Australia the current extent of the Mediterranean climate has been modeled to be stable along the coast, but with a likely contraction in the north (Klausmeyer & Shaw, 2009).

Using bioclimatic modelling at the species level, many authors have hypothesised that the projected change in climate will have an impact on the distribution of the flora of these regions (Hughes *et al.*, 1996; Fitzpatrick *et al.*, 2008; Gibson *et al.*, 2010; Brouwers *et al.*, 2013). For example, climatically suitable habitat is projected to decline under future climate scenarios for up to 66% of Banksia species in Australia, mostly driven by changes in precipitation regime (Fitzpatrick *et al.*, 2008). Similar declines in distribution of the majority of eucalyptus species in Australia has been suggested based on climate and temperature thresholds (Hughes *et al.*, 1996). This decline has already been reported for some species, such as *Eucalyptus wandoo*, where increased autumn temperature and decreased annual rainfall have impacted the health of this species in the low rainfall zone of its climatic range (Brouwers *et al.*, 2013).

Bioclimatic modelling studies aimed at projecting climate change impacts have been largely focused at the species level with few attempts at applying this approach to whole communities or vegetation groups. Modelling predefined communities (as opposed to individual species within the community) has the advantage of being able to rapidly analyse a very large number of species which may not have been possible if each were taken individually (Ferrier & Guisan, 2006). Brzeziecki *et al.* (1995) used a spatially explicit, climate sensitive vegetation model to examine the potential impact of climate change on zonal forest communities in Switzerland. A similar study was undertaken by Garcia-Romero *et al.* (2010) in Mediterranean mountains in Spain. Both of these studies focused on a relatively small geographic area with a large range in altitudes. In one of the few studies aimed at analysing communities at a larger scale, Prober *et al.* (2012) used artificial neural networks and generalised dissimilarity modelling, and found that large scale degradation has compromised the capacity of communities to adapt across a range of Australian agricultural landscapes.

An opportunity exists for bioclimatic modelling at the community or vegetation type level, rather than at the individual species for Mediterranean systems. Vegetation communities within all Mediterranean climate regions have been defined and mapped (Davis *et al.*, 1996). For example, the National Vegetation Information System (NVIS) provides information on the distribution and extent of vegetation types in Australia. The vegetation type is defined using floristic (*i.e.* dominant species), structural (*e.g.* closed forest, open woodland) and growth form (*e.g.* mallee, grass, tall tree etc*)* characteristics (Department of the Environment and Water Resources, 2007). This classification system identifies 39 vegetation groups in southern Australia.

This study investigated the impact of climate change on vegetation communities, rather than on individual species, occurring within a Mediterranean ecosystem in South-west Western Australia and southern South Australia using bioclimatic modelling. Given the influence of climate on vegetation (Allen, 2001; Dirnböck *et al.*, 2002), the predicted contraction of the Mediterranean climate under future climate scenarios (Klausmeyer & Shaw, 2009), and the projected loss of habitat of key plant groups (Fitzpatrick *et al.*, 2008; Gibson *et al.*, 2010), we hypothesised that contraction of individual vegetation sub groups would take place under the modelled climate scenarios. More specifically, we hypothesised that vegetation groups dominated by banksia and eucalypts would be subject to significant contractions and shift in distribution under a warmer, drier climate.

3. Methods

3.1 Vegetation community distribution records

Current distributions of vegetation sub groups within south-western Western Australia and in southern South Australia (Figure 1) were extracted using GIS (ArcMap 10) from the National Vegetation Information System (NVIS) (http://www.environment.gov.au/topics/science-and-research/databases-and-maps/national-vegetation-information-system). Of the 77 vegetation communities in the NVIS, 39 were found within the study area. These 39 vegetation sub groups ranged from those that only have a limited distribution, such as 'banksia woodland', to those such as 'mallee with an open shrubby understorey', which have a continental distribution. As many of the vegetation sub groups within the study area have distributions that extend beyond south-western Western Australia and southern South Australia, the sub group distribution was extracted at the continental scale to give the full extent of the sub group's distribution. To convert the NVIS sub group distributions from vector shapefiles to distribution records (latitude and longitude coordinates) required for modelling, shapefiles for each vegetation sub group were converted to a raster with a pixel size of 5km^2. The centre of each pixel where the vegetation sub groups were present was then used as an occurrence record.

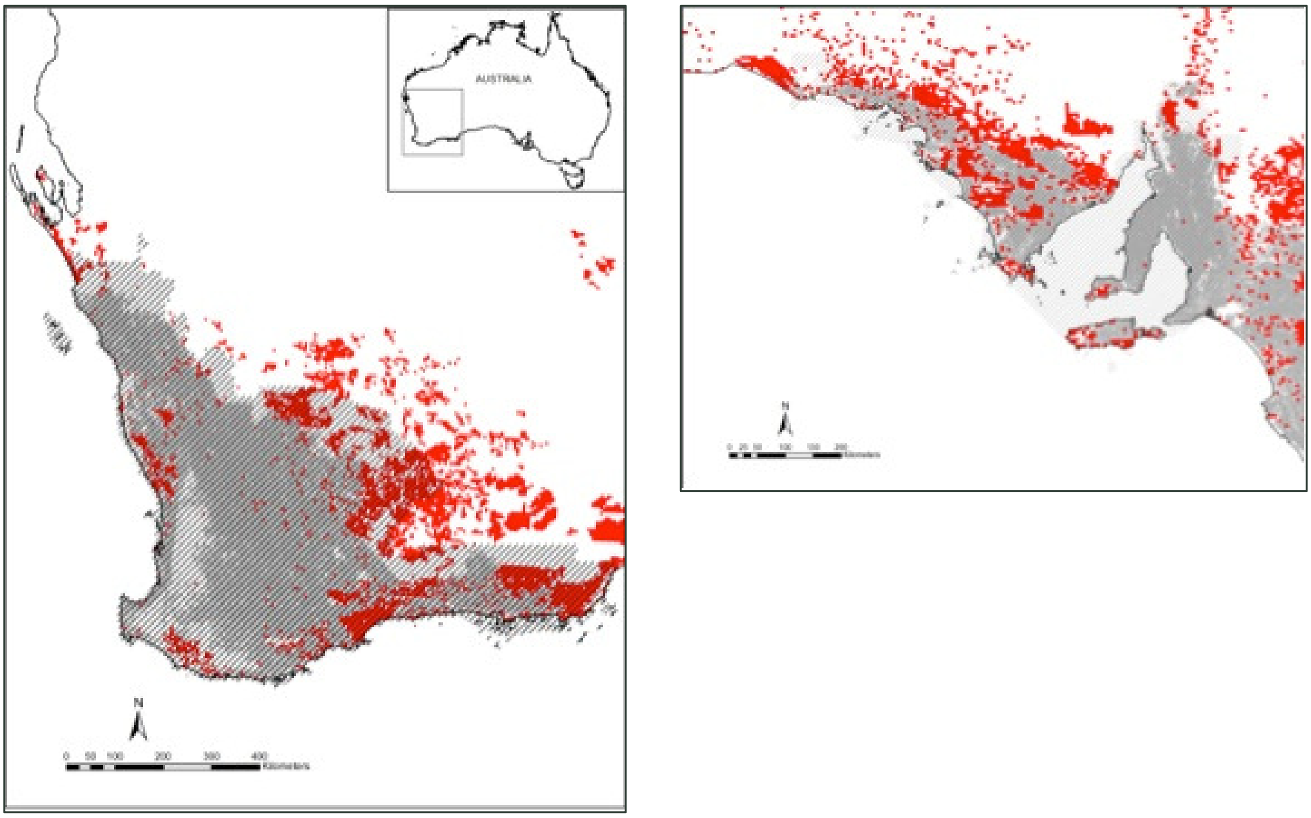


Figure 1. Maps showing Western Australian and South Australian study area (hatching), cleared land (dark grey) and native vegetation communities with AUC>0.7 (red) (note some vegetation communities occur both inside and outside study area). It should be noted that a large section of the study area in Western Australia is dominated by Eucalyptus forests with a shrubby understorey, this community had an AUC<0.7 and therefore was not modelled further (maps created in ArcMap 10 (http://www.esri.com)).

3.2 Bioclimatic modelling

Bioclimatic variables were obtained from WorldClim (http://www.worldclim.org/bioclim). The 19 bioclimatic variables were clipped to the Australian mainland and Tasmania at 5km^2 resolution. The bioclimatic variables utilised were Annual Mean Temperature, Mean Diurnal Range, Isothermality, Temperature Seasonality, Max Temperature of Warmest Month, Min Temperature of Coldest Month, Temperature Annual Range, Mean Temperature of Wettest Quarter, Mean Temperature of Driest Quarter, Mean Temperature of Warmest Quarter, Mean Temperature of Coldest Quarter, Annual Precipitation, Precipitation of Wettest Month, Precipitation of Driest Month, Precipitation Seasonality, Precipitation of Wettest Quarter, Precipitation of Driest Quarter, Precipitation of Warmest Quarter and Precipitation of Coldest Quarter. No significant correlation between bioclimatic variables was found at the continental scale. Altitude was also obtained from Worldclim. In addition to bioclimatic variables and altitude, regolith was also incorporated into the model and the data were obtained from GeoScience Australia (http://mapconnect.ga.gov.au/MapConnect). These data were converted from vector shape file to a raster format with 5km^2 resolution.

Future projections of climate were modelled for two time frames (2030 and 2080) and for three scenarios (A1B, A2 and B1) (IPCC, 2000). Selection of suitable Global Climate Models (GCM) was facilitated by the use of the Climate Futures Tool (http://www.climatechangeinaustralia.gov.au). This tool organises climate models according to their simulated changes in rainfall and temperatures. The three models selected (CSIRO Mk 3.5, MIUB ECHO-G, and MIROC-M) gave the maximum consensus for the study area. The Maxent modelling used an average of these three GCMs. Averaging of models has been shown to provide more consistent estimates of future climate change than use of single models (Fordham *et al.*, 2011). Modelling was carried out at 2.5arc minute (≈5km^2) resolution.

Maxent (v 3.3.3k) was used to model future distributions of the vegetation sub groups. Maxent is a program that uses presence only records and environmental predictors (such as climatic variables) to model species distribution (Elith *et al.*, 2011; Merow *et al.*, 2013). The software usually outperforms other methods with the accuracy of prediction of distributions (Merow *et al.*, 2013). For each vegetation sub group the model was run with a random seed and 10 replicates. Only sub groups with an area under curve (AUC) of greater than 0.7 were analysed further; AUC measures how predictions for presence sites are higher than predictions for absences over all possible threshold levels (Yates *et al.*, 2010).

Maxent was used to determine the main bioclimatic drivers for distribution of vegetation sub groups. Cluster analysis was performed on Maxent outputs to classify vegetation subgroups by common bioclimatic drivers.

To model distribution change under different climate scenarios, we calculated the probability of occurrence under current and future climate scenarios. The minimum training presence cumulative threshold was used as the threshold value for a vegetation sub groups' presence/absence within a pixel. If values fell below this threshold (null value), the vegetation sub group was considered to be absent in that pixel. Values above the threshold were retained as the probability of occurrence. To calculate changes in the probability occurrence values in each pixel for each vegetation sub group, probability of occurrence under current climate was subtracted from the probability of occurrence for future scenarios. A negative value indicated a decrease in the probability of the community occurring, as the suitability of climate in the future was project to be less that it is currently (*e.g.* if the current suitability of climate is 90% and the future is 80%, subtracting 90 from 80 results in -10%, the community still has an 80% of persisting but it is less than current probability). A positive value indicated an increase in the probability of the community occurring, and a zero value indicated no change.

Given that vegetation groups are made up of a number of species, each of which may respond in a different way to climate, it can be more useful to determine if the climate where particular vegetation groups are known to occur currently is still suitable under future climate scenarios. Change in the suitability of climate for the existing vegetation groups was calculated by noting the current vegetation group for each pixel. If the suitability of climate for that vegetation group was the same in future scenarios it was classified as unchanged. If the climate in the pixel under future scenarios was not suitable for the current vegetation group, it was classified as changed. This assumed no change to the current extent of vegetation i.e. areas currently cleared remain cleared and no revegetation or regrowth occurs.

4. Results

Cluster analysis of the vegetation sub groups with an AUC of greater than 0.7 (Table 1) showed that the vegetation communities could be divided into three groups based on the climatic determinants of their distribution. The main climatic driver of distribution for vegetation sub groups in the 'Bioclim8 assemblage', was the mean temperature in the wettest quarter (Bioclim8). The 'Bioclim19 assemblage' had precipitation in the coldest quarter (Bioclim19) as the main climatic driver of distribution. The remaining vegetation sub groups had a variety of climatic drivers of distribution, and were grouped into the 'miscellaneous assemblage' cluster.

Table 1. Vegetation sub groups (from NVIS) occurring in the study area. Only those with Area Under Curve (AUC) value of greater than 0.7 (bold) were used in the analysis. Sub groups are arranged by assemblages determined using cluster analysis. Sub-group code corresponds to points in Figure 3_Error! Reference source not found._.

Sub-group code	Vegetation sub-group	AUC
	***'Bioclim8* assemblage'**	
69	Open mallee woodlands and sparse mallee shrublands with a dense shrubby understorey	**0.924**
55	Mallee with an open shrubby understorey	**0.737**
65	Eucalyptus woodlands with a chenopod or samphire understorey	**0.852**
	***'Bioclim19* assemblage'**	
28	Low closed forest or tall closed shrublands (including Acacia, Melaleuca and Banksia)	**0.795**
29	Mallee with a dense shrubby understorey	**0.725**
30	Heath	**0.791**
50	Banksia woodlands	**0.950**
54	Eucalyptus tall open forest with a fine-leaved shrubby understorey	**0.855**
68	Open mallee woodlands and sparse mallee shrublands with an open shrubby understorey	**0.942**
	'***Miscellaneous* assemblage'**	
12	Callitris forests and woodlands	**0.785**
16	Other forests and woodlands	**0.759**
47	Eucalyptus open woodlands with shrubby understorey	**0.773**
49	Melaleuca shrublands and open shrublands	**0.745**
56	Eucalyptus (+/- low) open woodlands with a chenopod or samphire understorey	**0.925**
60	Eucalyptus tall open forests and open forests with ferns, herbs, sedges, rushes or wet tussock grasses	**0.736**
63	Sedgelands, rushes or reeds	**0.770**
64	Other grasslands	**0.896**
66	Open mallee woodlands and sparse mallee shrublands with a hummock grass understorey	**0.918**

Sub-group code	Vegetation sub-group	AUC
73	Casuarina and Allocasuarina open woodlands with a chenopod shrub understorey	**0.876**
74	Casuarina and Allocasuarina open woodlands with a shrubby understorey	**0.852**
75	Melaleuca open woodlands	**0.802**
	Vegetation types with AUC<0.7	
-	Eucalyptus open forests with a shrubby understorey	0.613
-	Eucalyptus woodlands with a shrubby understorey	0.551
-	Other Acacia forests and woodlands	0.610
-	Melaleuca open forests and woodlands	0.629
-	Mulga (Acacia aneura) woodlands +/- tussock grass +/- forbs	0.567
-	Other Acacia tall open shrublands and [tall] shrublands	0.601
-	Acacia (+/- low) open woodlands and shrublands with chenopods	0.671
-	Acacia (+/- low) open woodlands and shrublands with hummock grass	0.672
-	Casuarina and Allocasuarina forests and woodlands	0.697
-	Mallee with hummock grass	0.644
-	Saltbush and Bluebush shrublands	0.596
-	Other shrublands	0.632
-	Other tussock grasslands	0.583
-	Wet tussock grassland with herbs, sedges or rushes, herblands or ferns	0.670
-	Mixed chenopod, samphire +/- forbs	0.637
-	Mulga (Acacia aneura) open woodlands and sparse shrublands +/- tussock grass	0.584

4.1 Climate Based Assemblages

4.1.1 Bioclim 8 (mean temperature of the wettest quarter) assemblage

Three vegetation sub groups had Bioclim 8 as the main climatic driver of their modelled distributions (‘Open mallee woodlands and sparse mallee shrublands with a dense shrubby understorey’; ‘Mallee with an open shrubby understorey’; ‘Eucalyptus woodlands with a chenopod or samphire understorey’). These three sub groups have distribution ranges across southern Australia from west to east coast. In the study area the mean temperature of the wettest quarter is projected to rise between 1.5°C (low emission scenario) and 3°C (high emission scenario) by 2070 (bom.gov.au), with the most extreme changes occurring in the northern section of the study area.

For all three vegetation sub groups, the probability of occurrence declined sharply when the mean temperature of the wettest quarter exceeded 15°C. For both the mallee sub groups the probability of occurrence was constant for all temperatures below 15°C. In contrast, the probability of occurrence of the eucalyptus sub group declined at temperatures below 10°C.

Although, the ‘Eucalyptus woodlands with a chenopod or samphire understorey’ sub group was projected to experience declines in its overall continental distribution under the A2 and A1B scenarios (Figure 2), there was no substantial change in distribution or extent projected for this sub group within the current Mediterranean climate region (Figure 3). Similarly, the ‘mallee with open shrubby understorey’ sub group was projected to have no substantial change in its northerly extent or area of distribution under any of the scenarios or timeframes examined within the current Australian Mediterranean climate ecosystem (Figure 3). At a continental scale however, this sub group was exposed to less climatically suitable conditions within the northern parts of its range, and it showed a southerly shift in distribution under the A2 and A1B scenarios by 2030 (Figure 2). Within the study area there was no substantial change in the northerly extent or area of distribution for the ‘open mallee woodlands and sparse mallee shrublands with a dense shrubby understorey’ sub group under any of the scenarios or timeframes examined, with the exception of A1B 2080 where the northern extent of this sub-group was projected to shift south by 1° (approximately 110km) (Figure 3). The sub group was predicted to undergo increases at the continental scale in its distribution within its current range with some expansion in both the A2 and A1B 2030 scenarios with no significant change in distribution under the B1 scenario (Figure 2).

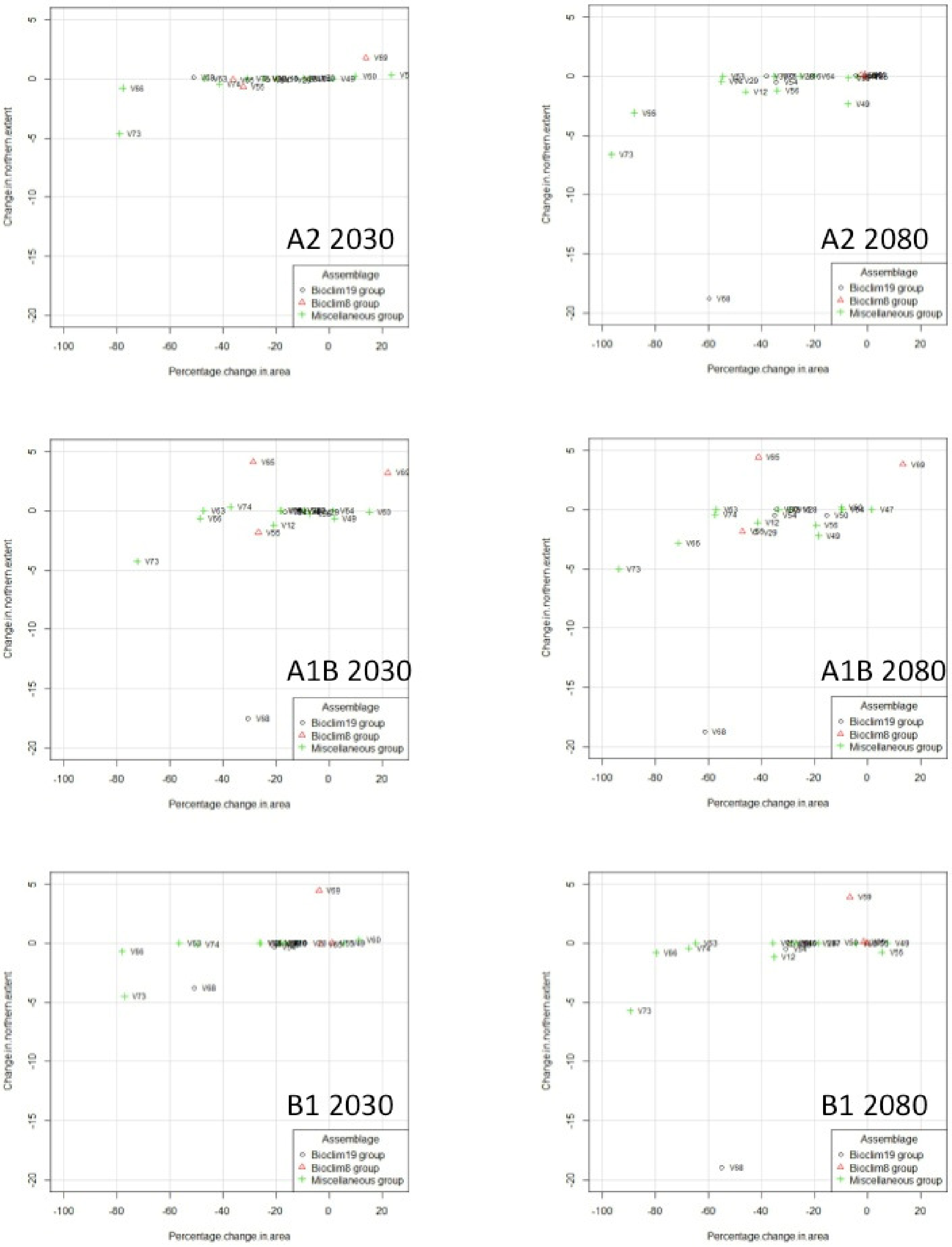


Figure 2 Continental scale changes in the northern extent (° latitude) and area (percentage change from current) for vegetation sub groups under three climate scenarios and two timeframes.

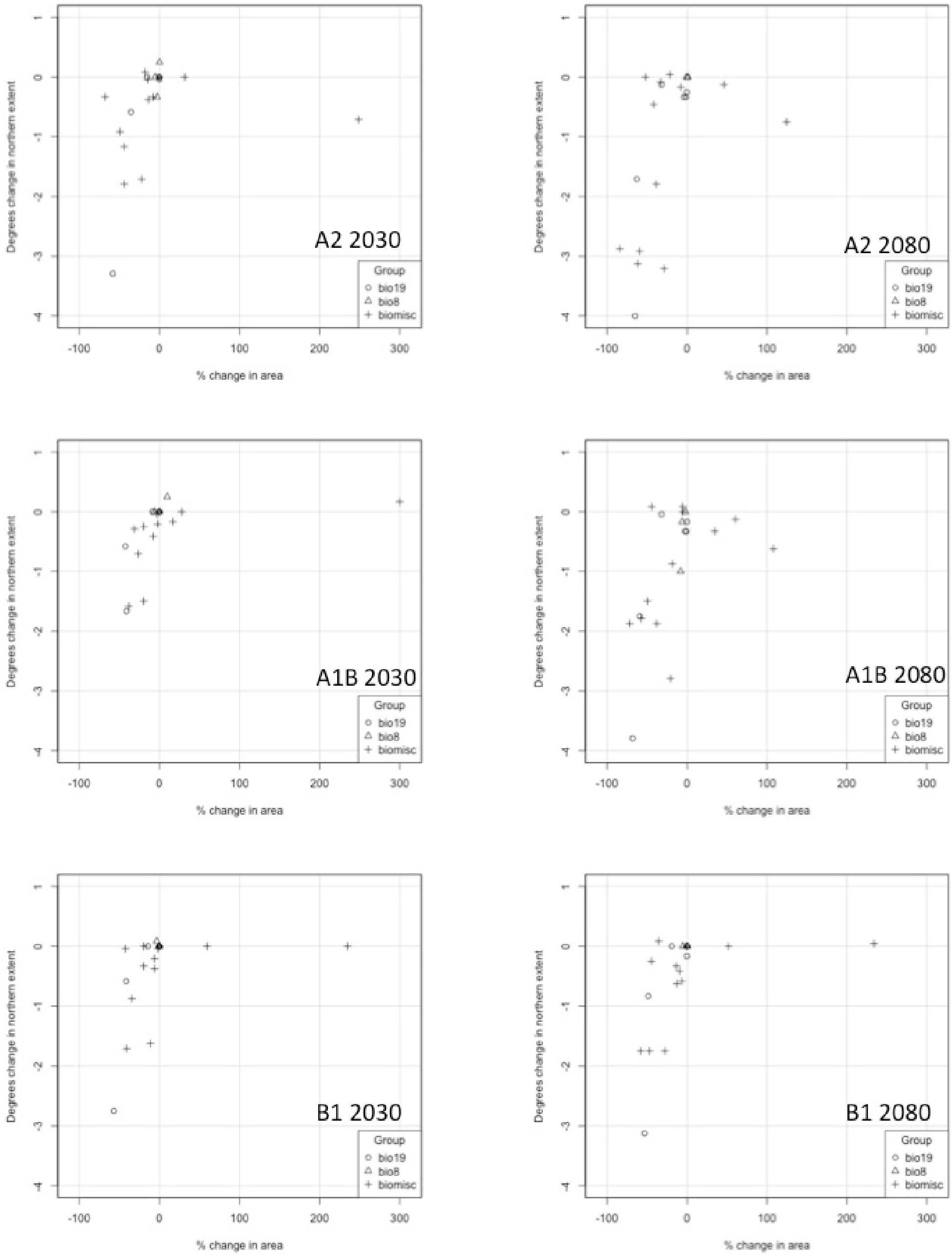
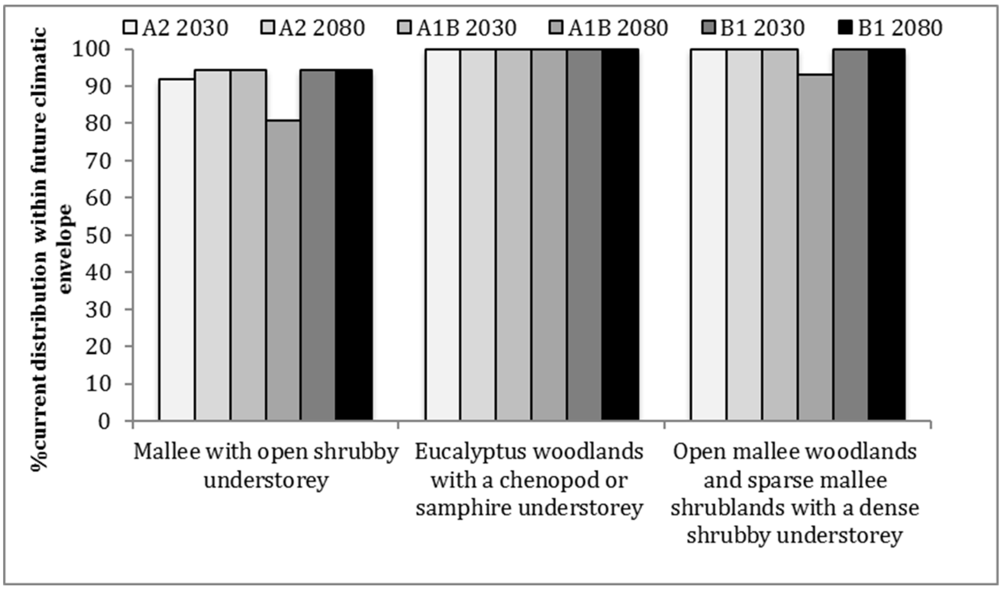


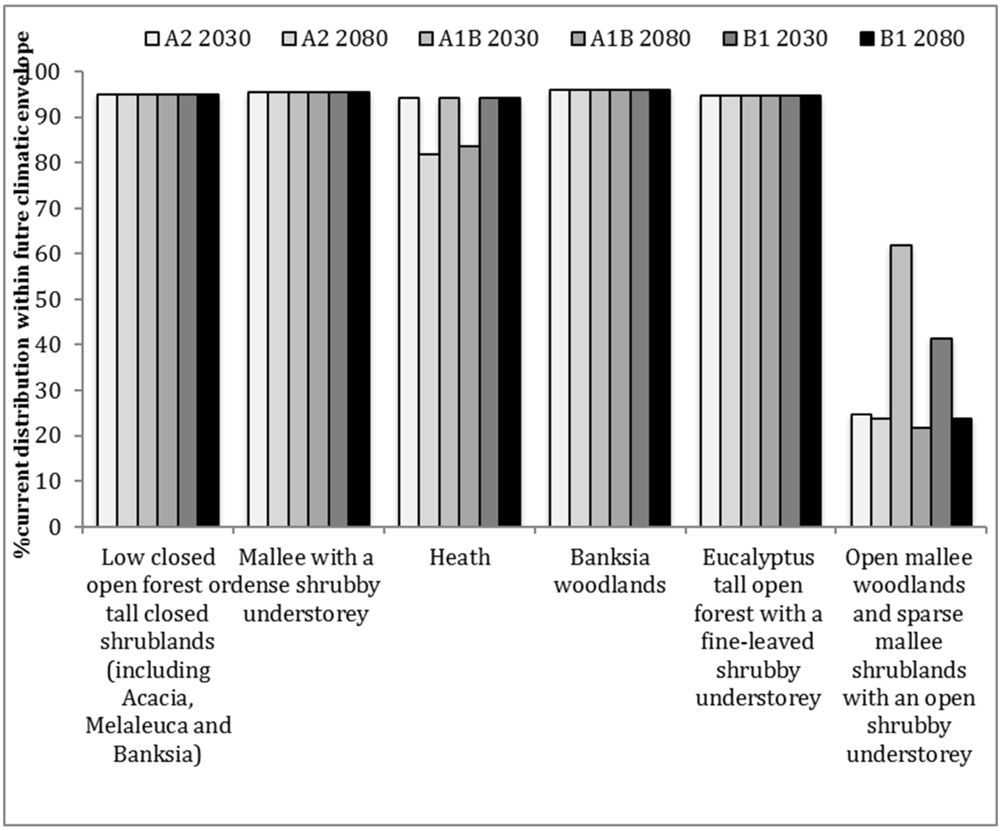
Figure 3 Changes in the northern extent (° latitude) and area (percentage change from current) for vegetation sub groups under three climate scenarios and two timeframes.

When the distribution of current location records relative to future climatic envelopes was considered for the study area for the three vegetation sub groups in the Bioclim8 assemblage, we found that the majority (80-100%) of current distribution records occurred within future bioclimatic envelopes (Figure 4).

(a)


□ A2 2030
□ A2 2080
□ A1B 2030
□ A1B 2080
■ B1 2030
■ B1 2080
%current distribution within future climatic envelope
100
90
80
70
60
50
40
30
20
10
0
Mallee with open shrubby understorey
Eucalyptus woodlands with a chenopod or samphire understorey
Open mallee woodlands and sparse mallee shrublands with a dense shrubby understorey

(b)


□ A2 2030
□ A2 2080
□ A1B 2030
□ A1B 2080
■ B1 2030
■ B1 2080
%current distribution within futre climatic envelope
100
90
80
70
60
50
40
30
20
10
0
Low closed open forest or tall closed shrublands (including Acacia, Melaleuca and Banksia)
Mallee with a dense shrubby understorey
Heath
Banksia woodlands
Eucalyptus tall open forest with a fine-leaved shrubby understorey
Open mallee woodlands and sparse mallee shrublands with an open shrubby understorey

(c)

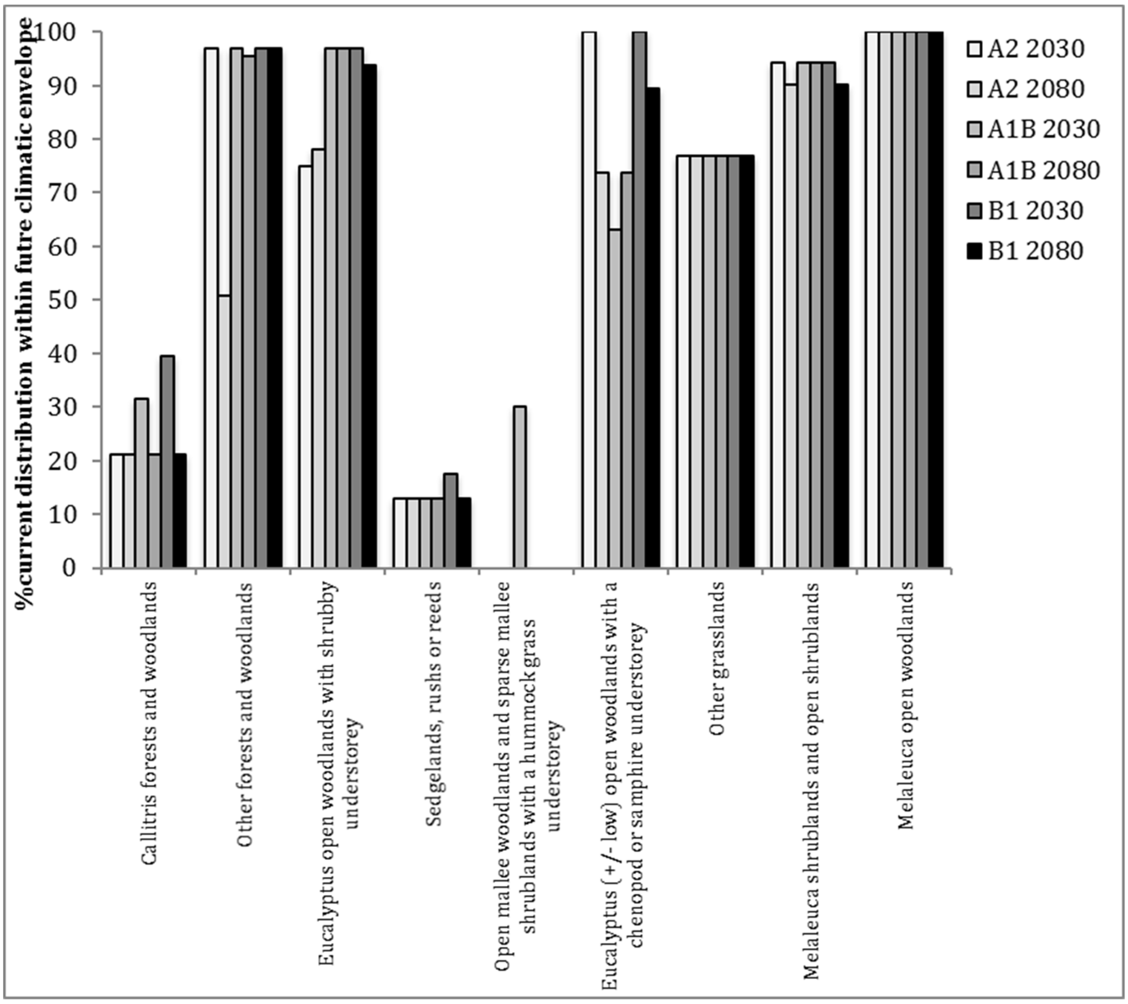


Figure 4 Percentage current distribution within future climatic envelope for (a) the three vegetation communities whose climatic envelope was largely driven by mean temperature of the wettest quarter ('Bioclim8 assemblage'), (b) the six vegetation communities whose climatic envelope was largely driven by precipitation in the coldest quarter ('Bioclim19 assemblage') and (c) vegetation communities not in Bioclim 8 or Bioclim19 assemblage (N.B. (1) Eucalyptus tall open forests and open forests with ferns, herbs, sedges, rushes or wet tussock grasses not shown as there was only one record within the study area (2) Casuarina and Allocasuarina open woodlands with a chenopod shrub understorey and Casuarina and Allocasuarina open woodlands with a shrubby understorey not shown as there were only two records each within the study area).

4.1.2 Bioclim 19 (Precipitation coldest quarter) assemblage

Six vegetation sub groups had their distributions largely governed by Bioclim19 (‘Low closed forest or tall closed shrublands (including Acacia, Melaleuca and Banksia)’; ‘Mallee with a dense shrubby understorey’; ‘Heath’; ‘Banksia woodlands’; ‘Eucalyptus tall open forest with a fine-leaved shrubby understorey’; ‘Open mallee woodlands and sparse mallee shrublands with an open shrubby understorey’). These sub groups occur in southern Western Australia and southern South Australia, and in some cases, have distributions extending northwards in the eastern states. For all these sub groups, the suitability of climate declined when precipitation in the coldest quarter was below 100-150mm. In the study area the precipitation in the coldest quarter was projected to decrease by between 10% (low emission scenario) and 20% (high emission scenario) by 2070 (bom.gov.au).

Within the study area there was no substantial change in the northerly extent or area of distribution for this assemblage under any of the scenarios or timeframes examined with the exception of the sub-groups ‘Open mallee woodlands and sparse mallee shrublands with an open shrubby understorey’ and ‘Eucalyptus tall open forest with a fine-leaved shrubby understorey’ (Figure 3). Both these sub-groups are projected to undergo a 50-75% reduction in area and a southerly shift of 0.75-1.17° (‘Eucalyptus tall open forest with a fine-leaved shrubby understorey’) and 2.8-4.0° (‘Open mallee woodlands and sparse mallee shrublands with an open shrubby understorey’). All of the vegetation sub groups in this assemblage underwent a reduction in their area of suitable of climate at the continental scale for most scenarios and timeframes (Figure 2). In the majority of cases, this decline occurred with a corresponding increase in suitability of climate in another area, generally to the south of the current distribution, reflecting a southerly shift in rainfall patterns.

Within the study area for all time frames and scenarios, the majority (all > 80%, majority > 95%) of current distribution records occur within future bioclimatic envelopes for the six vegetation sub groups belonging to the Bioclim19 assemblage (Figure 4). An exception was the ‘Open mallee woodlands and sparse mallee shrublands with an open shrubby understorey’ sub group, where only 20-60% of current sites, depending on timeframe and scenario, were projected to be climatically suitable in the future.

4.1.3 Miscellaneous Assemblage

The distributions of the remaining 12 vegetation sub groups were best explained by a variety of climatic drivers (Table 2). Four vegetation sub groups (‘Callitris forests and woodlands’, ‘Eucalyptus tall open forests and open forests with ferns, herbs, sedges, rushes or wet tussock grasses’, ‘Sedgelands, rushes or reeds’ and ‘Open mallee woodlands and sparse mallee shrublands with a hummock grass understorey’) had Bioclim14 (precipitation driest month) as the main driver of their climatic envelope. Within the study area there was no substantial change in the northerly extent or area of distribution for these sub-groups under any of the scenarios or timeframes examined, with the exception of ‘Callitris forests and woodlands’ (Figure 3). The northern extent of this sub-group was projected to have a shift of between 0.5 and 3.2° south, with only a small (10%) decline in area (Figure 3). At the continental scale, the majority of areas currently climatically suitable for the four sub groups driven by Bioclim14 are projected to be unsuitable in the future (Figure 2).

Table 2 Major bioclimatic drivers for the distribution of miscellaneous group of vegetation sub groups.

Vegetation community	**Bioclimatic variable (%contribution)**
Callitris forests and woodlands	Bioclim14 (55.6)
Eucalyptus tall open forests and open forests with ferns, herbs, sedges, rushes or wet tussock grasses	Bioclim14 (83.9)
Other forests and woodlands	Bioclim13 (40.2)
Casuarina and Allocasuarina open woodlands with a chenopod shrub understorey	Bioclim13 (39.6)
Eucalyptus open woodlands with shrubby understorey	Bioclim12 (24.3)
Sedgelands, rushes or reeds	Bioclim14 (19.8)
Open mallee woodlands and sparse mallee shrublands with a hummock grass understorey	Bioclim14 (19.5)
Eucalyptus (+/- low) open woodlands with a chenopod or samphire understorey	Soil (32)
Other grasslands	Altitude (37.5)
Melaleuca shrublands and open shrublands	Bioclim4 (47.3)
Casuarina and Allocasuarina open woodlands with a shrubby understorey	Bioclim17 (60.4)
Melaleuca open woodlands	Bioclim16 (67.8)

Two sub groups ('Other forests and woodlands' and 'Casuarina and Allocasuarina open woodlands with a chenopod shrub understorey') had Bioclim13 (Precipitation of wettest month) as their main climatic driver. Within the current Mediterranean climate region, the northern extent of the 'Casuarina and Allocasuarina open woodlands' subgroup shifted south approximately 3° (Figure 3). This sub-group has a wider distribution outside of the Mediterranean climate region, with only two distribution records within the study area. In the case of the 'Other forests and woodlands' sub group, there was no major decline under future scenarios in the number of sites where this vegetation sub group currently occur in the Mediterranean region (Figure 3). At a continental scale there was a southerly shift in climatic envelope (Figure 2).

The 'Eucalyptus open woodlands with shrubby understorey' sub group had its distribution determined by Bioclim12 (Annual Precipitation) (24.3%) and Bioclim13 (Precipitation of wettest month) (22.6%). Within the current Mediterranean climate region, there was no substantial change in the northerly extent or area of distribution for this sub-group under any of the scenarios or timeframes examined (Figure 3), most of the sites currently occupied by this vegetation sub group have a suitable climate into the future (Figure 4). This sub group, although projected at the continental scale to have some decline in its distribution had an increase in suitability of climate in other areas, generally to the north (Figure 2).

The distribution of two vegetation sub groups ('Eucalyptus (+/- low) open woodlands with a chenopod or samphire understorey' (soil) and 'Other grasslands' (altitude)) was best explained by non-climatic drivers. Both these sub groups had small sample sizes (Eucalyptus n=32 and grasslands n=13) within the study area therefore the loss of only a small number of the current sites has a large impact on the percentage change within the study area (Figure 4). Both these sub groups are widespread nationally and not common within the study area.

The three remaining sub groups ('Melaleuca shrublands and open shrublands', 'Casuarina and Allocasuarina open woodlands with a shrubby understorey', 'Melaleuca open woodlands') all had a southerly shift in the northern extent of their distribution (2-3 degrees) and approximately 50% reduction in area within the current Mediterranean climate region (Figure 3). These sub group are mostly found outside the study area. Nationally, the 'Melaleuca shrublands and open shrublands' sub group is projected to shift its climatic envelope south, while the other two sub groups are projected to decline in the core areas of their current distribution.

4.1.4 Overall change in vegetation sub groups

When all vegetation sub groups were considered together, we projected that remnant vegetation currently present in south-west Western Australia (Figure 5) and southern South Australia (Figure 6) could persist under a drier, hotter climate. Areas where climate was predicted to be no longer suitable for the vegetation sub group were mostly outside of the study area. For example, the area inland of the study area in Western Australia was found to be no longer climatically suitable for some vegetation sub groups (Figure 5). While in South Australia, the area to the north-east and also inland of the study area was no longer climatically suitable (Figure 6).

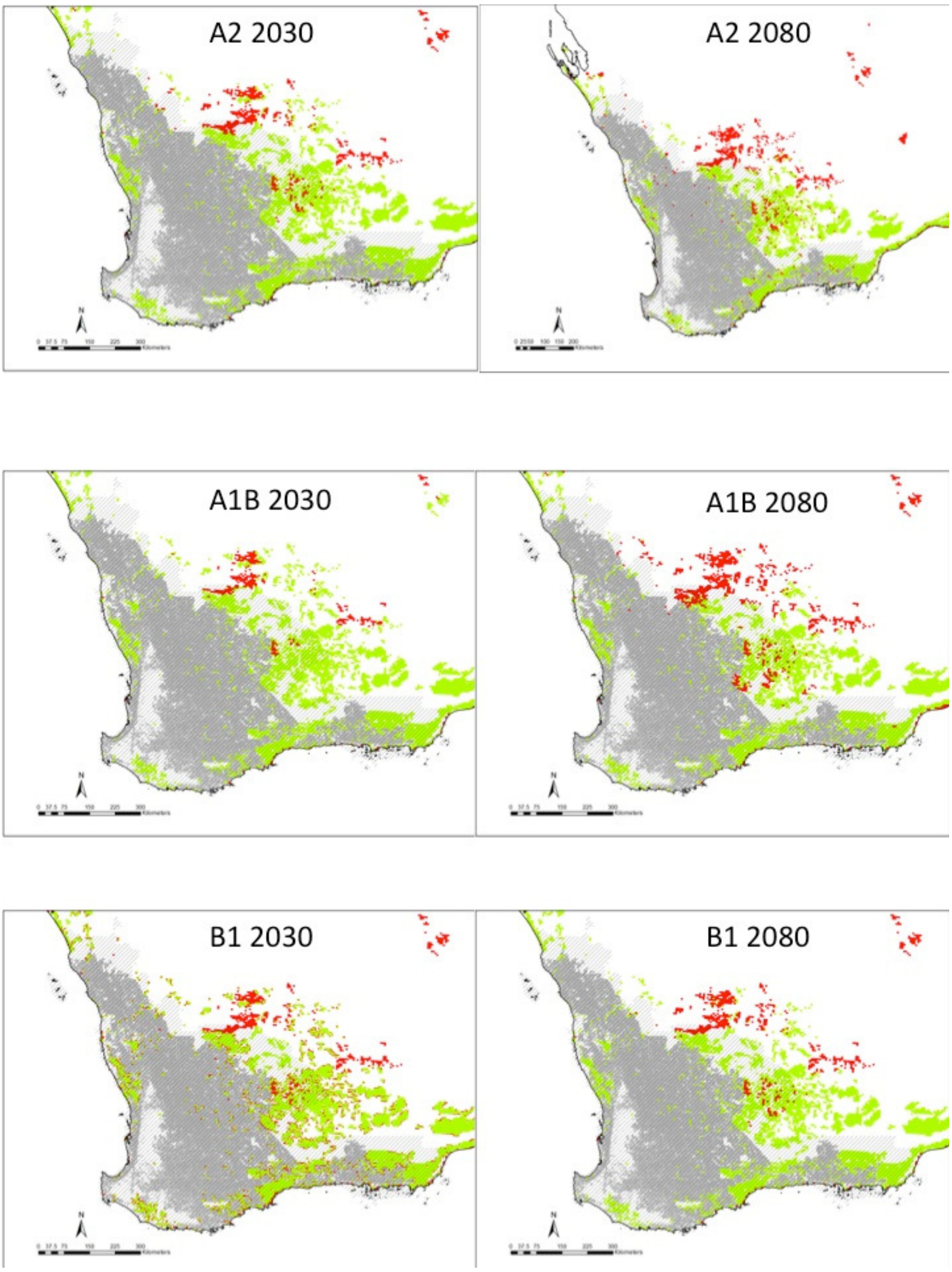


Figure 5 Projected changes in distributions of modelled vegetation communities in south-western Western Australian for three carbon emission scenarios (A2, A1B and B1) and two timeframes (2030,2080). Red shading indicates that vegetation sub groups currently in that pixel is projected to be absent in the future; green indicates the current vegetation sub groups will persist in the future; grey indicates cleared vegetation and white unmodelled vegetation sub groups (maps created in ArcMap 10 (http://www.esri.com)).

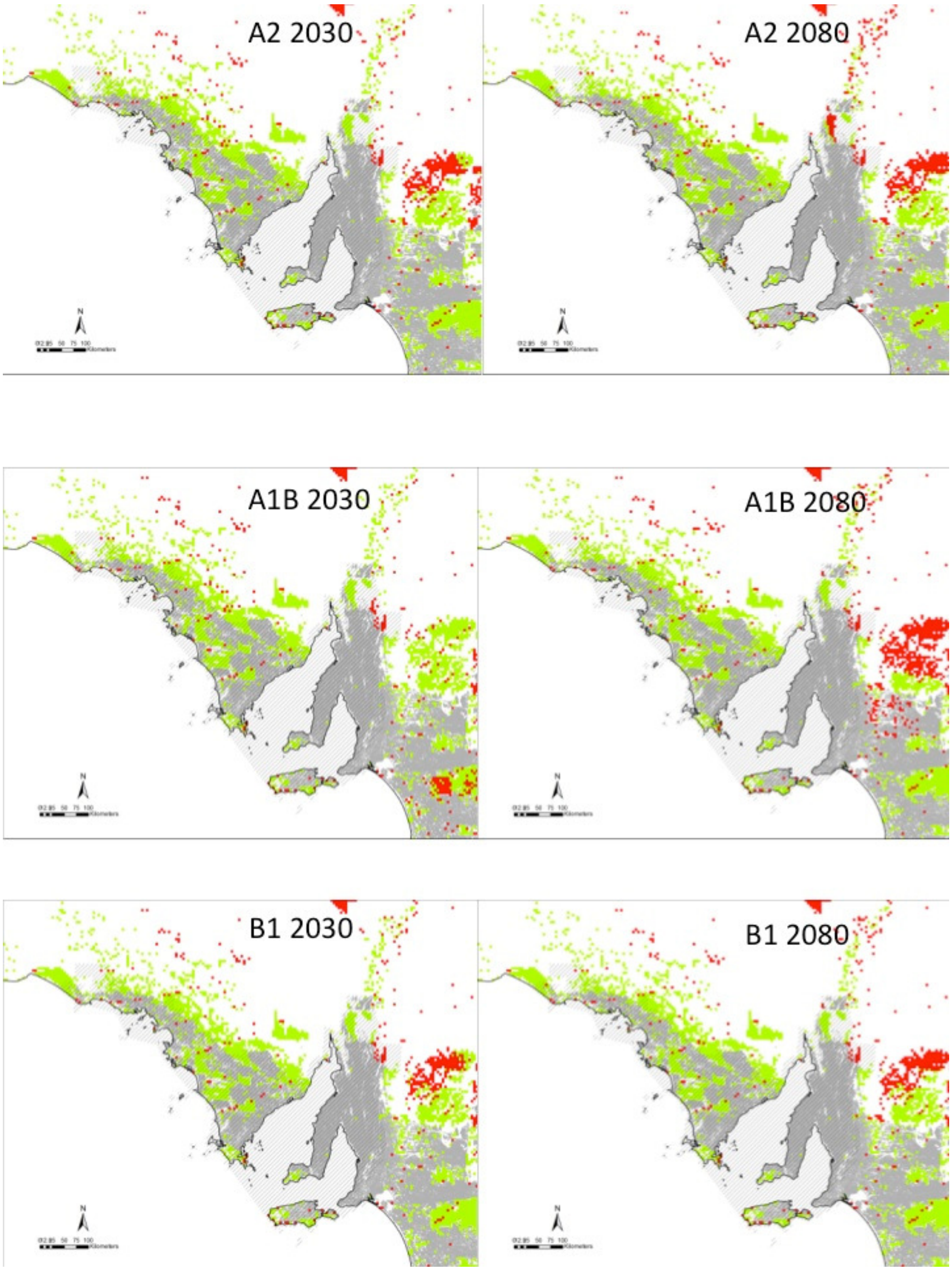


Figure 6 Projected changes in distributions of modelled vegetation communities in southern South Australia for three carbon emission scenarios (A2, A1B and B1) and two timeframes (2030,2080). Red shading indicates that vegetation sub groups currently in that pixel is projected to be absent in the future; green indicates the current vegetation sub groups will persist in the future; grey indicates cleared vegetation and white unmodelled vegetation sub groups.

5. Discussion

Given that Klausmeyer and Shaw (2009) projected that the area of the current Mediterranean climate in Australia would contract between 49-77% (depending on timeframe and scenario), we expected a significant decline and change in distribution of the major vegetation groups we examined. In particular, subgroups dominated by Banksia and Eucalypts were expected to show significant changes in distribution. Unexpectedly, our modelling suggested that the majority of vegetation sub groups we examined are likely to persist in their current locations under future projected climate scenarios in this region, resulting in the majority vegetation communities as we know them today, persisting until 2080. However, at a continental scale, our results did show that many vegetation types are likely to experience some decline in bioclimatic envelope and a southerly shift in distribution.

It is possible that the reason why we did not find significant declines in Banksia and Eucalypt dominated sub groups in the Mediterranean climate region is that we focused on realised rather than on potential distributions. Previous bioclimatic modelling studies that have projected dramatic distribution changes in Banksia and Eucalyptus have compared future predicted climatic envelopes with current climatic envelopes, without taking into account future climatic suitability at locations where species are currently found (Cowling *et al.*, 2004; Fitzpatrick *et al.*, 2008; Bambach *et al.*, 2013). In many cases, modelled potential distribution (bioclimatic envelope) and actual distribution do not correspond. Although species can potentially use a wider distribution, there are factors other than climate that could restrict utilisation of these potential distributions (Pearson & Dawson, 2003). For example, in both Western Australia and South Australia large sections of the study area have been cleared for agriculture, so although these cleared areas are climatically suitable, they are unavailable.

When we did examine changes in bioclimatic envelopes we found that most reductions in area and distribution shifts took place outside of the extent of the current Mediterranean climate area in Australia. Modelling of vegetation sub groups at the national scale showed that most vegetation communities are likely to decrease in occurrence in the northern extent of their distributions, with a corresponding increase in the southern extent of their distribution. This southerly shift in distribution is driven by increasing temperatures and decreasing rainfall. For most vegetation sub groups, the modelled potential distribution extended beyond the study area, and contractions in the extent of suitable climate had minimal impact within the study area. Our results showed that although the two bioclimatic variables (mean temperature of the wettest quarter and precipitation of the coldest quarter) that best explain the distribution of the majority of vegetation sub groups are projected to change under future climate scenarios, the range of these variables within the study area are still within the climatic thresholds for most vegetation sub groups.

We acknowledge that vegetation sub groups are made up of a number of species and the modelling undertaken in this study essentially modelled the climatic conditions where these species overlap. Most sub groups are classified by genus (*e.g.* Banksia woodland); the models did not account for any variation in thresholds between members of the genus. Individual species within a sub group may respond differently to the sub group itself, so therefore it is possible to end up with novel communities (different combinations of species not usually found together) (Lurgi *et al.*, 2012). New species may be able to move into the communities and outside the modelled distributions new assemblages may occur.

In summary our modelling shows that existing vegetation subgroups within the Mediterranean climate region in Australia will not be significantly impacted by climate change. The climatic conditions at locations where the vegetation sub groups currently occur are likely to remain within a range tolerated by these sub groups. The majority of changes in distribution, due to projected climate change, for the groups examined suggest the largest areas of change in vegetation communities are outside the current Mediterranean climatic region.

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